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EXTERNAL REFERENCE / VERSION

Top Level Project Technical Document

Project Requirements (PR)

This Project Requirements (PR) document contains the ITER project-level technical requirements that are needed to establish the suitability of the ITER design for its mission, as specified at the Council level in the Project Specification (PS) document.
The PR establishes the technical baseline for the ITER Project, and provides a common basis for the development of the System Requirements Documents (SRDs) for the ITER systems. The technical requirements that are in the PR are allocated and flown down to the ITER... (Please see complete abstract on document metadata.)

Approval Process			
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Change Log			
Project Requirements (PR) (27ZRW8)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	23 Oct 2007	2007 Baseline
v1.1	In Work	24 Oct 2007	2007 Baseline
v2.0	In Work	29 Apr 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.1	In Work	02 May 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.2	In Work	06 May 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.3	In Work	07 May 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.4	In Work	20 May 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.5	Signed	29 Jun 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.6	Signed	29 Jul 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.7	Signed	04 Aug 2008	2007 Baseline, Updated April 2008, expect signature June 2008
v2.8	Signed	20 Aug 2008	Updated April-Sept 2008, expect signature Late 2008
v2.9	Signed	02 Sep 2008	Updated April-Sept 2008, expect signature Late 2008
v2.10	In Work	13 Oct 2008	Updated April-Sept 2008, expect signature Late 2008
v2.11	Signed	27 Nov 2008	
v3.0	In Work	17 Apr 2009	
v3.1	Signed	11 Jun 2009	v3.0 on IDM was v33 on the author's PC v3.1 on IDM was v41 on the author's PC
v3.2	Signed	08 Jul 2009	Revised version ready for formal review (v45 on Wayne's PC)
v4.0	Signed	05 Aug 2009	1/ Internal IO review - 17 July 2009 - 5 August 2009 2/ new structure to the document, mainly by splitting the former "section 3. Project Requirements" following its sub-sections. 3/ the details of modifications between v3.2 and V4.0 are contained in the attached word file Draft version 48-1. 4/ The word file corresponding to the IDM 4.0 document is attached as Draft version 49-0.
v4.1	Signed	13 Sep 2009	Version 4.1 contains the Version 4.0 modified following comments and suggestions received from EU-DA, IN-DA, JA-DA and US-DA during August 2009. Additional modifications have been provided by IO. The main modification concerns the Plasma Scenarios Section and the Plasma Control Section that have been entirely reshaped.
v4.2	Signed	22 Sep 2009	Changes in response to reviewers' comments on previous version, including comments from the DAs As summarised in Table of modifications to the PR (2UXR4Y)
v4.3	Signed	25 Sep 2009	Changes in response to reviewers' comments on version v4.2,as summarised in Table of modifications to the PR (2UXR4Y)
v4.4	Approved	29 Sep 2009	Changes in response to reviewers' comments on version v4.3,as summarised in Table of modifications to the PR (2UXR4Y)
v4.5	Approved	07 Oct 2009	This version of the PR document has exactly the same content as version 4.4 It has been uploaded in IDM again to allow all reviewers to recommend it.
v4.6	Approved	07 May 2010	Changes in response to comments on version v4.5, made by IDM reviewers, STAC reviewers, and during the review of PCR-200, and are summarised in Table of modifications to the PR (2UXR4Y)
v5.0	Signed	02 Aug 2013	All changes to the PR are tracked, within the frame of PCR-300, and the table of "changes since v4.6" will be attached when v5.0 (or a subsequent version) is approved. Here is the list of changes to PR since version 4.6: • PCR-M026 (CN-000040) Deletion of PBS-67 • PCR-M215 (CN-000215 and 216) in Section 7.6 (was Section

			7.3 in PCR-200) • PCR-M250 in Section 7.1 • PCR-251 (CN-000190) Figure 5-1 and Table 4-8 (was Table 4-9 in PCR-200) • PCR-273 in PR453 and PR458 in Section 4.3.2.1, in Table 7-4 (was Table 7-2 in PCR-200) • PCR-300, harmonization of PR with RPrS • PCR-318, Table 5-2 • PCR-333 (CN-000173) full Section 6.13 • PCR-351 (CN-000213) Table 5-3 • PCR-385 (CN-000220) in Table 6-7 (was Table 6-6 in PCR-200), in PR1690 • PCR-387 (CN-000212) in Table 6-4 • PCR-393 in Section 7.3.4, 7.3.5 • PCR-398 (CN-000214) in Table 7-4 (was Table 7-2 in PCR-200) • PCR-402 Figure 5-1 • PCR-404, Table 5-3 • PCR-405, Table 5-1, Table 5-2 • PCR-408, Table 5-1, Table 5-2 • PCR-412, Table 7-4 (was Table 7-2 in PCR-200) • PCR-425 (CN-000218) in Section 6.10 • PCR-432 in Section 6.18, Section 7.3.4 • PCR-475, Figure 5-1 • PCR-495 (CN-000231) in Table 4-3, Section 4.3.5.1 • PCR-496 in Section 4.4.3
v5.1	Signed	10 Dec 2013	This version (v5.1) incorporates the accepted comments from the IDM reviewers of version v5.0. Also added, is the reference to the Order dated 7 February 2012 relating to the general technical regulations that are applicable to INB. The list of PCRs incorporated since the previous approved version is given in the description of version v5.0. (see change log on the second page of the the cover pages of this version). The table with track changes highlighting all changes to previous version and all comments to version v5.0 and, the responses of CIE/PEI, is given in the attached file.
v5.2	Signed	13 Jan 2014	This version (v5.2) incorporates the accepted comments from the IDM reviewers of version v5.1. Also added, is the decision of the ITER Council to have a full tungsten divertor since the begiinning of ITER. The list of PCRs incorporated since the previous approved version is given in the description of version v5.0. (see change log on the second page of the the cover pages of this version). The table with track changes highlighting all changes to previous version and all comments to version v5.0 and 5.1 and, the responses of CIE/PEI, is given in the attached file.
v5.3	Approved	02 Apr 2014	The version 5.3 of the PR includes changes due the PCR-300 and the following ones: PCR-M026, PCR-176, PCR-M125, PCR-M250, PCR-251, PCR-273, PCR-318, PCR-333, PCR-351, PCR-385, PCR-387, PCR-393, PCR-398, PCR-402, PCR-404, PCR-405, PCR-408, PCR-412, PCR-425, PCR-432 , PCR-475, PCR-495, PCR-496, PCR-582. Two companion documents are available to track changes between the version 4.6 (approved 14 May 2010) and version 5.3: - the change tracking text of the version 5.3: ITER_D_GGT4WD, that contains also the comprehensive list of the reviewer comments on V5.0, V5.1 and V5.2, with their answers. - the history of modifications to the PR since version 4.0: IDM_D_2UXR4Y
v6.0	Signed	25 Mar 2019	As part of establishing the 2016 ITER Technical Baseline (PCR-738 - Establishment of the 2016 ITER Baseline and its daughter PCRs ITER_D_UX2XW2 - PCR-738 Baseline 2016 daughters), the Project

			Requirements document (PR) has been revised to: • Reconcile it with the approved evolutions of the ITER Technical Baseline; • Ensure its consistent and integrated propagation across the ITER Buildings and Systems. The PR was consequently modified in order to: • Implement the new staged approach for ITER installation and operation and other approved project changes impacting the PR (PCR-M251, PCR-609, PCR-515, PCR-M354, PCR-710, PCR-722, PCR-755, PCR-M384); • Clarify, where necessary, the PR requirements to ensure that: o They reflect the current maturity in implementing the ITER Project needs; o They are suitably managed within the ITER Project. The approved evolutions to the PR between version 5.3 and version 6.0 are presented in • The PR change log document ITER_D_Y23R67 - Summary of PR revision for 2016 Baseline; • Its appendix ITER_D_Y244KY - Summary of PR revision for 2016 Baseline - Appendix A: Detailed modifications from PR v5.3 to Final PR v6.0.
v6.1	Signed	21 May 2019	Minor version to implement the reviewers comments as agreed. Record of implemented changes is provided in the comments. The PR Change Log Document and its annexes will be updated accordingly.
v6.2	Approved	28 May 2019	Minor version to implement the reviewers comments to version 6.1. Record of implemented changes is provided in the comments. The PR Change Log Document and its annexes will be updated accordingly.
v6.3	Approved	29 Apr 2020	Fast track revision for configuration management of this baseline document so that its last approved file available in IDM incorporates all the approved PR evolutions via: - the formal review & approval of PRv6.2 in IDM; - PR v6.2A addended with the PR Change Notice for PCR-001008 - Removal of the LHCD system from the upgrade scenarios [2FA42J]; - PR v6.2B addended with the PR Change Notice for PCR-738 - Additional minor corrections [2SXCVG]. This version of the PR (with its list of applicable documents [PR-ADMx, YQBMTQ) will be authorized in PLM for use within the whole ITER Project from May 2020. All the changes implemented in the PRv5.3 to produce this PR version 6.3 - as part of PCR-738 - Establishment of the 2016 Baseline - are outlined in the PR Change Log Document [Y23R67] and detailed in its appendix table [Y244KY]. There is also attached in the PR IDM metadata a Word file in track change between PRv5.3 and v6.3.

Table of Contents

List of Captions

1 INTRODUCTION

1.1 Purpose

[PR4-I] This Project Requirements (PR) document contains the ITER project-level technical requirements that are needed to establish the suitability of the ITER design for its mission, as specified in the Project Specification (PS) document [R01].

[PR1885-I] The PR establishes the technical baseline for the ITER Project.

[PR2075-I] The PR provides a common basis for the development of the System Requirements Documents (SRDs) for the ITER systems.

[PR1893-I] The technical requirements that are in the PR are allocated and flow down to the ITER systems for inclusion in the SRDs.

[PR5409-I] The PR (like the "Rapport Préliminaire de Sûreté" (RPrS) [R08]) is a Project Applicable Document; that means the PR applies to the full scope of the ITER Project.

1.2 Scope

1.2.1 Control, revision and applicability

[PR6-R] The PR shall be approved by the Director-General.

[PR1886-R] Once approved,

- Changes to the PR shall be controlled in accordance with the ITER Project Change Procedure [R10];
- Application of the approved version to the entire ITER Project shall be considered separately through the IO's Management and Quality Program (MQP) Level 1 process for authorization of use.

1.2.2 Relationship to other project documents

1.2.2.1 Process requirements for PR compliance

[PR30-R] The PR shall meet the overall requirements that are specified in the ITER Project Specification (PS) [R01].

[PR31-R] The performance requirements and the design constraints in the PR shall be applicable to ITER.

[PR2-R] In addition to the PR, specific criteria and specifications shall be developed to satisfy the needs for a particular system, and these are provided in the SRDs.

[PR32-I] It is recognized that organizations that have responsibilities for systems planning, design, and construction may establish and apply more comprehensive criteria to satisfy their particular mission.

[PR2076-I] There is no intent that the PR takes precedence over additional criteria, where those criteria meet or exceed the PR requirements.

[PR5301-R;Defined Requirement] In case of any conflicts between Defined Requirements and other requirements in this document, the Defined Requirements shall always take precedence. The same rule shall apply to any requirement documents derived from this one.

[PR5347-R;Defined Requirement] In case any potential conflict is detected between this document, or any requirement documents derived from it, and the ITER Safety Files, the potential conflict shall be immediately reported to the relevant IO's Safety Responsible Officer (SRO). Should the conflict be confirmed and a modification be necessary, it shall be immediately corrected according to the ITER Project Change Procedure [R10], [and the Safety Files will always take precedence on any other source of requirements].

[PR33-R] In case any potential conflict is detected between this document and any other project document (except ITER Safety Files), the potential conflict shall be immediately reported to the IO's Requirement Management Responsible Officer (RQM-RO). Should the conflict be confirmed and a modification be necessary, it shall be immediately corrected according to the ITER Project Change Procedure [R10] (and the PR will always take precedence on any other source of requirements).

1.2.2.2 Project Specification

[PR35-I] The Project Specification (PS) [R01] records verbatim, or points to the relevant texts, where the Parties to the Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project specify the scope of ITER, and lays down the constraints. The PS, therefore, represents the starting point for the development of the project and system requirements.

1.2.2.3 Configuration Management Model and Site Master Plan

[PR38-R] ITER Organization shall assure consistency among all project components.

[PR1894-R] ITER Organization shall establish three-dimensional (3D) CAD models that make up the ITER Configuration Management Model (CMM) which represents the geometry of the components in the facility. The CMM is specified in the Configuration Management Model process [R38].

[PR1895-I] The CMM is used to assure that interferences do not exist, and that the facility can be assembled and maintained as designed, taking into account tolerances, assembly operations, and operational movements. The CMM also defines envelopes for routing services to the tokamak for plant systems.

[PR1896-I] The CMM imposes design constraints for the design of the equipment that is within the facility.

[PR39-I] The Site Master Plan [A13] defines the footprints of the civil structures within the site boundary.

[PR40-I] The Site Master Plan imposes design constraints for buildings and site infrastructures.

1.2.2.4 Plant Description document

[PR43-I] The Plant Description (PD) document [R02] summarises the design originally proposed in 2009 of the ITER site, systems, materials, and the nuclear safety approach.

[PR42-I] The PD outlines the physics and fusion analysis, and the expectation to satisfy the principal physics and technology missions of the ITER Project.

[PR1897-I] Annexes of the PD provide the results of assessments and verifications that are applicable to the plant as a whole.

[PR1898-I] The PD is updated during the life of the project on request of the ITER Director General.

[PR1899-R] However, the PD is not kept updated to be always consistent with all changes that are implemented in the baseline documentation, and it shall not be used as a reference document for any safety or quality related activity.

1.2.2.5 System Requirements Documents

[PR45-I] The System Requirements Documents (SRDs) are the development specifications for the ITER systems. Each SRD provides those requirements that are needed to establish the suitability of the system (or sub-system) for its intended purpose during each of Plasma Operation phases.

[PR1900-I] A listing of the Level-1 PBS, sorted by PBS element, is provided in **Table 3-2**.

[PR1901-I] The PR, the CMM, and the Site Master Plan [A13], provide the performance requirements and design constraints for developing all SRDs.

[PR2077-I] In case any potential conflict is detected between this document and any SRD, the potential conflict shall be immediately reported to the IO's RQM-RO. Should the conflict be confirmed, it shall be immediately corrected according to the ITER Project Change Procedure [R10], [and the PR will always take precedence on SRD].

[PR1902-I] The SRDs are configuration-managed [R10].

1.2.2.6 Safety Files

[PR47-I;Defined Requirement] The "Rapport Préliminaire de Sûreté" (RPrS) [R08] is the preliminary safety report that is used in the licensing process with the French regulatory authorities. The RPrS has been developed based on the design that was presented at the 2001 Final Design Review (FDR), as modified by changes that have been approved in technical coordination meetings between February 2002 and November 2007 and in approved Project Change Requests (PCRs) thereafter, and which have been incorporated in the 2010 ITER baseline.

[PR1904-I;Defined Requirement] Safety requirements listed in the RPrS have been explicitly incorporated in the PR to ensure that they are propagated to all ITER systems, and that changes in the ITER design do not undermine the safety basis of the facility as documented in the RPrS.

[PR2372-I;Defined Requirement] Since the publication of the Decree for the ITER INB creation authorization (9 November 2012) [R31], this decree is the top level safety requirement document for ITER.

[PR2373-I;Defined Requirement] The ASN Decision 2013-DC-0379 [R32], establishes the prescription for the design and the construction of the licensed nuclear facility INB No. 174 called ITER.

