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Tritium Handbook

This is the main text of the Tritium Handbook. It defines what is meant by a tritium system and the requirements that are applicable.

Approval Process			
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v1.0	In Work	03 Jul 2009	
v1.1	In Work	23 Jul 2009	This is the main text for the Tritium Handbook that contains engineering requirements. All other information on tritium engineering will be placed into Appendices.
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ITER Tritium Handbook

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1 Scope of the Tritium Handbook

This Tritium Handbook defines the mandatory requirements for the design, manufacturing, testing, assembly and commissioning of systems and components which confine or may have contact with tritium. This handbook does not discuss or consider any radiological affects from any isotope other than tritium. Within the Appendices, this Handbook provides significant guides and helpful information on tritium.

The ITER Tritium Handbook is issued as a high level project requirements document, since it is necessary that the requirements contained in this Handbook are followed by the ITER Organisation, the Domestic Agencies and industry to ensure that ITER operations are ultimately safe, environmentally acceptable and successful.

The main Handbook is supported by a set of Appendices which are guidance documents subject to regular update. The Appendices may be used by Domestic Agencies and suppliers to aid in the production of tritium components and development of specifications and procedures which satisfy the mandatory requirements of the ITER Tritium Handbook.

1.1 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 Tritium 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.

Where the requirements of the ITER Vacuum Handbook are to be met for Tritium Classification 1, 2 & 3 vacuum systems without a Vacuum Classification (VQC), the ITER Vacuum RO shall be substituted by the ITER Tritium RO where *acceptance* is required.

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 Tritium Responsible Officer.

2 ITER Tritium Confinement

Confinement is the term used for the physical enclosure of tritium. The risk of release of tritium inventories shall be minimized by the use of confinement systems and barriers within the systems. The First Confinement System shall be enclosed within the Second Confinement System. Multiple barriers may be required as part of a First or Second Confinement System. The first barrier in a confinement system is designated as that which is closest to the hazardous material under normal operations.

2.1 First and Second Confinement systems

First and Second Confinement Systems are designed to prevent releases of radioactive materials into areas that impact workers, the public, and/or the environment. The First Confinement System (See Figure 1)[1] shall limit the impact of releases to the Second Confinement Systems. The purpose of the Second Confinement System (see Figure 2) is to limit the consequences in case of failure of the First Confinement System and is required for all areas containing First Confinement Systems. First and Second Confinement Systems may consist of one or more barriers as required to ensure confinement for all operational modes and design basis events and shall consider prevention and mitigation effects reported in beyond design basis events considered in the safety analysis. Confinement systems and their associated barriers as they relate to tritium classification can be found in Section 3 of this document. Appendix B6 also can be referenced for additional information.

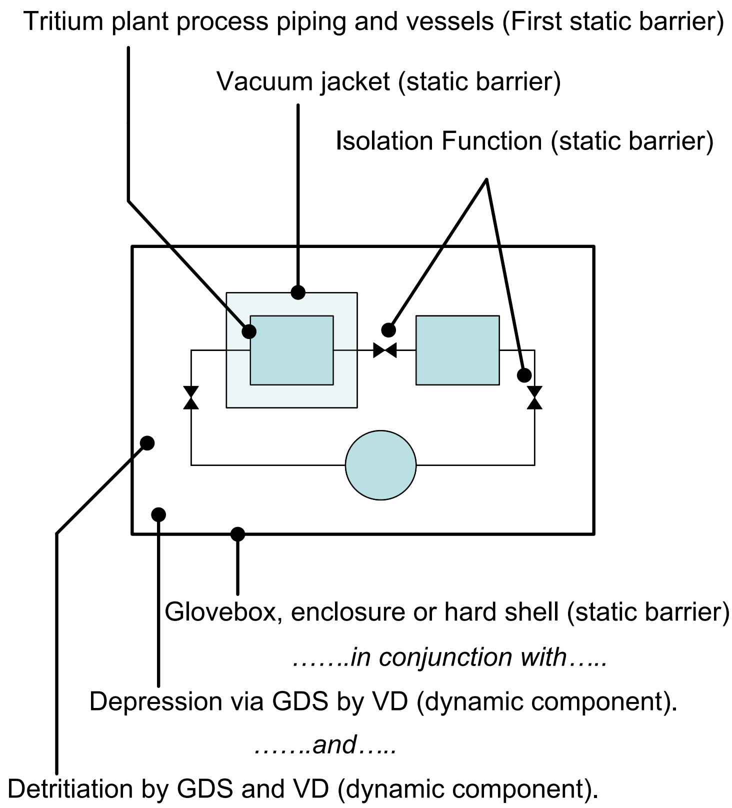

Figure 1 First Confinement System

[1] See ITER Plant Description (PD) [2X6K67] for First and Second Confinement Systems associated with the vacuum vessel.

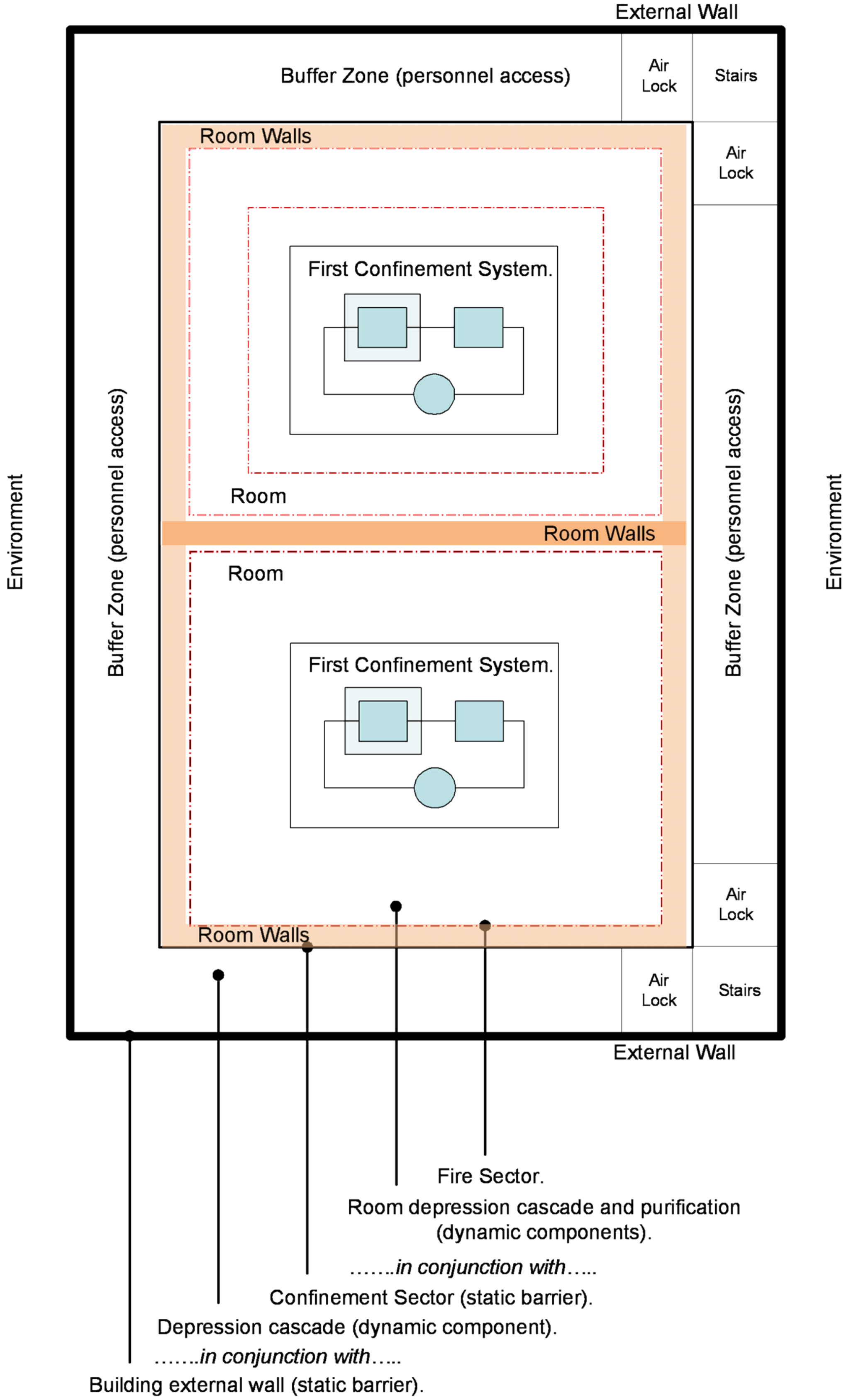

Figure 2 Generalized Arrangement of Second Confinement System

2.2 Number of Confinement Barriers

First Confinement Systems where the total concentration of hydrogen exceeds flammable limits[2] are required to have a minimum of two static barriers for all streams that contain tritium. Hydrogen gas mixtures with concentrations less than flammable limits in air or tritium contaminated liquids require a minimum of a single barrier for the First Confinement System.

First Confinement Systems that contain greater than 0.1 g of tritium even when below flammable concentrations should be considered for the application of a second confinement barrier as defence in depth. First Confinement Systems with a single barrier that contain greater than 0.8 g of tritium even when below flammable concentrations require *acceptance* by the ITER Tritium RO.

Vacuum systems potentially containing flammable quantities of hydrogen (where tritium is present) do not require a second barrier as part of the First Confinement System where safety analysis demonstrates there is no credible scenario for an explosion resulting in a release.

The Second Confinement System is required to have a minimum of one static barrier along with any associated dynamic components, such as depression cascade and detritiation.

Deviations require *acceptance* of the ITER Tritium RO.

2.3 Confinement Barrier Separation

Confinement barrier separation shall be provided between volumes that may contain air and hydrogen isotopes containing tritium during normal conditions. Detection and isolation functions shall be provided to prevent air ingress into the vacuum pumping system, fuelling system or Tritium Plant in the event of air ingress into the vacuum vessel. A means of detection for a flammable condition (e.g. oxygen or hydrogen, and/or tracer gas) is required. Deviations require *acceptance* of the ITER Tritium RO.

3 Tritium Classification (TC)

Components which may come into contact with tritium shall be assigned a Tritium Classification. The purpose of the classification is to identify requirements for design, fabrication, construction and commissioning so as to provide the necessary protection to personnel, the public and the environment graded appropriately to the chemical and radiological hazards presented by the tritium contained in the system.

The Tritium Classifications are defined as follows (see Figure 3 for pictorial representation on selection of Tritium Classifications and Figure 1 and Figure 2 for information on confinement systems and barriers).

[2] Refer to Appendix B3 for guidance on hydrogen flammability.