1.2.2.7 Strategy for ITER construction and plasma operations

[PR4943-I;Defined Requirement] The Overall Strategy to construct and to operate ITER is presented in ITER Research Plan [R07]. This strategy has been revised to integrate a staged approach with the following four plasma operation phases, as endorsed by the ITER Council [R37]: First Plasma (FP), Pre-Fusion Power Operation 1 (PFPO-1), Pre-Fusion Power Operation 2 (PFPO-2) and Fusion Power Operation (FPO). Each of these plasma operation phases corresponds to a particular configuration of the ITER Plant and is preceded by an assembly and an integrated commissioning campaign.

[PR4944-I] The Chapters 3 to 9 of the PR describe ITER in its final configuration, specifying the project-level requirements for the planned construction and operation campaigns as well as those specific to the ITER Plant and its systems to undertake the full Deuterium-Tritium (D-T) operations during the FPO phase. The Chapter 10 presents "intermediary" project-level requirements to be satisfied by ITER during the previous staged approach phases: FP, PFPO-1 and PFPO-2.

[PR4945-I] The allocation of all PR requirements to systems is not described in the PR.

1.3 Definitions

1.3.1 Structure of the document

[PR8-I] The PR is structured in eleven chapters.

[PR1887-I] The first chapter *Introduction* includes: the use; control and revision; structure; terminology, conventions, and units; and relationship to other project documents.

[PR9-I] The second chapter *Applicable and Reference Documents* lists all documents that are referenced in the PR.

[PR10-I] The third chapter *Project Description* for ITER Final Configuration provides a list of the ITER systems, and identifies their main functions in their final configuration (FPO). It also introduces the project functions and site requirements.

[PR11-I] Chapter 4 through to Chapter 9 contain requirements for ITER Plant in its final configuration (FPO):

- The fourth chapter (*Performance Requirements*) identifies the project requirements, organized following the sequence of project functions that are defined in Chapter 3;
- The fifth chapter (*Layout Requirements*) provides the requirements and overall constraints that result from the selection of the ITER concept (as represented by the top-level drawings and models);

- The sixth chapter (*Operational Requirements*) provides requirements that are related to the operation and maintenance of the plant;
- *Environmental, Safety and Health Requirements* are given in Chapter 7;
- *Construction Requirements* are provided in Chapter 8.

[PR18-I] The ninth chapter contains additional requirements that are linked to project functions, such as requirements on the documentation, and access policy.

[PR4949-I] The tenth chapter lists the additional requirements that are specific to each staged approach phase.

[PR19-I] The last chapter is an appendix containing the list of the abbreviations that are used in the text.

1.3.2 Terminology, conventions, and units

[PR25-I] Use of the words “system", "project", "facility” and "plant". In this PR, the top-level entity is referred to as the project or facility.

[PR5410-I] The term “Project” (upper case “P”) is used to designate the whole ITER Project from the Agreement to decommissioning. The term “project” (lower case “p”) is any subset of coordinated and controlled activities concurring to the delivery of a product for the ITER Project.

[PR1888-I] The facility is comprised of systems that are comprised of sub-systems.The term Plants, or Plant Systems, is used in the PR with the same meaning as systems; in particular, for fluidic systems such as cryoplant, and tritium plant.

[PR23-I] Abbreviations and acronyms. Abbreviations and acronyms are used consistently throughout, without definition. A glossary of such abbreviations and acronyms can be found in Section 11.1. An on-line abbreviation dictionary is available on the ITER Technical Web site.

[PR1813-I] The master of the PR is stored in the ITER requirements database (DOORS), and managed under configuration control in the ITER configuration management database (PLM).

[PR1889-I] Each element of the PR (paragraphs, references, headings, captions for tables and figures, tables, figures, or footnotes) has a unique and permanent identifier, displayed in this PR document.

[PR1890-I] The identifier for each paragraph is composed as follows:

- Its unique numbering in the requirement management database (for example PR1890);
- Its object type as one of the followings (see definitions below):
    - -R for requirement;
    - -I for information (including the PR references for information only);
    - -ADc for Complementary Applicable Document;
    - -ADi for Input Applicable Document;
- Its classification as Defined Requirement in accordance to the INB Order [R30], that is the paragraph expresses a requirement assigned to a Protection Important Component (PIC) or a related Protection Important Activity (PIA) so that the PIC may perform the function provided for in the safety demonstration, with the expected characteristics and under the specified conditions and environments. For example, Chapter 7 of the PR contains requirements and information, all classified as Defined Requirement, such as [PR1305-I, Defined Requirement]).

[PR4950-I] A **requirement** (expressed with the auxiliary "shall") is a technical statement identifying a capability, a functionality, a physical characteristic or a quality that shall be met or possessed by the ITER Plant and/or one or several of its systems/components. Compliance with each requirement shall be fully justified during the Project lifetime.

[PR26-I] Performance requirements state what functions the facility has to perform, and how well those functions have to be performed.

[PR1891-I] Design constraints are a set of limiting or boundary requirements that must be adhered to while allocating requirements or designing the facility. They are drawn from externally imposed sources (for example, statutory regulations) as well as from internally imposed sources as a result of prior decisions that limit subsequent design alternatives.

[PR4952-I] Information (expressed with the auxiliary "will" or "is") enables the understanding of the ITER Project and its requirements. There is no need to demonstrate the compliance with an information (only specific information (for example, safety information) may require to be transmitted down the suppliers' chain for awareness).

[PR5348-I] An **Applicable Document (AD)** is a specific version of a document which has been authorized and is mandatory for use for a given scope and usage (for the ADs to the PR that is the whole ITER Project over its entire lifecycle). An AD may be categorized as follows, according to the needs for managing the AD's technical requirements across the project:

- A **Complementary Applicable Document (ADc)** is a document that is complementary to the PR and as such contains requirements to be satisfied by ITER. Compliance with a ADc of the PR must be demonstrated, as for the PR, by justifying the propagation of its requirements (when applicable) to the ITER systems, sub-systems and/or components and by justifying compliance with the propagated requirements during the project lifetime.

- An **Input Applicable Document (ADi)** is a document used as input to produce the PR (for example the PS). It is a parent requirement document that has been fully propagated to ITER, with all the resulting project-level requirements recorded in the PR and/or its ADc. Compliance with an ADi will be demonstrated via compliance of the PR and/or its ADc.

In addition to ADs, the PR also uses reference documents, that are documents only "For information" providing background information to improve the understanding of the Project and its requirements. There is thus no need for ITER or its suppliers to demonstrate compliance with any such reference documents.

[PR24-I] Units. SI (System International) units and derived units are used throughout the ITER project design and procurement.

2 APPLICABLE AND REFERENCE DOCUMENTS

[PR50-I] This section lists the documents referenced in the PR, that are categorized – depending on their usage - as Complementary Applicable Documents (ADc), Input Applicable Documents (ADi) or documents for information only (I) – see PR5348 for definitions.

[PR5411-R] The ITER Project shall comply with the applicable version of each PR Applicable Document (tagged as ADc or ADi) that are specified in the **last** authorized version of the PR Applicable Document Matrix (PR-ADMx) ITER_D_YQBMTQ - Applicable Document Matrix of the Project Requirements document (PR-ADMx)

Note that:

- The Reference Documents listed in Section 2.2 are only provided for information;
- The applicable version of the referenced project management and quality processes is provided, for IO staff, in the ITER Management and Quality Process system; for IO's external interveners (DAs and contractors) in the applicable procurement documentation and their own quality systems as approved by IO (or DAs for their own contractors).

[PR51-I] Like the PR, all the PR Applicable Documents and the PR-ADMx are managed under configuration control, in accordance with the ITER Project Change Procedure [R10].A Project Change Request (PCR) identified as impacting one of these documents must be considered for potential impacts on the others.

2.1 PR Annex documents

[PR2284-ADc] [A01] Y. Gribov et al, "CS and PF coils data and requirements to separatrix positioning for analysis of ITER plasma equilibria and poloidal field scenarios" (ITER_D_2ACJT3)

[PR2286-ADc] [A02] Plant Control Design Handbook (ITER_D_27LH2V)

[PR2287-ADc] [A03] *Reference no longer required*

[PR2289-ADc] [A04] ITER Coordinate Systems (ITER_D_2A9PXZ)

[PR2290-ADc] [A05] ITER Vacuum Handbook (ITER_D_2EZ9UM)

[PR2291-ADc] [A06] Codes and Standards for ITER Mechanical Components (ITER_D_25EW4K)

[PR2292-ADc] [A07] Electrical Design Handbook, vol. 1 -5 (ITER_D_2F7HD2, ITER_D_2E8QVA, ITER_D_2E8DLM, ITER_D_4B523E), ITER_D_4B7ZDG)

[PR2300-ADc] [A08] Operations Handbook, vol. 2 (ITER_D_2LGF8N)

[PR2301-ADc] [A09] Magnet Structural Design Criteria, vol. 1 - 4 (ITER_D_2FMHHS, ITER_D_2ES43V, ITER_D_2FKTTG, ITER_D_2FDCA3)

[PR2308-ADc] [A10] In-vessel Components, SDC-IC (Structural Design Criteria for ITER In-vessel Components) (ITER_D_222RHC)

[PR2309-ADc] [A11] ITER Structural Design Code for Buildings, Part I: Design Criteria (ITER_D_283B24)

[PR2310-ADc] [A12] ITER Structural Design Code for Buildings, Part 2: Construction (ITER_D_2E2U9X)

[PR2313-ADc] [A13] ITER Site Master Plan (ITER_D_27X5FM)

[PR2314-ADc] [A14] Load Specifications (ITER_D_222QGL)

[PR2315-ADc] [A15] Heat and Nuclear Load Specifications (ITER_D_2LULDH)

[PR2316-ADc] [A16] Tritium Handbook (ITER_D_2LAJTW)

[PR2317-ADc] [A17] ITER Remote Maintenance Management System (ITER_D_2FMAJY)

[PR2322-ADc] [A18] Magnet Superconducting and Electrical Design Criteria (ITER_D_22GRQH)

[PR2324-ADc] [A19] Contents of PF scenario database (ITER_D_34263N)

[PR2328-ADc] [A20] ITER Site Meteorology (ITER_D_2UT36S)

[PR2329-ADc] [A21] ITER Materials Properties Handbook - Introduction (ITER_D_2NRCSB)

[PR2340-ADc;Defined Requirement] [A22] Safety Requirements for ITER Facility Buildings (ITER_D_2E4KSJ)

[PR2341-ADc] [A23] Safety Important Functions and Components Classification Criteria and Methodology (ITER_D_347SF3)

[PR4940-ADc] [A24] ITER Coordinate System and Coils Polarities (ITER_D_QRUDS6)

[PR4941-ADc] [A25] Chemical composition and impurity requirements for materials (ITER_D_REYV5V)

[PR4953-ADc;Defined Requirement] [A26] ITER Radiation Maps - **only applicable for equipment qualification**:

- During DT plasma operations (Mode 0): Radiation Maps During Plasma Operations (Mode-0) (ITER_D_RJLLFY);
- During Maintenance (Mode 1): Mode 1 Radiation Maps (ITER_D_V35THE);
- During cask movements (Mode 2): ITER Radiation Maps: Subtask 3 report (ITER_D_F8UEXR);
- ITER Radiation Maps: Subtask 4 report (ITER_D_67CN24);
- ITER Radiation Maps: Subtask 5 report (ITER_D_HPX254).

[PR5356-ADc;Defined Requirement] [A27] Safety requirement Roombook (ITER_D_KF63PB)

2.2 List of reference documents

[PR2281-ADi] [R01] Project Specification (PS) (ITER_D_2DY7NG)

[PR2285-I] [R02] ITER Plant Description (ITER_D_2X6K67) (based on 2009 ITER Technical Baseline)

[PR2299-I] [R03] ITER Plant Breakdown Structure (ITER_D_28WB2P)

[PR2282-I] [R04] ITER WBS Dictionary (multiple files, ITER_D_2FTRRV)

[PR2283-I] [R05] ITER Assembly Plan (ITER_D_2263T6)

[PR2288-I] [R06] Design Integration and Configuration Control Responsibilities for buildings/Areas on ITER Site (ITER_D_2F6ZKF)

[PR2311-I] [R07] ITER Research Plan (ITER_D_2FB8AC)

[PR2312-ADi;Defined Requirement] [R08] ITER INB Preliminary Safety Report (English version) (ITER_D_3ZR2NC)

[PR2318-I] [R09] ITER Plasma Performance Assessment (ITER_D_22HGQ7)

[PR2319-I] [R10] ITER Project Change Procedure (ITER_D_22F4E5)

[PR2320-I] [R11] ITER Quality Classification Determination (ITER_D_24VQES)

[PR2321-I;Defined Requirement] [R12] ITER Seismic Nuclear Safety Approach (ITER_D_2DRVPE)

[PR2323-I] [R13] ITER RAMI Analysis Program (ITER_D_28WBXD)

[PR2325-I] [R14] ITER Configuration Management Plan (ITER_D_27LHHE)

[PR2326-I] [R15] Design Review Procedure (ITER_D_2832CF)

[PR2327-I] [R16] ITER Quality Assurance Program (QAP) (ITER_D_2NS3UH)

[PR2330-I] [R17] *Reference no longer required*

[PR2331-I] [R18] Agreement on the Establishment of the ITER Organization (also called ITER Agreement) (ITER_D_2EW6RK)

[PR2337-I;Defined Requirement] [R19] ITER Remote Handling Code of Practice (ITER_D_2E7BC5)

[PR2338-ADc] [R20] Static and Transient Magnetic Field Maps in Tokamak Building (ITER_D_3BQBVY)

[PR2343-ADc;Defined Requirement] [R21] Load Specification Annex - Internal Explosions: Hydrogen Deflagration in Tokamak Complex (ITER_D_BMQ9XM)

[PR2344-ADc;Defined Requirement] [R22] ITER Human Factor Integration Plan (ITER_D_2WBVKU)

[PR2345-I] [R23] Site Support Agreement (ITER_D_2VU589)

[PR2346-ADc] [R24] MQP Policy for ITER Investment Protection (ITER_D_3VUMVW)

[PR2347-I] [R25] Agreement between the Government of the French Republic and the ITER International Fusion Energy Organization (ITER_D_29P59M)

[PR2348-I] [R26] Y.R. Martin and T. Takizuka [J Phys: Conf Ser 123 (2008).

[PR2349-I] [R27] Experimental studies of ITER demonstration discharges, A C C Sips et al, Nucl. Fusion 49 085015 (2009)

[PR2350-I] [R28] Development of ITER 15MA ELMy H-mode Inductive Scenario, C. E. Kessel et al, Nucl. Fusion 49 085034 (2009)

[PR2364-ADi;Defined Requirement] [R29] Etude d'impact - Partie 1: Analyse de l'état initial du site et de son environnement (ITER_D_7A7RDB)

[PR2369-I;Defined Requirement] [R30] Order dated 7 February 2012 relating to the general technical regulations applicable to INB (ITER_D_7M2YKF)

[PR2374-I;Defined Requirement] [R31] Decree No. 2012-1248 dated 9 November 2012 authorising IO to create a basic nuclear facility called «ITER» (ITER_D_CZK7M5)

[PR2375-I;Defined Requirement] [R32] ASN Decision 2013-DC-0379 dated 12 November 2013 establishing the prescriptions applicable to ITER Organization for the licensed nuclear facility INB No. 174 called ITER – FR, as modified the 24th August 2017 (ITER_D_LYH6QS)

[PR3212-ADc] [R33] ITER Site Signage and Graphics Standards (ITER_D_4ALJEU)

[PR4955-ADi;Defined Requirement] [R34] ITER Preliminary Functional Description (ITER_D_TVG7YK)

[PR4954-I;Defined Requirement] [R35] Staged Approach Configuration - PBS Level 3 (ITER_D_SNE6G8)

[PR5309-I;Defined Requirement] [R36] Staged Approach Configuration – List of Temporary Items (ITER_D_TVGG89)

[PR5412-I] [R37] IC/STAC-21/2.2.3. Update of the ITER Research Plan within the revised ITER Schedule (ITER_D_TPMLHZ)

[PR5423-I] [R38] Configuration Management Model (CMM) process (ITER_D_V2ERKH)

[PR5413-I] [R39] Safe Access for Maintainability (ITER_D_RUGWUK)

[PR5414-I] [R40] Protective Equipment and Hostile Environment Layout (ITER_D_RBYZ42)

3 PROJECT DESCRIPTION FOR ITER FINAL CONFIGURATION

[PR4956-I] The ITER Project aims at designing, constructing and operating the ITER Plant and systems that will enable to:

- Achieve extended burns (300-500 s) in inductively driven plasmas with the ratio of fusion power to auxiliary heating power (Q) of at least 10 for a range of operating scenarios, and with a duration sufficient to achieve stationary conditions on the timescales characteristic of plasma processes;
- Develop high reliability, long-pulse and fully non-inductive operation, aiming at Q≥5;
- Exploit the ITER's potential for technology testing of prototype components for fusion power plants.

[PR4957-I] This chapter describes ITER in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for the three previous configurations are given in Chapter 10.

3.1 General description of the ITER tokamak in its final configuration

[PR1905-I] As specified in the PS [R01], ITER is a long-pulse tokamak with elongated plasma and single null poloidal divertor.

[PR54-R] During nominal inductive operation, ITER shall produce a D-T fusion power of 500 MW, for a burn length of 300 to 500 seconds, with the injection of up to 50 MW of auxiliary power.

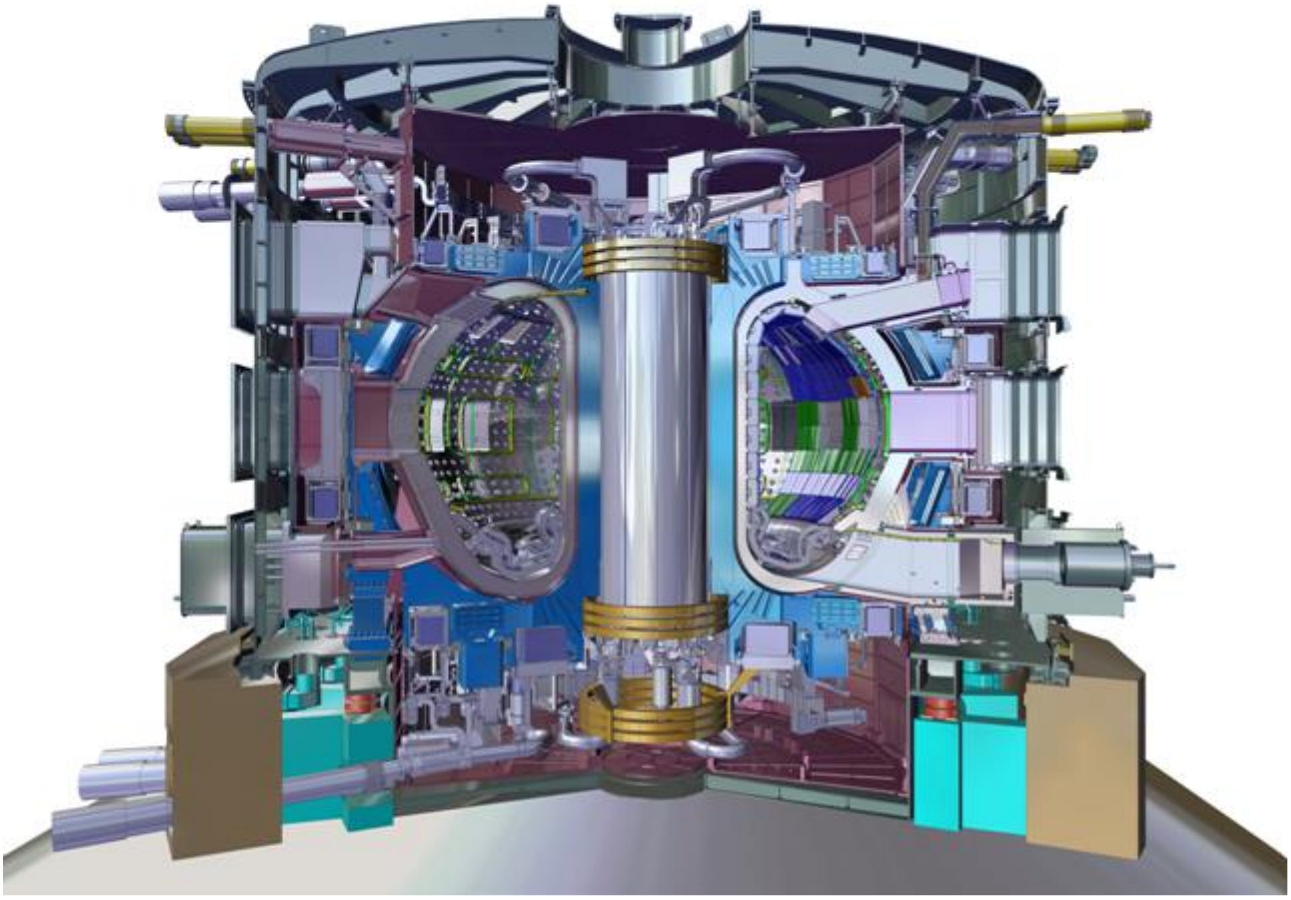
[PR1906-I] Reference tokamak parameters are provided in **Table 3-1**.

Table 3-1**: Reference plasma parameters**

Total fusion power	500 MW
Total fusion power (short pulse)	700 MW
Q - fusion power/additional heating power	>= 10
Average 14 MeV neutron wall loading	> 0.5 MW/m^2
Plasma inductive burn time	450 s
Plasma major radius (R)	6.2 m
Plasma minor radius (a)	2.0 m
Plasma current (I_p)	15 MA
Vertical elongation @ 95% flux surface Vertical elongation @ separatrix (κ_{95})	1.70 1.85
Triangularity @95% flux surface Triangularity @separatrix (δ_{95})	0.33 0.49
Safety factor @95% flux surface (q_{95})	3
Toroidal field in vacuum @6.2 m radius (B_t)	5.3 T
Plasma volume	816 m^3
Plasma surface area	680 m^2
Auxiliary heating/current drive power	73 MW
Peak power to remove from ITER Site	1200 MW

[PR56-I] A cut-away view of the ITER tokamak is provided in **Figure 3-1**. The magnet system provides a magnetic confinement shaping and control of the plasma inside the torus shaped vacuum vessel.

Figure 3-1**: Cut-away view of the tokamak**



[PR57-I] Inside the vacuum vessel, the internal components (and their water content), including blanket modules, divertor cassettes, glow discharge cleaning electrodes, in-vessel coils, and port-mounted components (such as heating antennas, test blanket modules, and diagnostics modules) absorb radiated heat and neutrons from the plasma, and protect the vessel and magnet coils from excessive neutron radiation.

[PR58-I] The heat that is deposited in the internal components, and in the vacuum vessel, is rejected to the environment by means of the Cooling Water System (CWS). The CWS is also employed to bake, and consequently clean, in conjunction with the vacuum pumping system, the plasma-facing surfaces that are inside the vacuum vessel, by releasing trapped impurities.

[PR1907-I] The entire tokamak is enclosed in a cryostat, with thermal shields between the hot components and the cryogenically-cooled magnets.

[PR1909-I] The main assumptions for the ITER design consider that:

- The centering force that acts on the D-shaped Toroidal Field (TF) coils is reacted by these coils by wedging in the vault that is formed by their straight sections. The TF coil windings are enclosed in strong cases that are used, also, to support the external Poloroidal Field (PF) coils;
- The out-of-plane forces on the TF coils are taken up by the wedging and the inter coil structures;
- The vacuum vessel is a double-walled structure that is directly supported via the lower ports by the cryostat pedestal ring;
- The magnet system is supported by gravity supports, one beneath each TF coil.

[PR1913-I] With non-inductive current drive from the Heating and Current Drive (H&CD) systems, the burn duration will be extended to 3000 s.

[PR1914-I] The integrated plasma control is based on feedback from diagnostic sensors, and will act on the PF system, the pumping, fuelling (H, D, T, He and impurities such as N_2, Ne and Ar), and heating systems.

[PR61-I] ITER will be constructed at a new facility near CEA Cadarache near St. Paul-lez-Durance, France. Major buildings to be constructed include:

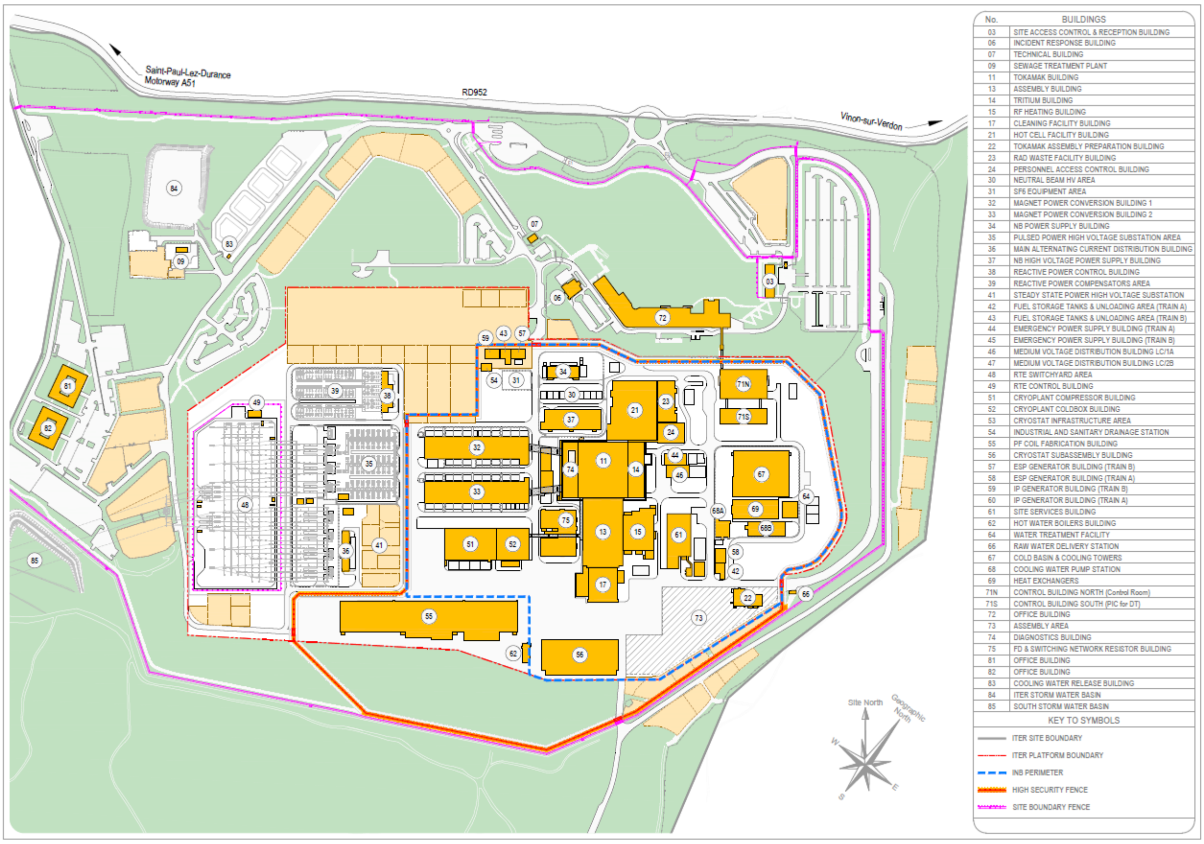
- Tokamak Complex comprising the Tokamak Building (B11), the Tritium Plant Building (B14) and the Diagnostic Building (74);
- Hot Cell Building (B21);
- Radwaste Building (B23);
- Personnel Access Control Building (B24);
- Laydown, Assembly Building (B13) and RF Heating Building (B15);
- Control Buildings (B71), equipped with centralized control systems for the entire ITER Installation;
- Utility-related buildings (such as electric utilities, and fluid utilities).

[PR260-I] The ITER Site comprises:

- INB Area: defined as the area comprised within the perimeter of the Nuclear Installation (Installation Nucléaire de Base);
- ITER Platform: defined as the levelled area that is within the ITER Site, comprising the INB Area, the PF Coil Fabrication Building (B55), the R.T.E. Switchyard Area (B48), the ITER electrical switchyard and Contractors Area Number 2;
- Site Outside Platform.

Figure 3-2 shows the various part of the ITER site.

Figure 3-2**: ITER site (as at April 2019)**



3.2 Description of the ITER Project in its final configuration

[PR73-I] The list of ITER systems is defined in the ITER Plant Breakdown Structure (PBS) [R03] and is summarised in **Table 3-2**. The scope of each system is defined in the ITER Work Breakdown Structure (WBS) [R03].

[PR71-I] The performance requirements in this document (Chapter 4) are allocated to the systems, and are documented in the System Requirements Documents (SRDs).

[PR72-I] Detailed functional and physical interface requirements between ITER systems are defined in the relevant Interface Control Documents (ICDs).

[PR75-I] A short description of each of the ITER systems, and their functions, is provided in the following sections.

Table 3-2: **ITER systems**

PBS	System
11	Magnet system
15-VV	Vacuum vessel
15-IV	In-vessel coil system
16	Blanket system
17	Divertor system
18	Fueling and wall conditioning system
22	Machine assembly and tooling system
23	Remote handling system
24-CR	Cryostat system
24-VP	Vacuum vessel pressure suppression system
26	Cooling water system
27	Thermal shields system
31	Vacuum system
32	Tritium plant
34	Cryogenic system
41	Coil power supply and distribution system
43	Steady-state electrical power supply networks
44	Cable trays system
45	Control, data access and communication system
46	Central interlock system
47	Plasma control system
48	Central safety system
51	Ion cyclotron heating and current drive system
52	Electron cyclotron heating and current drive system
53	Neutral beam heating and current drive system
55	Diagnostics system
56	Test blanket modules system
57	In-vessel viewing system
58	Port plug test facilities
61	Site facilities
62	Reinforced concrete buildings
63	Steel frame buildings
64	Radiological and environmental monitoring system
65	Liquid and gas distribution system
66	Radioactive waste treatment and storage system
69	Access control and security system
70	Site outside platform
98	External services and interfaces system

3.2.1 Magnet system (PBS 11)

[PR78-I] The magnet system consists of four coil systems — Toroidal Field (TF) coils, Central Solenoid (CS) coils, Poloidal Field (PF) coils, and Correction Coils (CC) — plus the feeders that bring helium cooling and electrical power to the coils.

[PR79-I] The TF coils provide the toroidal magnetic field for confining the plasma.

[PR83-I] The PF coils and the CS coils provide the change in poloidal magnetic flux that is needed to initiate the plasma, to generate the plasma current, and to maintain this current during the burn time.