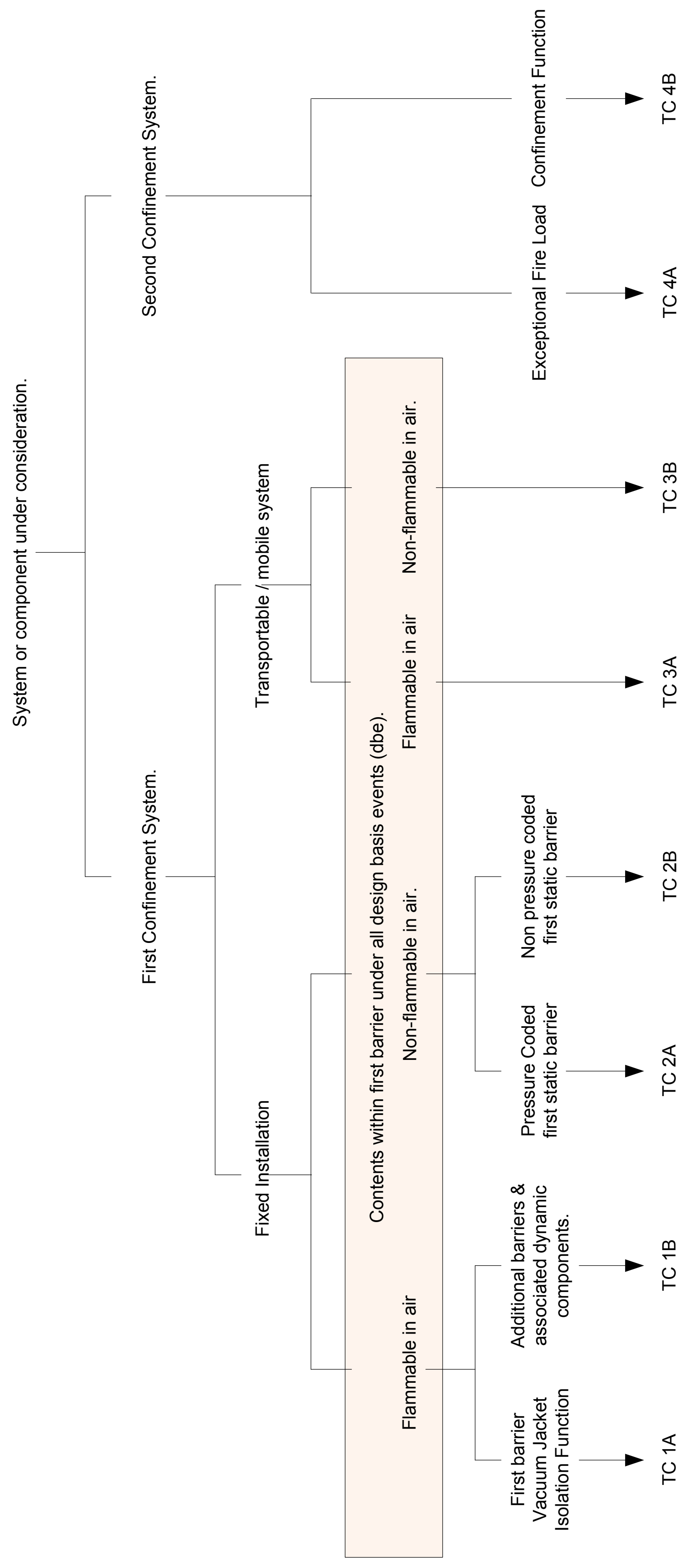
System or component under consideration.
Second Confinement System.
First Confinement System.
Exceptional Fire Load
Confinement Function
TC 4A
TC 4B
Transportable / mobile system
Fixed Installation
Contents within first barrier under all design basis events (dbe).
Flammable in air
Non-flammable in air.
TC 3A
TC 3B
Pressure Coded first static barrier
Non pressure coded first static barrier
TC 2A
TC 2B
First barrier Vacuum Jacket Isolation Function
Additional barriers & associated dynamic components.
TC 1A
TC 1B

Figure 3 Determination of Tritium Classification

TC 1: First Confinement System: Fixed installations containing potentially flammable (if exposed to air while also considering diluent gas impacts*) concentrations of hydrogen isotopes that include tritium.

- **TC 1A**: First barrier and associated vacuum jackets and isolation valves.
- **TC 1B**: Additional barriers and dynamic components. Gloveboxes fall within this category and their particular engineering requirements are called out separately.

Single barriers for flammable atmospheres shall only be permitted where justified to be safe through compensatory engineering measures or Operating Limits and Conditions (OLC) with *acceptance* by the Tritium RO.

TC 2: First Confinement System: Fixed installations containing non-flammable (if exposed to air while also considering diluent gas impacts*) concentrations of hydrogen isotopes that include tritium.

- **TC 2A**: Barrier(s) engineered to accepted code (ASME B31.3 for example).
- **TC 2B**: Barrier(s) where conventional codes and standards are not applicable. Unique engineering specifications are to be applied.

TC 3: First Confinement System; Mobile / Transportable devices.

- **TC 3A**: Mobile or portable devices containing potentially flammable (if exposed to air while also considering diluent gas impacts*) concentrations of hydrogen isotopes that include tritium. Examples of these devices include portable hydride beds, transport flasks, etc.
- **TC 3B**: Mobile or portable devices containing non-flammable (if exposed to air while also considering diluent gas impacts*) concentrations of hydrogen isotopes that include tritium. Examples of these devices include Molecular Sieve Beds (MSB) for the Glovebox Detritiation System (GDS), material transfer casks, etc.

Single barriers for flammable atmospheres shall only be permitted where justified to be safe through compensatory engineering measures or OLC's with *acceptance* by the Tritium RO.

TC 4: Second Confinement System.

- **TC 4A**: Any system or component located in an area served by the Detritiation System (DS) that must be included in a Fire Hazard Assessment.
- **TC 4B**: Systems and components that provide a confinement function.

Notes:

An SSC need not be assigned a Tritium Classification if the following conditions are satisfied:

- It does not need to be identified in the Fire Hazard Assessment (see TC 4A), **AND**
    - It has, by design, no exposure to tritium, **OR**
    - It presents no tritium hazard to personnel, the public or the environment

* As an example argon reduces the Limiting Oxygen Concentration (LOC) of Hydrogen in Air. Refer to Appendix B3 for information on hydrogen flammability.

Refer to Appendix A4 for guidance on the above.

Internal components: these shall be classified the same as the confinement barrier that encloses them. Where these do not provide a confinement function, the requirements in this handbook relating to confinement shall not apply.

Potential Flammability: Tritium contained on pyrophoric materials shall be designated as TC 1A or TC 3A because of the flammable nature of the material.

Fire Hazard Assessment: plant, components and services that have a high/concentrated fire load, rapid kinetic fuel or large physical size that must be taken into account in terms of the fire risk analysis, fire modelling and fire controls (such as sprinkler density or sprinkler positioning).

3.1 Documentation of the Tritium Classification

The Tritium Classification (TC) for systems and components shall be recorded on applicable design output documents and maintained in a retrievable form.

3.2 Deviations and Non-Conformances

Requests for deviations from, and non-conformance with, the requirements of the ITER Tritium Handbook shall be made to the ITER Organisation in writing following the procedures detailed in the ITER Quality Assurance Program (IDM Ref: ITER_D_22K4QX) and deviations and Non-conformities procedures, IDM 2LZJHB for ITER IO internal procedures and 22F53X for application by Domestic Agencies and contractors. Recommendations on the approval of the non-conformance report will be made by the ITER Tritium Responsible Officer.

Deviations or non-conformance to the requirements of the Tritium Handbook for a particular component can be agreed within the ITER Organisation through the joint approval of an Interface Control Document pertaining to tritium (PBS 3.2).

4 Design of Tritium Systems

4.1 General

The design of tritium systems shall include provisions to ensure that system tritium inventories cannot exceed the limits assumed in Safety Analysis. The design shall ensure that such inventories are isolable during accident conditions, e.g. fire, seismic events, etc. Additional information on design is given in Appendix B1.

4.2 Design Requirements & Regulations

Tritium systems shall be designed in accordance with the relevant design codes, regulations & requirements including those listed in this section.