[PR81-I] The PF coils provide the poloidal magnetic field for the plasma shaping and position control, and contribute to the inductive plasma current drive.

[PR84-I] The CS coils contribute towards the fields that are needed to shape and control the plasma.

[PR82-I] The CCs compensate for low mode number error fields that are due to asymmetries in the design of the tokamak, geometric tolerances during assembly, and the influence of magnetic materials.

[PR1915-I] The TF coils are arranged in a toroidal array of 18 Nb3Sn superconducting coils.

[PR80-I] The CS coils system is an assembly of six Nb3Sn superconducting coils that are positioned along the vertical axis of the tokamak.

[PR1916-I] The PF coils are arranged in an array of six NbTi superconducting ring coils that are positioned along the vertical axis of the tokamak, with three above the horizontal equatorial plane and three below.

[PR1917-I] The CCs are arranged in an array of 18 NbTi superconducting coils.

3.2.2 Vacuum vessel (PBS 15-VV)

[PR86-I] The Vacuum Vessel (VV) system provides:

- The vacuum boundary for the plasma vacuum;
- Shielding, to reduce the nuclear heating in the superconducting coils, and the activation of components that are outside the vacuum vessel;
- A primary confinement of tritium and activated materials, inside the vacuum vessel and in the vacuum vessel cooling water;
- Passive stabilization of the plasma, by providing a conductive shell that is tight fitting to the plasma, while allowing control of the plasma current by providing adequate toroidal resistance;
- Toroidal field ripple reduction, through the use of ferromagnetic inserts;
- Removal of decay heat in the in-vessel components, in the event of a loss of cooling or loss of flow to those components;
- Structural support for the in-vessel components, including blanket modules and in-vessel coils;
- Access for in-vessel component services and port-mounted equipment.

[PR96-I] The vacuum vessel is a double-walled structure, and has a set of upper ports, equatorial ports, and lower (divertor) ports, to allow access for plasma heating, fuelling, diagnostics, and in-vessel component services.

[PR1918-I] The interspace between the vacuum vessel walls contains the in-wall shielding blocks to absorb neutrons and to reduce toroidal field ripple, and is filled with cooling water.

[PR2078-I] The vacuum vessel is composed of nine toroidal sectors of 40° each.

3.2.3 In-vessel coils system (PBS 15-IV)

[PR99-I] Edge Localized Modes (ELMs) can produce large impulsive heat loads to the divertor. To mitigate this effect, resonant magnetic perturbations are introduced by a poloidal and toroidal array of in-vessel ELM coils that are mounted outboard of the plasma, on the vacuum vessel, behind the blanket modules. The ELM coils may also be used to control resistive wall modes as future upgrade.

[PR100-I] Fast vertical instabilities can exceed the stabilisation capacity of the external Poloidal Field (PF) coils. Included in the in-vessel coil array are two toroidally continuous Vertical Stabilisation (VS) coils, above and below the equatorial ports, that provide fast vertical position stabilisation of the plasma.

3.2.4 Blanket system (PBS 16)

[PR102-I] The blanket system provides the following functions:

- Contributing to absorbing radiation and particle heat fluxes from the plasma;
- Contributing to providing shielding to reduce heat and neutron loads in the vacuum vessel and ex-vessel components;
- Providing a plasma-facing surface that is designed for a low influx of impurities to the plasma;
- Providing limiting surfaces that define the plasma boundary during startup and shutdown;
- Providing passage for the plasma diagnostics, for the viewing systems, for the microwave antennas or launchers, and for other minor ancillaries.

[PR109-I] The blanket system comprises an array of Blanket Modules (BMs).

[PR1919-I] Each BM is mounted to the vacuum vessel through a mechanical attachment system of flexible supports and keys.

[PR1920-I] Each BM has electrical straps that provide electrical connection to the vacuum vessel.

[PR1921-I] Cooling water to the BM is supplied by manifolds that are supported by the vacuum vessel behind or at the side of the BM.

3.2.5 Divertor system (PBS 17)

[PR111-I] The divertor system contributes to the removing of the radiative and convective heat fluxes from the plasma.

[PR2079-I] The divertor system allows the control and the removal to the vacuum system of the ash that is produced by the fusion process.

[PR1922-I] The divertor system contributes to the nuclear shielding of the vacuum vessel and the superconducting magnets.

[PR2080-I] The divertor system facilitates the monitoring and the recovery of the tritium and of the activated dust.

[PR1923-I] The divertor system consists of 54 cassettes that are located at the bottom of the plasma chamber.

3.2.6 Fuelling and wall conditioning system (PBS 18)

[PR113-I] The fuelling and Wall Conditioning system provides several functions including:

- Providing gases (H, D, T and He) and pellets (H, D and T) to fuel the plasma;
- Providing pellets (D and T) to control ELMs;
- Providing gases (H and D) to the neutral beam injectors;
- Injecting minority species (gases H, D, He and ^{3}He; pellets H and D) into the plasma to enable the respective Ion Cyclotron Heating and Current Drive (IC H&CD) minority heating scenarios;
- Injecting impurity gases into the divertor plasma for radiative cooling, plasma detachment control and discharge termination;
- Injecting impurity pellets into the plasma for studies of impurity transport and radiative cooling enhancement;
- Injecting of gases and pellets for disruption mitigation and suppression of runaway electrons;
- Providing an emergency Fusion Power Shutdown System (FPSS);

- Providing wall conditioning systems that reduce and control impurity and hydrogenic fuel outgassing from plasma-facing components.

[PR1908-I] The tokamak fuelling system is designed to inject gas or solid pellets of hydrogen, deuterium, and tritium, as well as impurities in gaseous or solid form.

[PR59-I] During plasma start-up, fuel will be introduced into the vacuum vessel chamber by the gas injection system. The plasma will progress from electron-cyclotron-heating-assisted initiation, in a circular, limiter configuration, to an elongated divertor configuration as the plasma current is ramped up. The GIS is needed for plasma initiation, forming the current profile during the current rise, maintaining the burn conditions, and ensuring reliable current rampdown.

3.2.7 Machine assembly and tooling system (PBS 22)

[PR125-I] The machine assembly and tooling system enables the cleaning, handling, manipulation, alignment, and stabilization of the tokamak components from the outside assembly area to the tokamak pit, via the Cleaning Facility and the Assembly Hall (see the Site Master Plan [A13]).

[PR124-I] Assembly tooling is used during machine assembly. The tooling may also be used for maintenance, but in this case it may be necessary to modify the tooling to accommodate changes in the machine configuration. It enables the operations that are required for machine assembly, including the on-site handling, preparation, sub-assembly and assembly of the tokamak components.

[PR126-I] The machine assembly and tooling system includes all of the equipment that is required to control the tokamak assembly quality, with the exception of the vacuum testing (which is to be performed by PBS 31) and radiography equipment.

3.2.8 Remote handling system (PBS 23)

[PR129-I] The Remote Handling (RH) system performs maintenance operations on the machine components that are classified for remote handling maintenance.

[PR130-I] The RH system provides the following capabilities:

- Blanket module handling;
- Blanket manifold handling;
- Divertor cassette handling;
- Port plug handling;
- In-vessel component and port plug transfer to/from Hot Cell;
- In-vessel component and port plug maintenance and refurbishment in Hot Cell;
- Neutral beam maintenance;
- Neutral beam duct liner maintenance;
- Dust and tritium inventory control;
- In-service inspection;
- In-vessel diagnostics maintenance;
- VVPSS maintenance;
- Leak localization;
- Support to the maintenance of type-B radwaste system in the Hot Cell.

[PR139-I] The RH system will support the machine assembly operations.

3.2.9 Cryostat system (PBS 24-CR)

[PR141-I] The cryostat system provides a vacuum environment for the superconducting coils and other in-cryostat components that operate at cryogenic temperatures.

[PR1924-I] The cryostat provides penetrations for services to in-cryostat components and vacuum vessel ports.

[PR1925-I] The cryostat transfers all the loads that derive from the tokamak basic machine and the cryostat itself, during the normal and off-normal operational regimes, and at specified accidental conditions, to the floor of the tokamak pit through its support structures.

3.2.10 Vacuum vessel pressure suppression system (PBS 24-VP)

[PR1926-I] The Vacuum Vessel Pressure Suppression System (VVPSS) enables to protect the vacuum vessel against overpressure events, to maintain dynamic confinement in vacuum vessel during an accident and to purify the vent gas from the vacuum vessel prior to discharge to Detritiation System.

[PR2081-I] The VVPSS is sized to cope with the consequences of the most adverse in-vessel leaks.

3.2.11 Cooling water system (PBS 26)

[PR1927-I] The Cooling Water System (CWS) removes heat from the ITER components and rejects it to the environment.

[PR157-I;Defined Requirement] In addition, the CWS performs the following functions:

- Removing heat from client systems (including the decay heat following plasma operations);
- Baking of the VV and in-vessel components;
- Controlling water chemistry, to minimize corrosion in client systems;
- Providing the capability to drain and dry the cooling loops, to facilitate maintenance of the components in the CWS and client systems;
- Facilitating leak detection and leak localization, for CWS and client systems;
- Monitoring heat removed from the in-vessel components and vacuum vessel.

[PR145-I] The CWS consists of four systems: the Tokamak Cooling Water System (TCWS), the Component Cooling Water System (CCWS), the Chilled Water System (CHWS), and the Heat Rejection System (HRS).

[PR146-I] The TCWS removes heat from the divertor, blanket modules, vacuum vessel, in-vessel components, in-port components, and Neutral Beam (NB) system components that are within the NB enclosure, and controls the pre-pulse temperature of those components.

[PR1928-I] The TCWS provides baking for the vacuum vessel and in-vessel components, and decay heat removal in conjunction with other mechanisms of decay heat removal.

[PR1929-I;Defined Requirement] The TCWS clients all have the potential to be contaminated with tritium and activated corrosion products. TCWS components that are in contact with the cooling water provide primary confinement of these radioactive inventories.

[PR149-I] The CCWS is divided in two loops:

- CCWS-1 tranfers heat from TCWS to HRS, and could be radioactively contaminated.
- CCWS-2 transfers heat from ancillary equipment to HRS, and is not susceptible to radioactive contamination.

[PR153-I] The CHWS is divided in two loops:

- CHWS-H1 is safety-related and rejects heat directly to the environment through two separate and redundant air-cooled chillers (CHWS-1A and CHWS-1B).
- CHWS-H2 is non-safety-related and transfers heat to CCWS-2D.

[PR148-I] The HRS rejects the heat from CCWS to the environment.

[PR2082-I] Heat from all the cooling water loops, except CHWS-H1, is ultimately transferred to HRS, then rejected to the atmosphere through the induced draft cooling towers.

3.2.12 Thermal shield system (PBS 27)

[PR164-I] The thermal shields limit the radiation heat load to the superconducting coils, from warm internal or external sources, to levels that can be tolerated by the coils, and removed by the helium cryogenic system.

[PR1930-I] In particular, the shields intercept thermal radiation from the warm surfaces of the vacuum vessel and port outer walls, the VV supports, the cooling pipes, other warm ducting and the cryostat inner wall, as well as restricting heat loads that are transferred by conductance through the magnet gravity supports by means of thermal anchors.

[PR1931-I] The inlet temperature of the thermal shields is 80 K.

3.2.13 Vacuum system (PBS 31)

[PR1932-I] The vacuum system provides vacuum in the torus, cryostat, and auxiliary systems, at the level that is necessary for the operation of ITER.

[PR166-I;Defined Requirement] The vacuum system performs the following functions:

- Evacuating and pumping of client systems (torus, neutral beams, cryostat, cryogenic distribution systems, diagnostics, EC/IC transmission lines);
- Exhausting of pumped/released gases to the Tokamak Exhaust Processing, or to the Vent Detritiation System, or to the Non Active Exhaust System;
- Providing controlled venting of the torus, cryostat and all other vacuum systems;
- Providing the leak testing of the vacuum integrity of all systems that may be exposed to a primary, service or cryostat vacuum, both during construction and during operation;
- Measuring the total in-leakage into the vacuum vessel, cryostat and service vacuum clients (in particular for external air leaks into the vacuum vessel and cryostat) both during construction and operation;
- Measuring the in-situ leak rates of individual elements, both during construction and operation;
- Providing the capability to locate, at the component and element level, any unacceptable leak rate, both during construction and operation;
- Providing the capability for leak testing, in the operational configuration, the various systems of the torus, cryostat and pellet injectors, during the final construction and commissioning of the machine, and after upgrade, repair or maintenance;
- Periodic confirmation of the integrity of the radiological confinement boundaries and pressure boundaries to comply with regulatory and codes and standards requirements;
- Pumping of the interspaces between feedthroughs, seals, and bellows that are deemed sufficiently fragile to need a second vacuum barrier to enable differential pumping, to allow leak mitigation and continued plasma operation if the reliability of a single feedthrough would otherwise not be adequate to meet the overall availability requirements of the tokamak, or would result in excessive individual and collective maintenance worker dose during leak localization and repair;
- Filling and pressure monitoring of interspaces with inert tracer gas, to perform leak detection and localization.

3.2.14 Tritium plant (PBS 32)

[PR1933-I] The Tritium Plant processes the tritium and fuel gases from the whole ITER facility.

[PR2083-I] The Tritium Plant provides Detritiation Systems for detritiation of gases from the Tokamak Complex and from the Hot Cell.

[PR180-I] The Tritium Plant handles tritium shipments; storage of tritium and other fuel gases; tritium inventory measurements; delivery of gases to fuelling systems; delivery of divertor impurity seeding gases to fuelling systems; processing of tokamak and neutral beam exhaust to remove hydrogen isotopes for fuel recovery by isotope separation; removal and recovery of tritium from the Test Blanket Module extraction systems (if required); analysis of process gases; radiological control of vent atmospheres for normal operation including maintenance; mitigation of tritium release resulting from accidents; detritiation of tritium-contaminated water; and sub-atmospheric room pressure control (air depression) for establishing a release path in the case of incidents or accidents.

[PR181-I] Processes at ITER are engineered to minimize the production of highly-tritiated water. A Highly Tritiated Water Treatment technology (HTW) is available at ITER to deal with the transfer, storage, processing and recovery of tritium with a capability to process up to 2 $Pa.m^3/s$ from these process streams.

3.2.15 Cryogenic system (PBS 34)

[PR183-I] The cryogenic system performs the following functions:

- Cooling down and warming up of the cryostat and torus cryopumps;
- Cooling down, filling and warming up of the Magnet System, and of the 80 K Thermal Shield System;
- Cooling down and warming up of the Neutral Beam cryopumps, pellet injection system, diagnostics, and other small users;
- Maintaining magnets, current leads, and cryopumps at nominal operating temperatures, over a wide range of operating modes, with pulsed heat loads due to nuclear heating and magnetic field variations;
- Accommodating periodic regeneration of cryopumps;
- Accommodating resistive transitions and fast discharges of the magnets, and recovery.

3.2.16 Coil power supply and distribution system (PBS 41)

[PR192-I] The coil power supply and distribution system provides the pulsed power for energizing the TF, PF, CS, CCs, and In-Vessel Coils to generate, confine, and control the plasma.

[PR1934-I] The coil power supply and distribution system provides protection for the coils: in the event of quenches; in the event of over-currents or over-voltages due to abnormal or fault conditions in the power supplies; and in the event of high voltages due to earth faults.