Further information, including code selection, is provided in Appendix B7.

4.3 Nuclear Pressure Equipment (ESPN)

All tritium equipment designed to operate at pressures above 0.15 MPa (expressed as absolute pressure) and having a tritium inventory > 370 GBq shall comply with the ESPN regulations. Further information on ESPN classification and exemptions is found in Appendix B5.

4.4 ITER Vacuum Handbook

The ITER Vacuum Handbook (ITER_D_2EZ9UM) outlines the mandatory requirements for the design, manufacturing, testing, assembly and handling of vacuum items for use on ITER. In general, unless otherwise stated in this manual, application of the requirements of the ITER Vacuum handbook to tritium components apply up to and including the first isolation valves downstream of the vacuum vessel and cryogenic pumping/vacuum system.

Vacuum components for use on ITER systems will be assigned a Vacuum Classification (VQC) which denotes its area of service.

Tritium confinement systems which are assigned a VQC shall be designed, manufactured and tested in accordance with both the ITER Tritium & Vacuum Handbooks.

4.5 Materials

Tritium Classification 1 & 2 confinement systems shall be of all-metal welded construction where practical. Welds shall be radiographable butt welds where practical. Consideration shall be given to inspection and maintenance activities when designating all welded construction. Components that will require replacement or routine maintenance that is hindered by all-welded construction (e.g. access ports, valves, pumps) shall be considered for gas-tight demountable connections. Appendix B10 may be referenced for additional design suggestions.

Materials for use on Tritium Classifications 1A, 2A, and 2B systems / components with a vacuum classification shall be selected from the ITER Vacuum Handbook. Materials for use on Tritium Classifications 1, 2, 3 and 4 systems not assigned a vacuum classification shall be selected from Appendix B8.

Halogenated materials, sulphur and phosphorus, and processes involving the use of these materials, shall be avoided when possible for all components having a Tritium Classification. These materials lead to potential for oxidation catalyst poisoning and to metallic corrosion due to acid formation. If use of these materials cannot be avoided, the content of these materials in Tritium Classification 1 and 2 systems shall be limited to 0.025% of each. The use of materials exceeding these concentration requirements must be *accepted* by the ITER Tritium RO.

Hydrogenous materials (e.g. polymers, hydrocarbons) should be avoided to the maximum extent possible for components in direct contact with tritium due to hydrogen exchange leading to degradation of the components as well as high tritium content in the components when handled as waste.

All metallic material shall be specified at the design stage. Certification in accordance with EN 10204 Chapters 2.2, 3.1 or 3.2 for Tritium Classification 1 and 2 components shall be provided. Other materials, or materials without the EN 10204 certification, shall be supplied with a supplier's certificate of conformity to ensure compliance with the requirements of the material procurement.

4.6 Plate Material

For Tritium Classifications 1A, 2A and 2B materials, hot or cold rolled plate material shall be used with the direction of rolling parallel to the surface of the confinement boundary to the maximum extent practicable. Where transverse sections have to form part of the confinement boundary, a low inclusion rate material shall be used which meets the inclusion limits as specified in the ITER Vacuum Handbook and shall be proven by helium leak testing.

4.7 Additional Barriers in the First Confinement System

The components which are the first barrier of the First Confinement System which operate at tritium partial pressures above 100 Pa and temperatures above 150ºC shall be constructed with an additional barrier designed to minimize heat transfer and recover tritium permeating through the heated metal. The additional barrier(s) shall be classified the same as for the first barrier, which will typically be Tritium Classification 1A.

4.8 Fire Protection

Systems having Tritium Classifications 1, 2 and 3 shall be designed to fulfil all functions identified in the safety analysis, including achieving and maintaining safe state and maintaining confinement and isolation under exposure temperatures predicted in a fire scenario. Fire loading assumed in the design must be provided to ITER for incorporation into the overall building Fire Hazard Analysis.

Where an automatic water type fire suppression system is installed and credited within safety analyses, systems having Tritium Classifications 1, 2 and 3 shall be designed to 300 ^{o}C for fire exposure, unless another value is stated in Appendix B3. Appendix B3 will give results from analyses of fire in tritium plant process rooms that will take into consideration such factors as the room layout, ceiling height, combustible loading, heat plume rise, glove box glass reflective properties, nitrogen insulating effects and multiple fire and confinement barriers. Combustible control requirements (fire loading) assumed in such an analysis shall be stated such that the Domestic Agencies can adequately consider combustible loading.

In cases of multiple first confinement barriers (i.e. jacketed vessels) where, during a credible fire, the outer barrier is raised beyond temperatures where its confinement may be compromised, the outer barrier may continue to be credited as a fire barrier to protect and maintain the integrity of the inner barrier when analysis justifying this is *accepted* by the ITER Tritium RO.

Confinement Sectors shall have minimized quantities of combustible materials with low potential to ignite and low potential to burn. Consideration shall be given to material selection that has low fire loading.

The design and construction of each process system shall as far as practicable provide that its operation or failure shall not cause a fire.

Ignition sources, fire loads, and tritium inventory shall be segregated to the maximum extent possible to minimize the possibility of a fire starting and growing in intensity.

Components important for safety (SIC) shall be protected against the consequences of fires so that their safety functions are maintained.

Consideration shall be given to identification and design of controls to limit the spread of fire and may include physical separation, fire barriers and active fire detection/suppression.

Consideration of water spray effects shall be given to equipment located in areas subject to water spray if selected controls include the use of sprinkler systems.

The general fire protection requirements for a tritium plant room are depicted in Figure 4. Additional details for compliance with fire requirements are contained in Appendix B3.

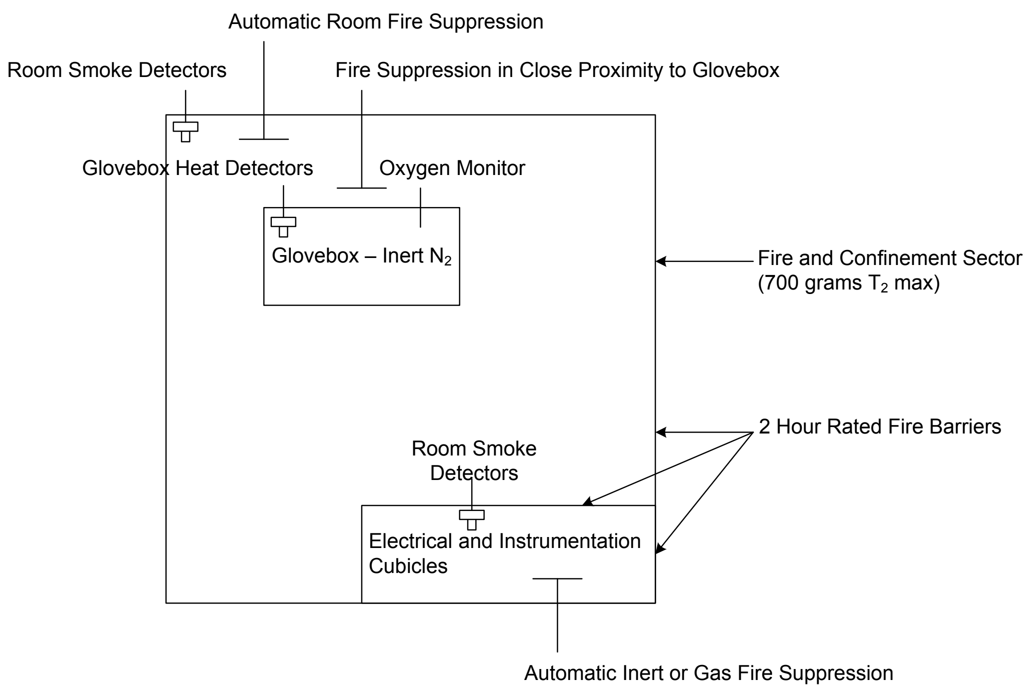

Figure 4 Tritium Process Room Fire Protection Measures.

4.9 Over-Pressure Protection

Tritium Systems are typically operated at pressures well below the potential design pressure of stainless steel vessels and piping manufactured using standard materials of construction. When possible, it is desirable to design tritium pressure vessels and piping such that a factor of nine exists between the normal operating pressure of the vessel/system and the Maximum Allowable Working Pressure (MAWP)[3]. As an example, a tritium system with a normal operating pressure of 0.2 MPa should have a MAWP of 1.8 MPa. NFPA[4] 69, Explosion Prevention Systems, provides additional guidance on use of this safety factor to contain potential hydrogen deflagrations.

It is desirable to design tritium processing systems such that all components can contain the maximum pressure possible under incident or accident conditions including fires. Components such as pumps and instrumentation are significantly weaker than the vessels and piping and often drive the need for relief protection.

When directed by nuclear pressure equipment (ESPN) requirements, over-pressure devices (typically rupture disks) on tritium systems shall vent to an evacuated blow-down tank. The blow down tank shall be sized to accept the maximum credible volume of any postulated release for

[3] This is a ratio of absolute pressures.

[4] NFPA – National Fire Protection Association – USA.

events with a frequency from 1 - 10^{-4}. For events with a lower frequency than 10^{-4}, it is acceptable to contain the gas for the higher frequency events and vent any excess gas using a re-seatable relief device that is vented to an enclosure serviced by the Detritiation System (DS). Reference Appendix B5 for additional guidance in compliance with pressure protection requirements.

There is a requirement to periodically inspect pressure relief devices. The design shall be such as to facilitate this inspection. Further information can be found in Appendix B5.

4.10 Heating Elements

For systems of Tritium Classification 1 or 2 having single-phase heaters shall have redundancy such that if one heater fails the process function can be performed by the remaining heaters if determined to be necessary through Hazard or RAMI analyses. Heaters shall be protected by one or more latching over-temperature trip circuits. It shall be possible to detect the failure of a heater and then take recovery action without breaching tritium confinement.

4.11 Filtering

Use of filters shall be specified in the design of beds and other sources of particulates, considering flow dynamics. These filters shall be located before valves which perform an isolation function.

Filtration shall be provided on the inlets to all mechanical pumping systems unless otherwise *accepted* by the ITER Tritium RO.

4.12 Instruments and Controls

Ion Chambers: Design of instrumentation which may be in contact with tritium (e.g. ion chambers, or other such tritium monitoring components) must consider the effect of tritium contamination on operation. Consideration shall be given to system designs which allow decontamination methods (e.g. flushing, cleaning, etc) to be performed on in-service chambers. The surface finish on the tritium-exposed areas of the ion chambers should minimize roughness to facilitate ease of decontamination. The tritium exposed surface area should be minimized.

Thermocouples and Resistance Temperature Detector (RTD): thermocouples and RTDs shall be installed within thermal wells unless otherwise *accepted* by the ITER Tritium RO.

Periodic Recalibration: Consideration shall be given to system design which allows in-service periodic recalibration. Guidance on methodologies to achieve this design is given in Appendix B-15.

4.13 Enclosures[5]

Glovebox enclosures served by the Detritiation System (DS) shall be designed in accordance with American Glovebox Society "Standard of Practice for the Design and Fabrication of Nuclear-Application Glove boxes" AGS-G006.

[5] Requirements under this section are not applicable to Tritium Classes 3 & 4.

Glovebox enclosures served by DS shall be constructed on a modular basis to a standard model as described in Appendix B10.

Enclosures served by DS shall also meet the following requirements:

- enclosure windows shall comprise of a double pane of tempered safety glass of 12.7 mm total thickness with a layer PVB (polyvinylbutyral) sandwiched between, in accordance with American Glovebox Society standard AGS-001
- enclosure shells shall be uncoated stainless steel
- glove ports shall be fitted with *accepted* removable covers
- enclosures shall operate at least 250 Pa below ambient room pressure

Enclosures shall be designed with airlocks such that process equipment within it can be removed and replaced without the removal of glass panels or access panels whenever possible. Tritium RO *acceptance* shall be obtained for any equipment requiring removal and replacement where removal of a glass or metal panel is required

Enclosures shall be designed with over pressure protection such that the failure of any pressure or vacuum containing First Confinement System barrier within it will not exceed the enclosures design pressure. Overpressure protection shall be vented to DS or to an enclosure served by DS.

Enclosures shall be designed to operate with a nitrogen blanket gas atmosphere at 60% of the Limiting Oxidant Concentration (LOC) of Hydrogen. Considerations must be given for the reduction of the LOC resulting from the presence of all gases that may leak into the enclosure. As a practical example, argon reduces the LOC to 3.3%. Therefore, if the potential exists for argon being present in the enclosure, the operating limit for oxygen shall be reduced.