3.2.17 Steady-state electrical power supply networks (PBS 43)

[PR195-I] The steady-state electrical power supply networks provide different voltage class power supplies as described in [A07]:

- Steady-state power, in class IV, to all the electrical loads of the ITER plant auxiliary and utility systems, during normal operation, from the power grid;
- Steady-state power, in class I, II and III, to the safety-related and investment protection loads of the ITER plant auxiliary systems, in case of unavailability of the class IV network, from diesel motor generators;
- Class II AC power to plant loads, from class III or IV power through AC/DC/AC inverters that are connected to batteries;
- Class I DC power to plant loads, from class III or IV power through AC/DC rectifiers that are connected to batteries.

3.2.18 Cable trays system (PBS 44)

[PR1760-I] Cable trays system manages a centralized control of cables, cable trays and pneumatic lines for all ITER systems.

[PR1935-I] The cable trays system provides the infrastructure and the tools for the management and the routing of all cables, cable trays and pneumatic lines.

3.2.19 Control, Data Access and Communication System (PBS 45)

[PR201-I] The Control, Data Access and Communication System (CODAC) performs the following functions:

- Networking, to communicate information between all ITER systems and CODAC;
- Monitoring the ITER plant, and displaying the status to operator stations;
- Acquiring, archiving and providing controlled access to all engineering and scientific data concerning the operation of ITER, for the duration of the project and beyond;
- Specifying and verifying the parameters that are used during ITER operation, including during plasma pulses both on-site and remotely;
- Providing, distributing and monitoring a project-wide time reference;
- Providing, distributing and recording audio and video information inside the plant;
- Operating ITER in terms of Global Operating States that are linked to the Operation Limits and Conditions (OLC);
- Managing Instrumentation and Control (I&C) for all ITER systems.

[PR2084-I] The CODAC includes the following:

- The infrastructure for controlling plasmas and other pulse-related activities;
- The infrastructure for providing all calculations that are needed for ITER operation, including verification before and during plasma pulses, and diagnostic data evaluation during plasma pulses;
- Features allowing ITER to be efficiently exploited from remote sites;
- Equipment allowing the ITER systems to be operated independently, for commissioning, testing and maintenance;
- Features allowing the collaborative research activity to be efficiently executed, given the distributed nature of the research teams;
- Operator consoles, allowing the operation of the ITER facility at the engineering level of each plant, and at the operation level of the integrated plant.

3.2.20 Central interlock system (PBS 46)

[PR218-I] The Central Interlock System (CIS) provides investment protection for the ITER systems by:

- Inhibiting combinations of actions among all ITER systems that might endanger the integrity of any ITER component;
- Applying automatic interlocks that are generated on the basis of the ITER status;
- Applying automatic interlocks that are generated on the basis of the interlocking levels that are defined in the Operation Limits and Conditions (OLC);
- Applying manual interlocks.

[PR224-I] The Central Interlock System signals the internal and external status of the ITER systems to CODAC, for monitoring, displaying and archiving, and provides warning threshold information to ITER operators.

3.2.21 Plasma control system (PBS 47)

[PR226-I] The Plasma Control System (PCS) controls nearly all aspects of plasma operation including:

- Certain types of wall conditioning and tritium removal that are performed during plasma operation with toroidal field;
- Plasma initiation;

- Control of plasma current shape and position during all phases of the pulse: ramp-up, flat-top, and ramp-down;
- Control of power and particle flux to the first wall and divertor;
- Control of plasma fuelling, isotopic mixture, non-inductive current profile, plasma pressure and fusion burn;
- Disruption prediction, avoidance, and, when necessary, mitigation via the Central Interlock System;
- Control of non-axisymmetric plasma stability, including sawteeth, ELMs, Neoclassical Tearing Modes (NTMs), error field and Resistive Wall Modes (RWMs), and Alfvén eigenmodes;
- Exception handling, which is the first level of machine protection, including controlled plasma termination, for plasma and plant events that lie inside the Central Interlock System interlock limits.

[PR237-I] The Plasma Control System will not control the toroidal field, the vessel and in-vessel baking and the steady glow discharge cleaning.

[PR238-I] The Plasma Control System uses input data from scenarios and sequence algorithms, together with real-time data from plasma diagnostics and machine instrumentation, to produce outputs to actuators that are used to set up the necessary conditions for plasma operation, to produce plasma, to control all aspects of the plasma evolution and all plasma parameters that are necessary to operate ITER throughout all phases of the plasma discharge.

3.2.22 Central safety system (PBS 48)

[PR1936-I] The ITER safety control systems provide protection for the personnel and the environment by executing safety Instrumentation and Control (I&C) functions.

[PR1937-R;Defined Requirement] The ITER safety control systems, both central and local ones, shall enable the control of the ITER safety I&C functions by managing the safety thresholds. They include all I&C devices from sensor signals to actuator commands, including operator desk controls and processing equipment that is responsible for generating the signals that are required to fulfill the safety functions. They also include the processing of data that are necessary for operator control in accident or post-accident conditions.

[PR1938-I] The Central Safety System (CSS) coordinates the distributed safety systems, presents central and local safety systems data to the Safety Operator’s Desk, and executes manual commands from the Safety Operator’s Desk.

[PR241-I] The Central Safety System transfers its data and signal status information to CODAC for archiving, and additional monitoring and displaying.

3.2.23 Ion cyclotron heating and current drive system (PBS 51)

[PR243-I] The Ion Cyclotron Heating and Current Drive (IC H&CD) system provides ion cyclotron radio frequency power for plasma heating, current drive, control of sawteeth activity, and wall cleaning.

3.2.24 Electron cyclotron heating and current drive system (PBS 52)

[PR245-I] The Electron Cyclotron Heating and Current Drive (EC H&CD) system provides electron cyclotron microwave frequency power for plasma heating and current drive, control of instabilities via localized current drive, wall conditioning (TBC), and RF-assisted breakdown for plasma initiation.

3.2.25 Neutral beam heating and current drive system (PBS 53)

[PR1939-I] The Neutral Beam Heating and Current Drive (NB H&CD) system provides neutral beams for plasma heating and current drive, plasma rotation, fuelling, and plasma current and density profile control.

[PR1940-I] The Diagnostic Neutral Beam system provides a dedicated neutral beam, for helium ash measurements, using Charge Exchange Recombination Spectroscopy (CXRS). It also allows localized measurement of various plasma parameters, such as ion temperature and impurity density.

[PR247-I] The heating beams are also used to measure the magnetic fields in the plasma, by Beam Emission Spectroscopy.

3.2.26 Section no longer required

3.2.27 Diagnostics system (PBS 55)

[PR251-I] The diagnostics system provides measurements of plasma behavior and performance, including those that are needed for machine protection and basic machine control, those that are required for advanced plasma control and those that are required for evaluation and physics studies.

3.2.28 Test blanket modules system (PBS 56)

[PR253-I] The Test Blanket Modules (TBM) system provides blankets for testing and validating design concepts of tritium breeding blankets that are relevant to a power-producing reactor.

[PR254-R] The test of Test Blanket Modules and associated systems shall be accommodated. For each TBM, the testing includes the initial installation during the non-nuclear phase and replacements during the further ITER operation.

3.2.29 In-Vessel Viewing System (PBS 57)

[PR1762-I] The ITER In-Vessel Viewing System (IVVS) allows for in-vessel inspection of plasma-facing surfaces to look for possible damage caused during plasma operations. It is also used for metrology measurements of the plasma chamber and its components.

3.2.30 Port plug test facilities (PBS 58)

[PR258-I] The port plug test facilities allow testing and qualification of port plugs prior to installation on the tokamak, or after refurbishment in the Hot Cell Facility.

3.2.31 Site facilities (PBS 61)

[PR1942-I] The Site facilities include the fencing, water drainage, outdoor lighting, bridges, roads, footpaths, special foundations, and service trenches, as identified on the Site Master Plan [A13].

3.2.32 Reinforced concrete buildings (PBS 62)

[PR262-I] The Reinforced Concrete Buildings comprise all concrete buildings on the ITER site, including the Tokamak Complex buildings, the Laydown and Assembly-Hall Building, the Cleaning Facility Building, the Hot Cell Building, the Radwaste Building, the Personnel Access Control Building, and the Control Buildings.

3.2.33 Steel frame buildings (PBS 63)

[PR264-I] The Steel Frame Buildings include all steel frame buildings on the ITER site that are not part of the PBS 62.

3.2.34 Radiological and environmental monitoring system (PBS 64)

[PR1945-I;Defined Requirement] The Radiological and Environmental Monitoring System (REMS) performs radiological monitoring to assist in protection of personnel from ionizing radiation, including from tritium.

[PR2354-I;Defined Requirement] The REMS performs airborn beryllium monitoring.

[PR2085-I;Defined Requirement] The REMS performs routine data collecting on the radiological state of the ITER plant throughout the whole lifetime of the ITER project.

[PR1946-I;Defined Requirement] The Environment Monitoring System (EMS) provides information on the environmental impact of ITER operations, as necessary to ensure compliance with environmental regulations.

[PR266-I;Defined Requirement] In certain buildings, the Heating, Ventilation and Air Conditioning (HVAC) system must change configuration automatically in the event of increased tritium-in-air levels, for the protection of the environment and the public. This function is performed by specific tritium-in-air monitors that are included in the Radiological and Environmental Monitoring System.

3.2.35 Liquid and gas distribution system (PBS 65)

[PR268-I] Liquid and Gas Distribution system distributes non-cryogenic fluids to buildings within the ITER site: potable water; fire-fighting water; demineralized water; hot water for heating purposes; compressed air; breathing air; nitrogen, helium.

3.2.36 Radioactive waste treatment and storage system (PBS 66)

[PR278-I] The Radioactive Waste Treatment and Storage system performs the following functions during the ITER operation phase, and until the deactivation phase:

- Treating and storing intermediate-level and long-lived (Type B or MAVL, "Moyenne Activité et durée de Vie Longue") radioactive waste in the Hot Cell Building;
- Storing purely tritiated waste in the Hot Cell Building, or in an adequate area;
- Treating and storing low- and intermediate-level and short-lived (Type A or FAVC, "Faible et Moyenne Activité à durée de vie courte") solid radioactive waste and liquid effluent in the Radwaste Building;
- Treating and storing very low-level radioactive waste (TFA, Très Faible Activité).

3.2.37 Access control and security system (PBS 69)

[PR1947-I] The Access Control and Security System (ACSS) provides for the safety of personnel by ensuring that access to hazardous or potentially hazardous areas is possible only if certain protective conditions are satisfied, and by limiting such access to suitably qualified personnel.

[PR287-I] The Access Control and Security System provides for the security and protection of the ITER plant from sabotage and from access by unqualified personnel.

3.2.38 Site outside platform (PBS 70)

[PR1764-I] The Site Outside Platform includes all infrastructure and support facilities that are part of the ITER scope, and that are located outside of the ITER platform, as shown in **Figure 3-2**.

3.2.39 External services and interfaces system (PBS 98)

[PR1766-I] The External Services and Interfaces system groups all functions that are required by ITER Organization and that are provided by external services, such as nuclear services, off-site electricity supply, water supply, other fluids supply (such as cryogenics), drains, telecommunications and networks.

3.3 ITER Project lifecycle phases

[PR289-I] The lifecycle phases for the ITER project are:

- Construction;
- Operation;
- Deactivation;
- Decommissioning.

[PR296-I] **Figure 3-3** shows the flow of these lifecycle phases throughout the operational campaigns identified in the ITER Research Plan [R07], as amended by [R37].

3.3.1 Construction of ITER

[PR299-R] The construction of ITER involves the preparation of the site, civil construction works, machine assembly, plant system installation and individual system testing. This shall be phased in four construction periods, as shown in **Figure 3-3**.

3.3.2 Integrated commissioning

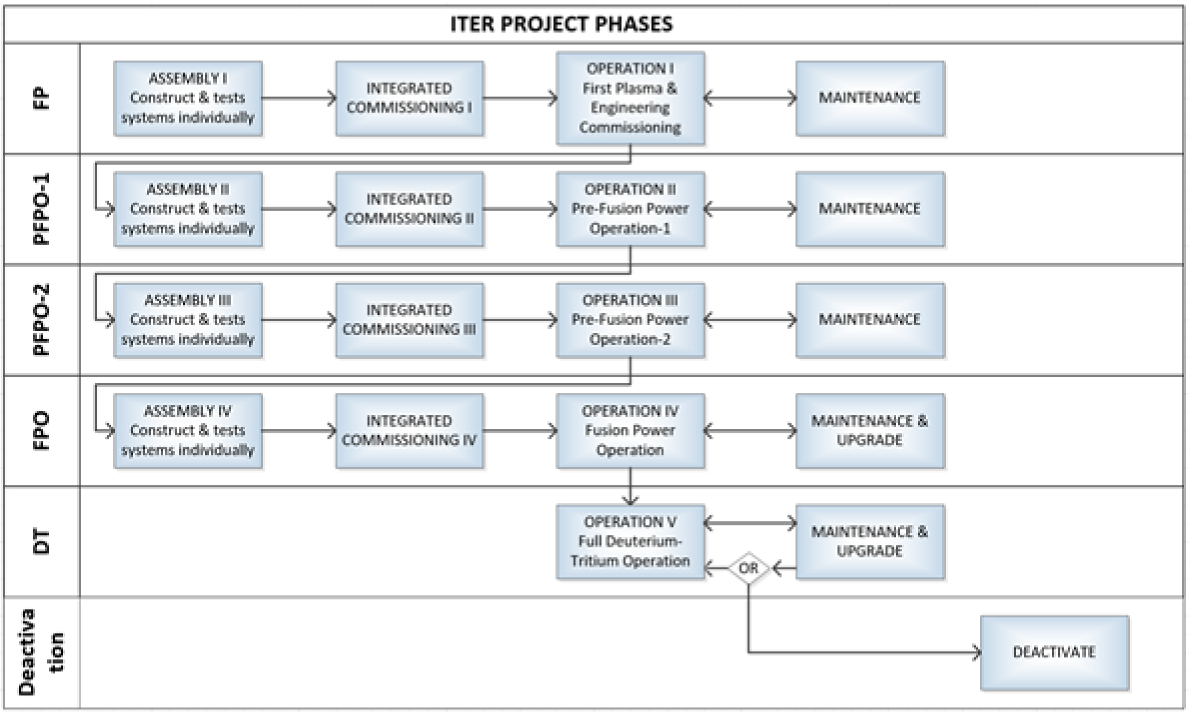
[PR301-R] At the end of each construction period, an integrated commissioning of ITER systems shall be performed, to ensure correct functioning, and to assure readiness for plasma operations.

[PR2382-R;Defined Requirement] At the end of the integrated commissioning, the mechanical position, loads, stresses, strains, magnet wedging, vibrations and temperatures under operational conditions shall have been verified (applying the appropriate "graded approach" as defined in the ITER Quality Assurance Program [R16]).

[PR2383-I] The successful integration of ITER systems will be demonstrated by establishing the plasma specified for each plasma operation phase.

[PR2386-I] Man access to the cryostat is only allowed during first installation phase.

Figure 3-3**: ITER Project Lifecycle Phases**



3.3.3 ITER operations

[PR303-I] The ITER operation campaigns include preparation for and execution of plasma operation, and the implementation of the ITER Research Plan [R07].

[PR304-I] An operational campaign during D-T plasma operation consists of typically 16 months of operations (see Section 6.6).

[PR305-I] Each operation day will have three 8-hour work shifts, as defined in Section 6.6.