Enclosures shall be designed to minimize the in-leakage of oxygen and permeation of moisture through gaskets, gloves and glove port covers into its environment. Moisture permeation through enclosures provides a significant source of water loading for the Glovebox Detritiation System (GDS) and DS. An in-leakage rate of 0.01%hr^{-1} of air is the maximum acceptable leak rate. Moisture permeation rate per glove box assembly shall not exceed ten litres per year.

4.14 Interconnections between enclosures

Interconnecting lines between enclosures shall be confined (e.g. in a guard tube) unless *accepted* by the ITER Tritium RO. A single guard tube may contain multiple lines.

The internal volume of the guard tube shall share an atmosphere with only one of the enclosures.

4.15 Temporary enclosures

Temporary enclosures (e.g. isolators, tents etc) associated with work involving the potential for tritium release shall be designed and manufactured in accordance with American Glovebox Society “Standard Practice for design and fabrication of glove bags” AGS-002 1998.

4.16 Post Accident Safe State

Tritium Classifications 1, 2 & 3 systems shall have defined safe state(s) that can be reached from each operating mode (including maintenance) in response to all incident or accident scenarios.

For Tritium Class 1 systems, and all systems with an ESPN classification, three levels of safe state conditions shall be identified:

- immediate safe state
- persistent safe state
- long term safe state.

A plan detailing the transition from one state to the next and the systems to allow the transitions shall be submitted for *acceptance* by the ITER Tritium RO.

Where personnel intervention is required to achieve system safe state, procedures for the intervention shall be submitted to the ITER Tritium RO for *acceptance*. The procedure(s) shall state how personal safety is to be ensured, take into account access restrictions that may be present during machine operations and state measures which are to be implemented to minimize risk of exposure.

Further information is to be found in Appendix B2.

4.17 Minimization of Tritium Inventory at Risk

Each tritium circuit shall be analyzed to establish the minimum tritium inventory needed to meet its operational requirements. Appendix B1 provides guidance on analysis methodology. If the analysis indicates that the process will exceed an inventory limit stated in the Project Requirements Document [27ZRW8], then utilization of an isolation function (e.g. isolation valves) shall be used to provide isolation within the process to maintain the inventories within bounds. For Defence in Depth purposes, consideration shall also be given to inclusion of additional isolations and physical barriers.

Where it is not possible to limit the inventory of tritium by physical barriers, the use of tritium tracking procedures (addressed in Appendix B13) may be *accepted* by the ITER Tritium RO.

The design of tritium process systems shall be reviewed by the Tritium RO and the number of “isolable inventories” shall be *accepted*.

4.18 Inventory Isolation

Where isolation valves are performing the isolation function in the safety analysis, they shall meet the following requirements:

- fail closed on loss of signal or actuating gas pressure
- valves subject to frequent switching, or operate where the process medium may have particulates present, shall be fitted with an additional isolation valve in series
- valves must remain operable for any conditions where they are credited, e.g. fire and seismic loading.

4.19 Measurement of Tritium Inventory

Tritium systems requiring accountability controls as defined in Appendix B13 shall satisfy the following requirements for measurement of tritium inventory:

- tritium remaining in the system (hold-up) shall be minimised by design. (e.g. minimise dead volumes etc)
- conversion of tritium away from T_2 form shall be minimised (e.g. by the use of tritium compatible materials etc)
- systems shall include facilities to allow tritium inventory to be measured during accounting procedures. Tritium Class 1A systems shall include facilities for the determination of tritium inventories during system operation.

The methodology and accuracy to which measurements shall be performed shall be submitted for *acceptance* by the ITER Tritium RO.

4.20 Design for Maintenance of Tritium Systems

The design of Tritium systems shall be such that planned maintenance can be performed with the risk of exposure and release of tritium minimised. A plan detailing planned maintenance to be performed and the controls in place to minimise the risk of exposure shall be submitted to the ITER Tritium RO for *acceptance*. The plan shall also detail the actions to be taken in the event of an off-normal event requiring intervention to bring the system to an operable status via system maintenance.

4.21 Second Confinement Systems

The Second Confinement System is provided by the building structure served by the ITER Detritiation System (DS) in which the First Confinement Systems are located and shall be engineered in accordance with:

- abstract of ITER Fire Safety Approach [ITER_D_25SDBD]
- Tokamak and Tritium Building Confinement Abstract [ITER_D_256AB2]
- implementation of the fire measures concerning the Order dated 31/12/99 [ASN/ GUIDE /7/01]
- ISO-17873 “Criteria for the design and operation of ventilation systems for nuclear Installations other than nuclear reactors”.

5 Design Safety Assessment

The design of Tritium Classifications 1A, 1B, 2A, 2B, 3A, 3B and 4B systems shall be assessed for safety. The results of assessments performed shall be included in the required design reviews for *acceptance* by the ITER Tritium RO. The results of the assessments shall feed back to the system design.

The requirements for design and safety assessment are detailed in the following section with further information in Appendix B1.

The results of the safety analysis shall be recorded using the Tritium Safety Analysis Report (TSAR) and submitted for *acceptance* by the ITER Tritium RO and **Nuclear Safety & Environment Division Head**. A completed example of the TSAR can be found in Appendix B1.

5.1 Hazards Assessment

Systems having Tritium Classification 1A, 1B, 2A, 2B, 3A, 3B or 4B shall undergo an accepted Tritium Process Hazards Analysis (PHA) in accordance with ITER_2MF4G7 (phase description), ITER_D_2LTV8Z (approval process), ITER_D_2F6B9M (HAZOP procedure) and ITER_D_2F9G2P (HAZOP guide).

The normal operating modes and how transitions will be made from one mode to another shall form part of the input to the assessment.

The Hazards Assessment shall identify and record basic initiating events (e.g. fire, seismic load etc). For events determined to have No Credible Cause (NCC) or No Consequence of Interest (NCI), no further action is required other than to record the events. For all other basic initiating events, the nature of the consequence of the event, the hazard it poses and its severity and likelihood of occurrence is to be recorded, along with any measures (or “controls”) to mitigate the risk. Basic initiating events shall be grouped according to their effect and the Postulated Initiating Events (PIEs) identified for the Safety Assessment.

Further information is provided in Appendix B1.

5.2 Loads

Each tritium system shall be designed to withstand the normal operating loads in combination with loads arising from abnormal events within the system’s design basis. Each of these loads shall be identified and specified. The results of the assessment and the controls to be put in place to mitigate the effect of the events shall be recorded in the Tritium Safety Analysis Report (TSAR).

5.2.1 Load Combination and Categorization

The loads arising from normal, incident and accident events shall be categorized according to their probability of occurrence either singly or in combination. ITER Load Specifications ITER_D_27ZRXQ details event combinations and categorization.

5.3 Safety Assessment

The impact of the loads identified from the hazards assessment shall be analyzed for each tritium bearing system. All Postulated Initiating Events (PIEs), the effect(s) of the PIE and the controls to be implemented to mitigate the effect of the PIE shall be recorded using the Tritium Safety Analysis Report (TSAR).

5.4 Design Basis events

The effect of all design basis events identified during the Hazards Assessment shall be assessed for Tritium Classifications 1A, 1B, 2A, 2B, 3A, 3B and 4B systems.

Further information can be found in Appendix B1.

5.4.1 Fire Assessment

The effect of fire shall be assessed for all Tritium Classified systems. The effects on the system of fire in adjacent fire zones shall be included in the assessment.

Further information can be found in Appendix B3.

5.4.2 Seismic Assessment

Tritium Classification 1A, 1B, 2A, 2B, 3A, 3B and 4B systems shall undergo a seismic assessment in accordance with the system seismic class.

Further information can be found in Appendix B4.

5.4.3 Further Assessments

All Tritium Classified systems shall be subject to assessment of the effects of all remaining design basis PIEs identified in the Hazards Assessment.

Further information can be found in Appendix B3.

5.5 Beyond Design Basis Events

All Tritium Classified systems shall be assessed for the effects of beyond design basis events or combinations of events identified in the Hazards Assessment. If the effect of the beyond design basis events leads to a disproportionate increase in consequence should they occur (the cliff-edge effect), then the system design margins shall be reviewed and further controls imposed to mitigate the risk.

For further information refer to Appendix B1.

5.6 Damage Limits

Damage limits are defined in the ITER Load Specification (ITER_D_222QGL).

For each Postulated Initiating Event (PIE), the damage limits on a component and plant level basis shall be established in accordance with the ITER Load Specification respecting the additional requirements for tritium systems that are not Tokamak components as listed in Table 1.

5.7 Operating Limits and Conditions

The Safety Assessment of the Tritium Classified systems shall be used to derive a set of Operational Limits and Conditions. These limits and conditions shall include safety limits, safety system settings, operational limits and conditions for equipment and inventories, surveillance and administrative requirements.

Tritium Classified system alarms settings shall have sufficient margin to ensure the systematic functions of alarm before trip take place whilst avoiding spurious fleeting alarms and trips arising from normal operating fluctuations and measurement uncertainties.

Operating limits and conditions shall be recorded in the Tritium Safety Analysis Report (TSAR).

Table 1 Additional Damage Limits

Damage Limits	Damage Limits to Component Level	Damage Limits in Plant Level and Recovery of the Plant (Plant Operational Condition)
Normal/test	No additional requirements.	For test, all protection systems that were disabled shall be reinstated and proven before return to service. For maintenance, all activities shall be controlled with ITER procedures.
Upset	No additional requirements.	There shall be no significantly adverse effects on confinement systems. Safety and interlock functions must withstand this level of loading. (Processes may switch to redundant or back-up equipment to maintain safety function). Plant must be able to assume safe state.
Emergency	Components fulfilling safety function must fully withstand this level of loading. Notwithstanding the above, should the component providing the safety function fail, then it must be possible to maintain the safety function through other means, such as by redundancy or back-up of components.	At least one confinement barrier – with its associated dynamic components and isolation functions – shall be maintained for each of the two confinement systems. Equipment providing safety functions must withstand this level of loading. (Processes shall switch to redundant or back-up equipment to maintain safety function as required). Plant must be able to assume safe state.
Faulted	Components fulfilling safety function must adequately withstand this level of loading without loss of safety function. Notwithstanding the above, should the component providing the safety function fail, then it must be possible to maintain the safety function through other means, such as by redundancy or back-up of components.	At least one confinement barrier shall be maintained for each of the two confinement systems. If required by analysis, Tritium Classifications 1A, 1B, 2A, 2B, 3A, 3B and 4B systems shall withstand this level of loading. Plant must be able to assume safe state.

6 Manufacture

For TC 1A systems/components, the ITER Vacuum Handbook requirements for VQC 1A systems/components are invoked for the following:

- bellows and flexible connections
- metallic machined components and fittings
- castings
- use of cutting fluids
- cleaning

For TC 1B systems, refer to Appendix B10 for manufacturing requirements.

For TC 2A systems, manufacturing requirements will be those specified by the applicable code and standard.

For TC 2B systems, manufacturing requirements shall be specified by the designer organisation and *accepted* by the ITER Tritium RO.

For TC 3A or TC 3B IAEA type B(U) tritium shipping containers:

- IAEA requirements shall be followed for manufacturing
- inner containers shall follow the ITER Vacuum Handbook for castings, cleaning, use of cutting fluids, metallic machined components and fittings.

For TC 3A or TC 3B internal transport casks, manufacturing requirements shall be specified by the designer organisation and *accepted* by the ITER Tritium RO.

For other systems/components falling within TC 3A or TC 3B definitions, manufacturing requirements shall be specified by the design organisation and *accepted* by the ITER Tritium RO.

For TC 4A, no specific manufacturing requirements are identified

For TC 4B, manufacturing requirements will be those specified by the applicable code and standards.

6.1 Additional Requirements for manufacture of systems/components

Pipework

- For TC 1A systems/components, pipe and tube shall be of seamless construction (see Appendix B8).

Permanent joining processes

- For TC 1A systems/components, joining techniques to be used are given in the ITER Vacuum Handbook for VQC 1A. Proposals for joining techniques not listed shall be submitted to the ITER Tritium RO for *acceptance*.

Welded joints

- For TC 1A systems/components, TC IB and TC 2A nuclear pressure equipment (ESPN): for the qualification and execution of production welded joints forming a confinement barrier refer to the ITER Vacuum Handbook for VQC 1A.

Inspection and Testing of Production Welded Joints

- All TC 1A welded joints shall meet the requirements of VQC 1A weld inspections unless a method of pre-production proof sampling is agreed by the ITER IO.