3.3.4 Maintenance and upgrades

[PR307-I] In the maintenance and upgrades phases, major interventions are possible on the Tokamak machine, to repair or upgrade ITER systems.

[PR1949-I] The first steps in performing maintenance and reconfiguration involve diagnosing and isolating faults, and making restricted areas safe for personnel access.

[PR5415-I] Personnel access to various areas of the ITER Plant will comply with the requirements for the different applicable zoning as defined in Section 7.9.

[PR1950-I;Defined Requirement] Waiting periods, of up to 24 hours for contact dose rates to subside, may be required in the TCWS vault and other areas that surround the tokamak, after D-T operations commence.

[PR1951-I] Access to the inside of the cryostat will require extended periods of time for warming up the superconducting coils and thermal shields to room temperature.

[PR1952-R;Defined Requirement] As the vacuum vessel will be activated during the plasma operation, all in-vessel maintenance activities shall be designed to be performed remotely.

[PR1953-R;Defined Requirement] Before venting the vacuum vessel, the vessel and in-vessel components shall be baked to remove tritium until the tritium venting rate is deemed acceptable (operational decision).

[PR1954-I] In-vessel dust will be collected and removed to mitigate the spread of contamination throughout the facility.

[PR1955-R;Defined Requirement] The Neutral Beam enclosure vessels will become activated during D-T operations, and consequently shall require remote maintenance.

[PR1956-R] The TF coils shall be discharged prior to deploying personnel or in-vessel remote handling equipment in the vacuum vessel.

[PR5302-I] The in-vessel viewing equipment is designed to be deployed when the vacuum vessel is under vacuum and the TF coils are energized. Remote handling equipment is designed to be deployed when the TF coils are de-energized and the vacuum vessel is vented.

[PR1957-R] Major reconfigurations and upgrades of the Tokamak machine shall be completed prior to machine activation.

[PR1958-R] The Hot Cell Facility shall be used for the refurbishment of worn and failed activated components.

[PR1959-R;Defined Requirement] The discarded and activated materials shall be treated and stored in the Hot Cell Building or in the Radwaste Building, depending on the radioactive waste classification.

3.3.5 Deactivation of ITER

[PR1960-I;Defined Requirement] The deactivation of ITER involves deactivating the facility, and removing tritium, beryllium and readily mobilizable sources of radioactivity.

[PR310-R;Defined Requirement] Following deactivation of the facility, the Host Member (see Sections 3.4 and 4.5) shall be responsible for dismantling the facility and disposing of the waste.

3.3.6 Plant operational state

[PR1819-I] The ITER Plant is always in one of the following four well defined Global Operational States:

- **Long Term Maintenance (LTM) state:** This is used for long term maintenance or upgrade. A sufficient nuclear decay period is required before starting the LTM. Some systems may be in operation during LTM.
- **Short Term Maintenance (STM) state:** This may be scheduled or unscheduled following a failure. The vessel is evacuated, all magnets are at zero current but are cooled (except TF coils that are cooled but still energized).
- **Test and Conditioning State (TCS):** Most systems are ready for test-pulsing (with no plasma); cooling systems are in low-flow; magnets can be operating; access is very restricted and tightly controlled.
- **Plasma Operation State (POS)**: This is the state waiting for, during the countdown, execution and end of a plasma pulse, including IC wall conditioning.

[PR1961-I] Transitions from one state to another are well controlled, and require a number of conditions to be satisfied.

3.4 Site requirements

[PR312-R] The Host Member, EU, shall make available, or cause to be made available, to ITER Organization land, facilities, buildings, goods and services in support of the site, as summarized in the annexes to the Site Support Agreement [R23].

[PR313-I] The details of such support, as well as the procedures for cooperation between ITER Organization and the Host Member, are covered by the Site Support Agreement [R23].

3.4.1 Land

[PR1962-I;Defined Requirement] The Host Member has made available to ITER Organization a land area of approximately 181 ha for the duration of the ITER project (construction, operation and deactivation): a period of at least 35 years [R18], [R23].

[PR316-I] The main part of this land area, around 115 ha, as indicated in the Site Master Plan [A13], is managed by ITER Organization, while the remaining area continues to be managed by the Host Member. The land has been provided ready to use, cleared of forest and with platforms created. The external fencing was constructed by the Host Member [R23].

[PR1963-R] The foundation soil of the ITER site shall have the capability to bear building loads of at least 25 t/m^2 at locations where buildings are to be constructed.

[PR1964-I] It is expected that it will be possible to provide, at the specific location of the Tokamak Building, means to support the average load of 65 t/m^2 at a depth of 25 m.

[PR1965-R] The soil (to a depth of 25 m) shall not have unstable surrounding ground features.

[PR317-R] The building sites shall not be susceptible to significant subsidence and differential settlement.

3.4.2 Headquarters construction

[PR319-R] Certain infrastructure facilities, buildings and services shall be provided by the Host Member in support of the design, procurement, construction, installation, commissioning and operation activities for the ITER project, as agreed in various agreements and amendments thereto.

3.4.3 Roads

[PR1966-R] The roads and paths, both internal and external to the ITER nuclear site boundary (see the Site Master Plan [A13]) shall be of a standard to permit access to the ITER buildings for all ITER goods, including all the components that are provided in-kind, and for personnel.

[PR321-R] The lighting and drainage of the roads and paths, both internal and external to the ITER nuclear site boundary, shall be up to the Host Member's legislation and standards [R23].

3.4.4 Transport of components

[PR323-R] The Host Member shall provide transport services from the Port Autonome de Marseille or, in case of air transport from Marignane airport, to the ITER site for all components that are contributed by the Members or purchased by ITER and that are delivered using the Logistics Service Provider that is selected by ITER Organization in collaboration with the Domestic Agencies.

[PR1967-I] The maximum size and weight of the transported components (including packaging and frames) are given in Section 8.8.1.

3.4.5 Electrical power

[PR325-R] The Host Member shall provide installation and maintenance of a 400 kV AC power source that is able to provide up to 500 MW for the pulsed loads, as well as 120 MW for the continuous loads, with a total reactive power up to 200 Mvar demand from the pulsed loads, and 48 Mvar from the continuous loads.

3.4.6 Water supply and sewage

[PR328-R] The Host Member shall provide a continuous supply of potable water that meets the average (0.2 m^3/mn) and peak (3 m^3/mn) consumption rates of the ITER facility (the average daily consumption is estimated to be about 400 m^3) [R23].

[PR1970-R] The peak consumption rates for potable water shall cover leaks and fire protection.

[PR1971-R] The potable water supply shall require no treatment or processing for normal industrial purposes (such as for drinking water or for makeup of the demineralized water system).

[PR1972-R] The potable water connections shall be at the site boundary.

[PR1969-I] The detailed functional and physical interface requirements for potable water are defined in the relevant interface control documents.

[PR1973-R] The Host Member shall supply raw water for use in cooling towers to dissipate on average 450 MW (thermal) energy to the environment [R23].

[PR1974-I] The total raw water consumption of about 16 m^3/mn is determined for the average heat load of a complete plasma pulse cycle (450 MW) [R23].

[PR1975-I] During periods of no pulsing, the raw water consumption would drop to about 5 m^3/mn [R23].

[PR1976-R] The raw water connections shall be inside the ITER site boundary, near the Cooling Tower Basin. (See the Site Master Plan [A13]).

[PR330-I] The detailed functional and physical interface requirements for the raw water supply are defined in the relevant interface control documents.

[PR1977-R] The Host Member shall provide a sanitary water drainage system with a capacity for a peak ITER site population of 1000, up to 4000 during construction, on two shifts, including IO staff, DA staff and contractors [R23].

[PR1978-R] The sanitary water drainage system shall be adequate for a construction workforce of up to 3000 people, and will be provided by the Host Member [R23].

[PR1979-R] The sanitary waste connections shall be at the ITER site boundary.

[PR1980-R] The Host Member shall provide an industrial drainage network with a capacity for an average of 200 m^3/day [R23].

[PR1981-R] The industrial water drainage connections shall be at the ITER site boundary.

[PR336-R] The peak water flow rate from the Cooling Tower Basin shall be 4000 m^3/day based on two-shift operations, and 6000 m^3/day based on three-shift operations, with a monthly average of less than 3000 m^3/day.

[PR1982-R] The maximum annual flow rate from the Cooling Tower Basin shall be 1 020 000 m^3/year.

[PR337-R] The Cooling Water System discharge connections shall be inside the ITER site boundary, near the Cooling Tower Basin.

[PR338-I] The detailed functional and physical interface requirements (including administrative limits on tritium and other radioactive materials) for the Cooling Water System discharge from the Basin are in the relevant interface control documents.

[PR340-R] The Host Member shall provide a precipitation water drainage system.

3.4.7 Waste disposal

[PR342-R;Defined Requirement] The Host Member shall accept for disposal industrial, radioactive, and toxic waste and effluents that is generated during the course of the ITER construction, operation and deactivation.The detailed functional and physical interface requirements (including administrative limits and packaging requirements) are defined in the Site Support Agreement [R23] between ITER Organization and the Host Member.

3.4.8 Communications

[PR346-R] The Host Member shall provide a high-speed network connection with high availability to support data transfer and other communication requirements during the ITER construction and operation, as specified in the Site Support Agreement [R23].

[PR1986-I] The high-speed network provider will provide this service in compliance with standards for comparable large scientific projects.

[PR1985-I] The other standard communications infrastructure such as (mobile) telephone connections will be provided with the support of the Host Member.

[PR347-I] All the ITER participating countries are expected to provide compatible network infrastructure and assist in the establishment of efficient routing protocols as needed.

4 PERFORMANCE REQUIREMENTS

[PR4958-I] This chapter identifies the overall performance requirements that ITER must achieve in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

4.1 Construction and facility start-up

4.1.1 Assembly sequence

[PR351-I] The assembly sequence is described in the ITER Assembly Plan [R05].

4.1.2 Fabrication and assembly tolerances

[PR353-R] Fabrication and assembly tolerances for ITER components shall be established during ITER design and verified during the fabrication and assembly of ITER components to ensure that ITER can be constructed and operated.

[PR357-R] Position and alignment requirements for ITER coil systems shall be established during ITER design and verified during assembly and commissioning to ensure that:

- ITER can be constructed and operated;
- The error field requirements in Section 4.3.2.4 can be met.

[PR361-R] Position and alignment requirements for the ITER vacuum vessel and plasma-facing components shall be established during ITER design and verified during assembly and commissioning to ensure that:

- ITER can be constructed and operated;
- The power handling requirements in Section 4.3.10 can be met.

4.1.3 Vacuum acceptance leak rates

[PR367-R] All components and system forming a vacuum boundary shall be designed to facilitate leak testing using tracer gas leak detection methods during the construction of ITER.

[PR368-R] Vacuum components shall be acceptance leak-tested prior to delivery to the ITER site, prior to installation, and as part of an installation where it reduces the risk of installing leaking components.

[PR369-R] The air-equivalent leak rate for the total torus vacuum system (including all in-vessel components and attachments) shall be less than 2×10^{-7} Pa.m^3.s^{-1}.

[PR370-R] The leak rate for an individual vacuum vessel sector (that is, 40° of the total torus) shall be less than 1×10^{-8} Pa.m^3.s^{-1}.

[PR371-R] The leak rate for the completed cryostat (including all in-cryostat components and attachments) shall be less than 1×10^{-4} Pa.m^3.s^{-1}.

[PR372-R] Testing methods and principles, and the acceptance leak-rate, for all vacuum components shall be in accordance with the ITER Vacuum Handbook [A05].

[PR2086-R] Vacuum envelopes (that is, any components that form part of the vacuum boundary, including their penetrations) shall be designed and manufactured using appropriate standards and processes to guarantee that sufficient margins exist in all loading conditions.

[PR2087-R] During maintenance operations, appropriate measures shall be taken to protect vacuum envelopes.

[PR2088-R] The failure of a vacuum envelope shall be monitored (by measuring pressure within the envelope), with appropriate alarm systems provided.

4.1.4 Integrated systems testing

[PR374-R;Defined Requirement] A comprehensive integrated test program for each system shall be provided to verify, prior to plasma operations, that applicable ITER systems operate safely and as expected.

[PR375-R] Distributed systems shall be tested according to an approved test plan prior to their operation.

4.2 Preparations for plasma operations

4.2.1 Cryostat evacuation

[PR384-R] The cryostat shall be designed for 100 vacuum pump-downs.

[PR385-R] The in-cryostat equipment shall be designed for 100 cool-down and warm-up cycles.

[PR387-R] Prior to cool-down, the cryostat shall be evacuated to a base pressure of 10^{-4} Pa.

[PR388-R] The cryostat shall be evacuated from atmospheric pressure to 10 Pa within 24 hours.

[PR389-R] The cryostat shall be evacuated from 10 Pa to less than 10^{-4} Pa within 160 hours.

[PR391-R] The maximum global in-leakage of helium into the cryostat, at cryogenic temperature, shall not exceed 10^{-2} $Pa.m^3.s^{-1}$.

[PR392-R] The base pressure of the cryostat shall be maintained at less than 10^{-4} Pa when the superconducting magnets are below room temperature.

[PR4959-R] The cryostat, and all components within or forming a boundary to vacuum, shall comply with the ITER Vacuum Handbook [A05].

4.2.2 Vacuum vessel and neutral beam enclosure evacuation

[PR398-R] The vacuum vessel and neutral beam enclosures shall be designed for 500 vacuum pumpdowns.

[PR394-R] The isolation valve between neutral beam and vacuum vessel enclosures shall be closed when one of these enclosures is vented.

[PR395-R] The vacuum vessel shall be capable of being pumped down from atmospheric pressure to 10 Pa within 24 hours.

[PR396-R] A base pressure of less than 10^{-5} Pa (for hydrogen isotopes) shall be achieved in the vacuum vessel, after wall conditioning, prior to plasma operations.

[PR397-R] A base impurity pressure of less than 10^{-7} Pa (the sum of partial pressures of impurity gases) shall be achieved in the vacuum vessel, after wall conditioning, prior to plasma operations.

[PR399-R] The vacuum vessel, and all components within or forming a boundary to vacuum, shall comply with the ITER Vacuum Handbook [A05].

[PR400-R] The HNB/DNB enclosure, and all components within or forming a boundary to vacuum, shall comply with the ITER Vacuum Handbook [A05].

[PR401-R] The neutral beam enclosure shall be capable of being pumped down from atmospheric pressure to 10 Pa within 24 hours.

[PR402-R] The global air-equivalent in-leakage into the neutral beam enclosure shall not exceed $1x10^{-8}$ $Pa.m^3.s^{-1}$.

[PR143-R] The Vacuum Vessel Pressure Suppression System (VVPSS) shall limit pressurization of the vacuum vessel to a maximum of 0.15 MPa absolute.

4.2.3 Magnet cool-down and warm-up

[PR409-R] The superconducting coils shall be designed for 100 cool-down and warm-up cycles.

[PR407-R] Superconducting magnet systems shall be capable of being cooled down from room temperature to operating temperature within 30 days.

[PR1029-R] Superconducting magnet systems shall be capable of being warmed up from operating temperature to room temperature within 30 days.

[PR1030-R] The cryogenic system shall be capable of warming up or cooling down superconducting coils within 30 days.

[PR408-R] It shall be possible to cool down the TF coils to operating temperature within four days of a fast discharge.

4.2.4 Coil charging and discharging

[PR488-R] The TF, PF, CC and CS coils shall be designed to withstand the number of pulses that are specified over the life of ITER (Section 6.2) when operated for any of the reference scenarios (**Table 4-1** and Section 4.3.1) or the equivalent for other scenarios when adjusted for fatigue life according to the procedures in the design criteria.