For TC 1A systems/components, TC IB and TC 2A nuclear pressure equipment (ESPN): 100 % helium leak testing of all welds forming a confinement barrier shall be carried out with the *acceptance* criteria listed in Table 2.

Demountable joints

- TC 1A systems shall utilize metal seals as detailed in Appendix B10
- sealing materials for use on TC 1B, TC 2A, TC 2B, TC 3A, TC 3B and TC 4B systems providing a confinement function shall be selected from Appendix B10
- TC 1A, TC 1B demountable joints shall be selected from Appendix B10
- all demountable joints must be accessible for maintenance and testing.

Surface Roughness

- metallic components for TC 1A shall be supplied with the maximum average surface roughness of 6.3 μm as measured by electric stylus. Surface roughness is defined in accordance with ISO 4287: 2000.

Connection to Vacuum Systems

- Interspaces for connection to the ITER Service Vacuum Systems in the tokomak complex and interspaces for connection to the tritium process vacuum line in the Tritium Plant (vacuum line in the tritium building served by TEP) shall be fitted with a minimum of two independent connections in accordance with the ITER Vacuum Handbook. On *acceptance* by the ITER Tritium RO, interspaces for connection to the tritium process vacuum line in the Tritium Plant may be fitted with one vacuum connection
- The size of the vacuum connection shall be in accordance with the ITER Vacuum Handbook section 11.
- Vacuum connections not permanently connected to a vacuum system shall be provided with an isolation valve and terminated with a sealing blank.

Valve Assemblies and Valve Actuation

- Tritium Classifiaction 1A valves with VCR fittings shall be supplied with the fittings butt welded to the valve.
- Consideration shall be given to requirements for valve seat maximum differential pressure before opening. This consideration must take into account the tritium circuit design related to means of valve operation including valve operation during maintenance activities.

- Tritium Classifcation 1A manual valves used only for isolation purposes shall have metal stem tips except where the valve is to provide the isolation of metal getter storage beds which shall have Vespel® tips. Valves with Vespel® tips shall be fitted with torque limiting handles unless *accepted* by the ITER Tritium RO.
- Actuated valves shall fail safe in the event of loss of valve control.
- Further information on valves for use in tritium systems can be found in Appendix B10.

Proprietary Components

- Proprietary components are unmodified off-the-shelf items which are fabricated using standard manufacturing techniques. As such, unless otherwise stated within the context of this handbook, these components are acceptable for use in Tritium Classification 1A systems when specified directly by design. The design shall designate any special requirements to be performed in conjunction with use of these components, and these special requirements shall be recorded on design output documents. Further information is contained in Appendix B11.

7 Inspection and Testing

7.1 Leak testing

Leak Testing shall be performed for Tritium Classified systems and components. Design considerations and methodology for leak testing TC 1A components shall follow the ITER Vacuum Handbook. Leak testing methodology for other TC systems/components is discussed in appendix B12.

Selection of criteria from Appendix B12 shall be determined with consideration given to service fluid, accessibility, and potential hazards in the event of a leak. Leak test methods and acceptance criteria shall be submitted to the ITER Tritium RO for *acceptance*.

The maximum acceptable leak rate pertaining to Tritium Classifications 1, 2 and 3 components/systems is given in Table 2.

Table 2 Maximum Acceptance Leak Rates for Tritium Class 1, 2 and 3 Systems/Components

Tritium Class	Maximum Leak Rate (Pam^3s^{-1} air equivalent)	
	Component	System
TC 1A	1 x 10^{-10}	1 x 10^{-9}
TC 1B	---	1 x 10^{-5} or $0.01\%_{vol.}hr^{-1}$
TC 2A and TC 2B	---	1 x 10^{-5}
TC 3A*	1 x 10^{-10}	1 x 10^{-9}
TC 3B*	---	1 x 10^{-5}

*For IAEA type packages, IAEA codes shall be followed. For Remote Handling material transfer casks, the leak rate specified in Table 2 shall be applied to the design and the equipment acceptance test under static, unladen conditions at ambient temperature.

7.2 Packaging and Handling

System and components shall be prepared and packed so as to provide protection from environmental exposure and transportation loads. Additional discussion is contained in Appendix B12.

7.3 Receipt Inspection

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

The following inspections of tritium equipment shall be incorporated into the inspection/acceptance tests carried out on equipment and components delivered to ITER:

- visual inspection
- cleanliness check
- leak test.

On completion of the incoming inspection any non-conformance with this Handbook shall be handled in accordance with ITER Deviations & Nonconcormity Procedure ITER_D_2LZJHB.

7.4 Long Term Storage of Tritium Equipment

In many cases tritium components will be delivered to the ITER site in advance of installation. Tritium components shall be stored in such a state as not to degrade the tritium (or vacuum) performance.

8 Commissioning of Tritium Systems

For Tritium Classifications 1A, 1B, 2A, 2B, 3A, 3B and 4B systems, commissioning procedures shall be submitted to the ITER Tritium RO for *acceptance*. The procedures shall detail the required operations both manual and automatic to commission the system(s). Where safety features of the system are to be disabled during the commissioning phase, details of how tritium confinement is to be ensured shall be provided and the actions to be taken in the event of an accident or incident given within. Further information on the commissioning of tritium systems including the commissioning of safety related systems is to be found in Appendix B14.

9 Operation of Tritium Systems

For Tritium Classifications 1A, 1B, 2A, 2B, 3A, 3B and 4B systems, operating procedures shall be submitted to the ITER Tritium RO for *acceptance*. The procedures shall include details of all the operations, manual or automatic, for the safe operation of the system. The procedures shall also include details of actions to be taken in the event of accident or incident.

10 Maintenance of Tritium Systems

For Tritium Classifications 1A, 1B, 2A, 2B, 3A, 3B and 4B systems, detailed maintenance plan and procedures shall be submitted to the ITER Tritium RO for *acceptance*. The maintenance plan shall detail the routine maintenance operations to be performed. Maintenance procedures shall detail the operations required to maintain the systems either routinely or in the case of accident or incident. Details of systems which shall be in place to minimize worker dose during maintenance and ensure tritium confinement shall be also be provided.

Further information is provided in Appendix B14.

11 QA and Documentation

All tritium components supplied to ITER shall be subject to the ITER Quality Assurance Program and the ITER Procurement Quality Requirements.

12 Acknowledgements

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