[PR492-R] A plasma disruption shall not trigger discharge of any of the superconducting coils.

[PR412-R] It shall be possible to charge the TF coils from zero current to full current (corresponding to 5.3 T at a major radius of 6.2 m) within 2 hours.

[PR413-R] Under normal conditions, it shall be possible to discharge the TF coils from full current (corresponding to 5.3 T at a major radius of 6.2 m) to zero current within 2 hours. This is referred to as a slow discharge.

[PR1767-R] Under abnormal conditions, it shall be possible to discharge the TF coils from full current (corresponding to 5.3 T at a major radius of 6.2 m) to zero current within 30 minutes. This is referred to as an accelerated discharge.

[PR414-R] The coils shall be protected against damage in case of a superconductor resistive transition. The magnets quench detection system and the Fast Discharge Units shall be designed for this purpose. This event is referred to as a fast discharge.

[PR1820-R] In the event of a TF fault, quench, or otherwise abnormal condition, all TF, CS, PF and CC coils shall be discharged to divert stored magnetic energy to an external energy sink.

[PR493-R] In the event that a fast discharge of the TF coils is required, a fast discharge of all the CS, PF and CC coils shall be invoked.

[PR489-R] In the event that a fast discharge of any PF or CS coil is required, a fast discharge of all of the PF and CS coils shall be invoked.

[PR491-R] A fast discharge of the PF and CS and CC coils shall not trigger the fast discharge of the TF coils.

[PR421-R] The time constant for TF fast discharge shall be greater than 11 s.

[PR418-R] The TF coils shall be designed to withstand 1000 charge-slow or accelerated discharge cycles over the life of ITER.

[PR419-R] The TF coils shall be designed to withstand 50 charge-fast discharge cycles over the life of ITER.

[PR420-R] The TF coils shall be designed to withstand 10 quenches over the life of ITER.

[PR490-R] The PF, CC and CS coils shall be designed to withstand 100 quenches over the life of ITER.

[PR416-R] The CS, PF and CC systems shall be designed for 500 fast discharges.

[PR415-R] The magnets and auxiliary systems shall be ready for plasma operation within 2 hours of a fast discharge of the CS, PF or CC.

4.2.5 Baking

[PR425-R;Defined Requirement] The divertor shall be capable of being baked up to 350°C.

[PR2090-R;Defined Requirement] The Blanket Modules, Divertor Cassettes, In-Vessel Coils, Vacuum Vessel ports and In-Ports Components shall be capable of being baked at 240°C.

[PR426-R;Defined Requirement] The main part of the Vacuum Vessel (torus) shall be capable of being baked at 200°C.

[PR427-R] All surfaces other than blankets, divertor, vacuum vessel and in-vessel components, that are exposed to the primary vacuum shall be baked at a temperature greater than 180°C, including the neutral beam port (up to the torus isolation valve) and the VVPSS piping (up to the rupture disk). Exceptions for lower-temperature baking of components that are at or beyond the vessel ports boundary shall be treated on a case-by-case basis.

[PR428-R] The capability for baking shall be provided while the superconducting coils are at any temperature between 5 K and 293 K.

[PR430-R] The vacuum vessel and in-vessel components shall be capable of being raised from operating temperature to the baking temperature within 2 days.

[PR431-R] Following baking, the vacuum vessel and in-vessel components shall be capable of being returned to their pre-pulse operating temperature (see Section 4.3.2.1) within 24 hours.

[PR432-R] The rate of change of temperature of the vacuum vessel and in-vessel components shall not be faster than +5 K/h during warm-up, and -7 K/h during cool-down, considering thermal stresses.

[PR434-R] All ITER systems shall be designed to accommodate 500 baking cycles from the commissioning phase to the end of life of ITER.

[PR2092-I] During D-T pulse operation, the estimated baking cycles are 40.

4.2.6 Glow discharge cleaning (GDC)

[PR436-R] The facility shall provide the capability to perform GDC indefinitely with the vacuum vessel and all in-vessel components at their nominal pre-pulse operating temperatures.

[PR437-R] The facility shall provide the capability to perform GDC indefinitely with the vacuum vessel and all in-vessel components at their nominal baking temperatures.

[PR438-R] The facility shall be capable of using any of the following gases for GDC: hydrogen, deuterium, and helium.

[PR439-R] PF, CS, CC and VS coil currents shall be zero during GDC.

[PR440-R] Provisions shall be made to isolate the neutral beam enclosures during GDC.

4.2.7 NB H&CD source conditioning

[PR442-R] It shall be possible to isolate the neutral beam enclosures from the main vacuum vessel vacuum when conditioning the NB H&CD sources.

4.2.8 IC H&CD launcher conditioning

[PR444-R] The IC H&CD launchers shall be able to be conditioned, both in vacuum and in the presence of plasma.

4.2.9 EC H&CD launcher conditioning

[PR446-R] The EC H&CD launchers shall be conditioned in the presence of plasma.

4.2.10 Pre-operational commissioning and testing

[PR448-R] Prior to the initiation of plasma operations, the operation state of ITER systems shall be determined.

4.3 D-T Plasma operations

[PR4960-I] This section presents plasma performance requirements for the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

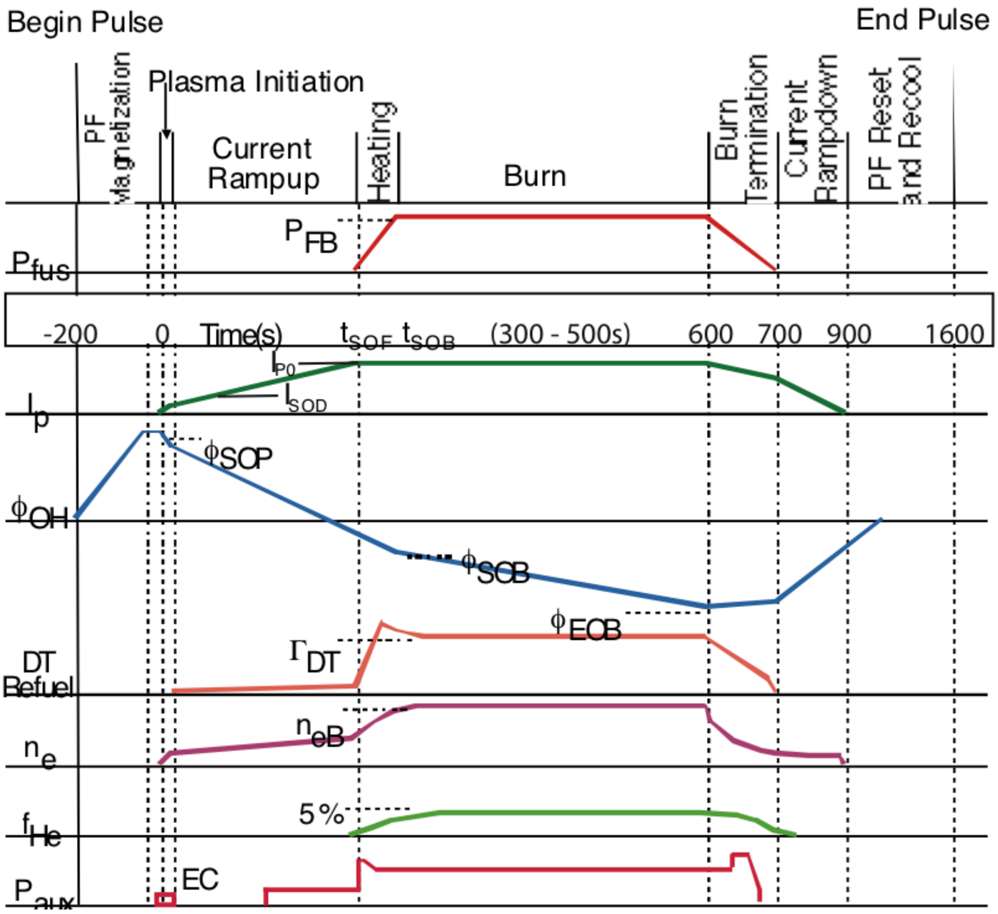
4.3.1 *D-T Plasma scenarios*

[PR2097-I] Five types of plasma scenarios have been defined to organize the plasma operations, based on different parameters used during the plasma discharge:

- Three D-T reference plasma scenarios (see Section 4.3.1.1);
- The flexibility scenarios (see Section 4.3.1.2) that will be prepared to operate ITER at enhanced parameters

[PR504-I] An ITER D-T discharge should have the schematic form illustrated in **Figure 4-1**, which defines the conceptual structure of the plasma scenario. According to the scenario heating and current drive will also be exploited during the current ramp-up phase to optimize the use of inductive flux and to control the plasma current profile.

Figure 4-1**: Schematic of ITER D-T plasma discharge scenario**



[PR506-I] The timing shown is illustrative and referred to the 15 MA Q=10 Inductive scenario. The Hybrid and Non-inductive scenarios will have similar generic waveforms, but the details, in particular, for the timing of fuelling, H&CD operation and critical pulse transitions will differ.

4.3.1.1 *D-T reference plasma scenarios*

[PR510-I] The following three plasma scenarios, defined as "reference" scenarios have been developed as illustrations of scenarios demonstrating the key ITER mission goals:

- Inductive operation: 500 MW, Q = 10, 15 MA operation with heating during current ramp-up;
- Hybrid operation;
- Non-inductive operation: weak negative shear operation.

[PR515-R] ITER shall be designed to meet the requirements of the three reference scenarios.

[PR4961-R] The Hybrid and Non-inductive scenarios shall be achievable within the design requirements of the inductive scenario, excepting additional investments for auxiliary systems upgrades (see Section 4.4.4, and **Table 4-9**).

[PR516-I] Nominal plasma parameters, for the reference scenarios, are shown in **Table 4-1**.

[PR507-R] All ITER systems, including plasma-facing components, shall be designed to withstand the heat and nuclear loads derived from the three reference plasma scenarios as defined in [A15].

[PR509-I] ITER is designed to conduct experiments in a wide range of experimental parameters in D-T operation. The limiting values of coil currents, fusion power, heating powers and other plasma-related requirements have been determined after complex studies of the expected regimes to obtain a broad operational window consistent with the requirements of satisfying the ITER mission as defined in the Project Specification [R01].

[PR1822-I] The Poloidal Field scenario database obtained through self-consistent simulations of ITER plasma scenarios [A19] describes key features of the scenarios and gives IDM links to the corresponding folders with scenario data.

Table 4-1**: D-T reference plasma scenario parameters [R09]**

Parameter	1. Inductive operation	2. Hybrid operation	3. Non-inductive operation
Plasma major radius (R) / Plasma minor radius (a) (m/m) (note 1)	6.2 / 2.0	6.2 / 2.0	6.35 / 1.85
Toroidal field, BT (T)	5.3	5.3	5.18
Plasma current, IP (MA)	15.0	13.8	9.0
Elongation, κx/κ95	1.85 / 1.7	1.85 / 1.7	2.0 / 1.85
Triangularity, δx/δ95	0.48 / 0.33	0.48 / 0.33	0.6 / 0.4
Fusion power, Pfus (MW)	500	400	356
Auxiliary heating/current drive power (Padd) (MW)	50	73	59
Energy multiplication, Q	10	5.4	6
Burn time during Flat Top Phase (s)	450	1000	3000
Total heating power, PTOT (MW)	151	154	130
L-H transition power, PL-H (MW)	76	66	48
Plasma thermal energy, Wth (MJ)	353	310	287
Maximum fuelling input (Pa-m^3/s)	200	160	120

[PR1634-I] Note 1: As defined in equation 2 of [R26].

[PR518-I] The methodology and physics basis for the definition of the three reference scenarios are provided in the Plasma Performance Assessment [R09].

[PR519-I] Although experimental uncertainties remain, the maturity of the physics basis for the type I ELMy H-mode scenario leads to its selection as the ITER baseline scenario for the Q greater than or equal to 10 mission. The physics bases for the Hybrid and Non-inductive scenarios continue to evolve rapidly and the parameters listed in **Table 4-1** are nominal values which allow testing of design assumptions for ITER systems.

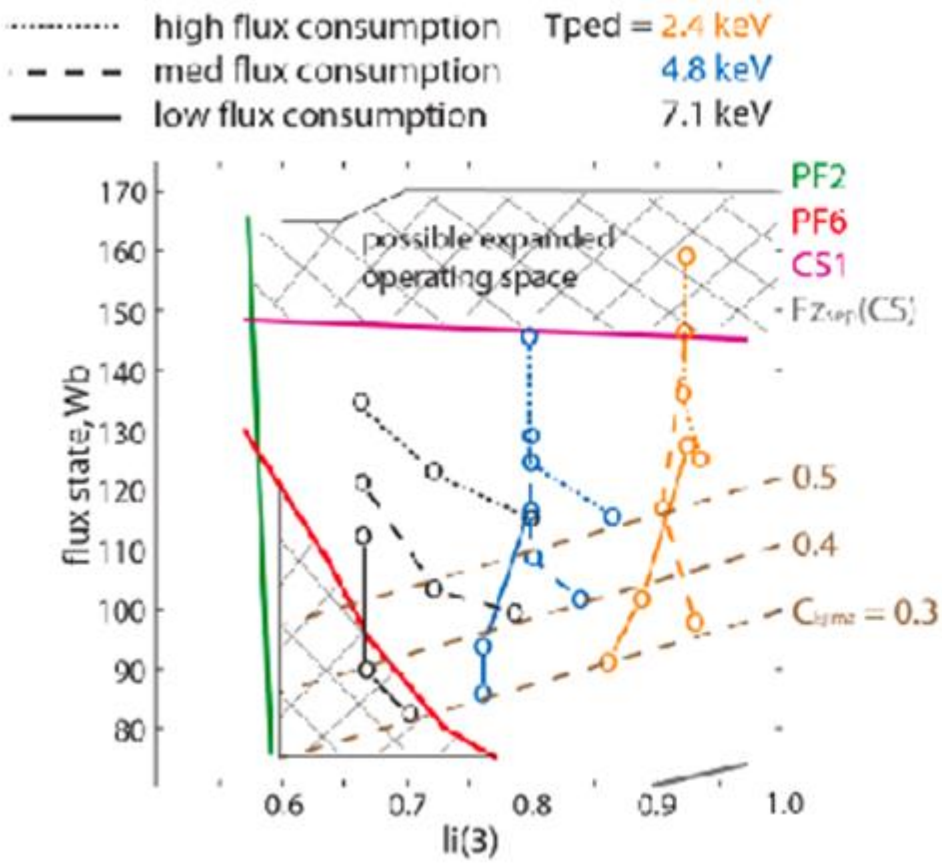
[PR520-I] Within the current physics basis, the illustrative parallel heat loads specified for the 15 MA reference scenario are expected to provide an upper limit for the Hybrid and Non-inductive reference scenarios.

[PR521-I] The 15 MA Q = 10 Inductive scenario provides the design basis for key tokamak systems, in particular the Central Solenoid, Poloidal Field and in-vessel coil systems.

[PR522-I] The basis for the specification of the Central Solenoid, Poloidal Field and power supply requirements for plasma control detailed in Section 4.3.4 is provided by results of extensive analyses that have been performed for the 15 MA, Q = 10 Inductive scenario using free boundary equilibrium/scenario numerical codes over ranges in critical plasma parameters (li, βp …) validated in tokamak experiments (see [R27]). The results of these analyses, expressed in terms of the plasma flux state at the Start Of Burn are shown in **Figure 4-2** and **Figure 4-3**, below. (The formal definition of parameters utilized in the flux state analysis is given in [R28]).

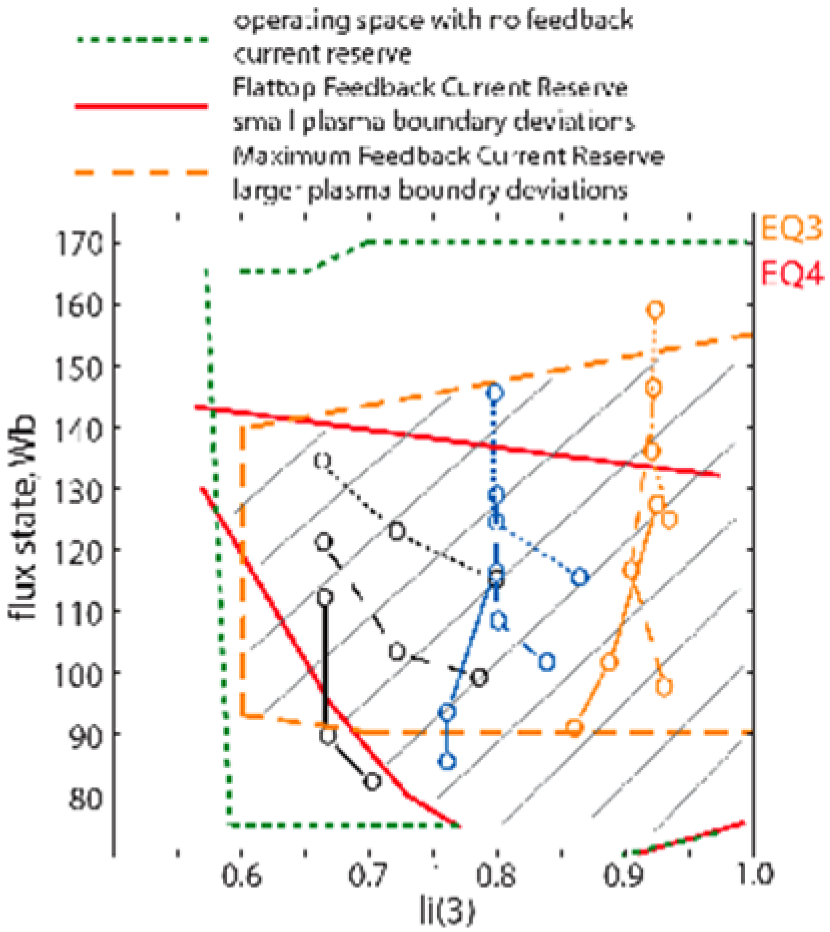
[PR523-I] The variation in the flux state diagrams among figures reflects the uncertainties associated with assumptions on parameters such as the current profile and with different optimization algorithms for plasma control currents. The target equilibrium used for these analyses is shown in **Figure 4-5** in Section 4.3.4.1.

Figure 4-2**: Flux state diagram for the start of burn to end of burn phase for 15 MA Q = 10 Operation (I)**



[PR525-I] (I) The flux state diagram shown in **Figure 4-2** has been calculated by the TSC, Corsica, TOSCA and CREATE-NL codes which use free-boundary equilibrium codes to establish existence boundaries for the reference separatrix of **Figure 4-5** consistent with the ITER Central Solenoid and Poloidal Field systems. For a given value of internal inductance (li3), the flux difference between the boundaries at low values of flux at the boundaries at high value defines the maximum flux available for the current flat-top, including burn. Also shown are the minimum values of flux consumption associated with several values of the Ejima coefficient, CEjima, which accounts for resistive flux consumption during the current ramp-up. These lines are indicative of the additional constraint on flux available for the current flat-top associated with the evolution of the plasma from the CS premagnetization state to the point tSOF in **Figure 4-1**. The variation in available flat-top flux among the codes results from variations in the assumptions made relating to plasma equilibrium profiles and to the assumed permissible deviation from the reference separatrix of **Figure 4-5**. The formal definition of parameters utilized in the flux state analysis is given in [R28].

Figure 4-3: **Flux state diagram for the start of burn to end of burn phase for 15 MA Q = 10 Operation (II)**



[PR527-I] (II) The flux state diagram shown in **Figure 4-3** has been calculated by the Corsica code and provides additional information relating to **Figure 4-2**. In particular, a series of time-evolved plasma scenarios encompassing ohmic, L-mode and H-mode operation in D-T plasmas has been calculated and superimposed on the operating space, demonstrating the capability for long duration current flat-top or plasma burn under varying assumptions [A19]. Trajectories of D-T H-mode plasmas are shown for a range of values of H-mode pedestal electron temperature, illustrating the capability of the Central Solenoid and Poloidal Field systems to support D-T H-mode operation over a substantial range in this key parameter.

4.3.1.2 Flexibility scenarios parameters

[PR2098-R] The possibility to operate ITER at enhanced parameters shall be assessed. Flexibility requirements include:

- D-T plasma scenarios with up to 700 MW of fusion power for 100 s;
- D-T plasma scenarios with plasma currents of up to 17 MA.

[PR549-I] These flexibility requirements do not lead to additional technical requirements for the ITER systems and structures with respect to those derived from the three D-T reference plasma scenarios in **Table 4-1**.

[PR1770-R] Magnet systems shall be designed to operate with a plasma current of 17 MA. All other systems shall be designed for 15 MA operation.

[PR836-R] ITER auxiliary (non-tokamak) systems shall be upgradable (with additional investment) to operate with a fusion power of 700 MW for 100 s.

4.3.2 Readiness for plasma operation

4.3.2.1 Vacuum vessel and in-vessel component coolant parameters

[PR452-R] The inlet pre-pulse and during pulse coolant temperature of the Vacuum Vessel and Neutral Beam ports (up to the torus isolation valve) shall be 100°C, with a range ±10°C at nominal flow rate and pressure.

[PR5395-R] The inlet pre-pulse and during pulse coolant temperature of all in-vessel components shall be 70°C, within a range of ±5°C, at nominal flow rate and pressure.

[PR1774-R] The maximum inlet water differential temperature between the Integrated Blanket ELM/VS Coils and Divertor (IBED) PHTS loop and the Vacuum Vessel (VV) cooling loop shall be controlled to be below 50°C during the entire duration of the Plasma Operation State (POS) and Testing and Conditioning State (TCS) and during the transients between these and Short Term Maintenance (STM) and also between POS and Long term Maintenance (LTM) [A08].

[PR2371-R] The measurement accuracy for the pressure, temperature and flow rate of TCWS shall be ±2% of the nominal value.

[PR453-R] The pre-pulse and during pulse coolant parameters at the divertor inlet (that is, at cassette pipe stubs) shall be:

- Inlet operating temperature: 70°C with range (-5 / +5 °C);
- Inlet pressure: 4.0 MPa with range (-0.2 / +0.6 MPa);
- Flow rate for all 54 divertor cassettes: minimum 870 kg/s.

[PR458-R] The pre-pulse and during pulse-coolant parameters at the blanket inlet (that is, at chimney bulk head) shall be:

- Inlet operating temperature: 70°C with range (-5 / +5 °C);
- Inlet pressure: 4.0 MPa with range (-0.2 / +0.6 MPa);
- Flow rate for all 440 wall mounted Blanket modules: minimum 3140 kg/s.

[PR1773-R] The VVPSS piping (up to the rupture disk) during the pre-pulse and pulse shall be controlled at 100°C, range ±10°C, accuracy ±2%.

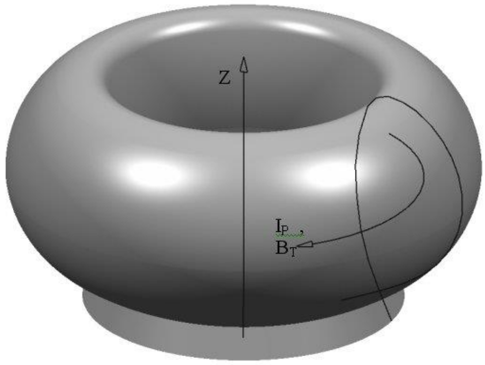
4.3.2.2 Toroidal field and plasma current direction

[PR464-R] The reference directionality of the toroidal plasma current and field shall be as follows: both the plasma current and toroidal field shall point in the clockwise direction looking from above, giving a downward (towards divertor X-point) ion grad-B drift direction (see **Figure 4-4**). This is in the opposite (that is, negative) direction with respect to the toroidal direction as given by the ITER standard co-ordinate system [A24].

[PR466-R] The direction of the toroidal field and plasma current shall be reversible, in such a way that the field line maintains the same pitch angle orientation (that is, the directions of the toroidal field and the plasma current can only be changed together).

[PR467-R] The magnet systems shall be designed to operate for any combination of the directions of the plasma current and the toroidal field.

Figure 4-4: **Toroidal field and plasma current direction**



4.3.2.3 Toroidal field ripple

[PR472-I] The toroidal field ripple is defined as $\delta(R, Z) = (B_{max}-B_{min})/(B_{max}+B_{min})$, where B_{max} and Bmin are maximum and minimum values of the toroidal magnetic field on the circle with coordinates (R, Z).

[PR470-I] The ripple requirements are determined by loss of fast particles and by potential changes in H-mode characteristics. A maximum toroidal field ripple at the plasma separatrix of <1% is enough to avoid excessive fast particle losses in all reference scenarios defined in **Table 4-1**. The quantitative influence of toroidal field ripple on plasma performance in the H-mode remains the subject of continuing research and development, and at this time the prudent approach is to make ripple as small as reasonably achievable.

[PR469-R] Ferromagnetic inserts in the in-wall shielding near the outboard mid-plane shall be used to minimize the toroidal field ripple.

[PR2099-R] The toroidal field ripple due to the TF coils in the regular sectors of the vacuum vessel (with ferritic inserts but without Test Blanket Modules) shall be less than 0.5% at full toroidal field on the target separatrix, as defined in [A01].

[PR473-R] The toroidal field ripple in non-regular sectors (Neutral Beam sectors) shall be as small as reasonably achievable but in any case below 0.7% at full toroidal field on the target separatrix, as defined in [A01].

[PR474-I] The ripple requirement in the presence of TBMs remains the subject of continuing research and development.

4.3.2.4 Error fields requirements

[PR476-I] Error fields are non-axisymmetric magnetic fields due to design asymmetries, finite tolerances in fabrication and assembly, eddy currents, and magnetic materials and they may affect plasma performances by such effects as plasma braking and mode locking, loss of fast particles, degraded confinement of plasma, and localized heat fluxes.

[PR477-I] The goal of introducing error fields requirements is to:

- Define an accepted method to calculate error field;
- Define allowable geometric tolerance for the fabrication and installation of the main tokamak systems and metrology accuracy requirements;
- Control of other possible source of error fields (such as magnetic material masses and locations, design and location of current leads and joints);
- Define the current and voltage requirement for correction coils.

If these requirements are met, plasma performance will not be significantly impacted by error fields.

[PR479-R] The calculation and assessment of acceptability of the design shall be based on the "3-mode" locked mode threshold (LMT) criterion:

$$B_{3\text{-mode}}/B_0 = \sqrt{\left((B_{2,1} / B_0)^2 + 0.8 (B_{3,1} / B_0)^2 + 0.2 (B_{1,1} / B_0)^2 \right)} < 5.0 \times 10^{-5}$$

where $B_{1,1}$, $B_{2,1}$, and $B_{3,1}$ are the amplitudes of the normal component of the helical magnetic field on the q = 2 magnetic surface and 5.3T is the nominal value of toroidal magnetic field (B_0) at a major radius of 6.2 m. This is explained in Section 5.1.2.1. of [R02].

[PR2100-I] The misalignment of the Central Solenoid, Toroidal Field, and Poloidal Field coil current centrelines, arising during the coil manufacture, installation and assembly, is the main contributor to the error field.

[PR482-R] Installation and fabrication tolerances for the coils shall be designed taking this requirement into account.

[PR2101-I] Other sources of error are magnetic field compensation coils for the neutral beam and passive magnetic shielding located around the machine, magnetic masses in the test blanket modules, currents in reinforcement in concrete structures, tilt or rotation in Central Solenoid.

[PR2102-R] Error fields ($B_{3\text{-mode}}$) from individual sources shall be less than $5x10^{-6}$ B_0 unless formal project approval is granted.

[PR483-R] The Correction Coils shall be capable of reducing $B_{3\text{-mode}}/B_0$ to 5×10^{-5}.

4.3.3 Plasma initiation

[PR497-R] The vacuum vessel shall have a toroidal electrical resistance at operating temperature between 6 and 10 μΩ.

[PR498-R] The nominal toroidal resistance of equipment within the cryostat (excluding coil circuits) shall be greater than 4 μΩ.

[PR499-R] The combination of resistors for the switching network units (Central Solenoid modules, Poloidal Field coils PF1 and PF6) and waveforms in the AC/DC converters (11 independent circuits) shall be chosen so as to produce an almost central plasma initiation. The plasma may contact predominantly either the inboard or the outboard wall.

[PR500-I] Breakdown occurs when the toroidal electric field in the centre of the breakdown region reaches approximately 0.3 V/m.

[PR501-R] An EC H&CD power of at least 6 MW shall be delivered to the plasma for breakdown and burn-through assist (relevant for toroidal magnetic fields near to 50% and 100% of nominal field).

[PR495-I] The plasma initiation occurs in a central location and the startup gyrotron frequency is 170 GHz, the same as the Heating and Current Drive frequency.

[PR1821-I] At plasma initiation, the Poloidal Field system can reduce the axisymmetric component of stray magnetic field over an acceptable volume of the breakdown region to less than 3 mT.

[PR502-R] After breakdown, the Poloidal Field system shall support a stable plasma equilibrium with an increasing current. This corresponds to the following conditions: (i) an average radial magnetic field component within the plasma of zero, where the magnetic field is produced both by coil currents and currents induced in conducting structures; (ii) a time-varying increase in the average vertical magnetic field component consistent with the increase of the corresponding “Shafranov field” required for plasma equilibrium at a given major radius; and (iii) to a nominal value of the decay index of the vertical magnetic field of 0.5.

[PR496-R] The IC H&CD shall contribute to achieving plasma breakdown, burn-through and assisted current rise by delivering a fraction of the nominal power. These functions are assumed not to drive the IC system design.

4.3.4 Plasma control

[PR554-R] The evolution of the plasma shape, current, and profiles shall be controlled to meet experimental objectives.

[PR1808-I] The Plasma Control functions operate over a range of timescales, from quasi-stationary conditions to rapid (about 1 ms) plasma disturbances.

[PR2103-R] Electromagnetic loads shall be kept within acceptable limits even in the event of potential failures in control, as specified in the ITER Load Specification [A14].

[PR1809-R] The plasma shape, position, and divertor strike point locations shall be controlled to avoid overheating plasma facing surfaces.

[PR1810-R] Edge Localized Modes (ELMs) shall be controlled to avoid excessive heat loads on plasma facing surfaces.

[PR1812-R] Neoclassical Tearing Modes (NTMs) shall be controlled to optimize plasma performance and to minimize the frequency of disruptions.

[PR4962-R] The need to control Resistive Wall Modes (RWMs) to optimize performance in non-inductive scenarios shall be assessed to allow necessary upgrades (if needed) to be specified.

[PR652-R] The thermonuclear burn shall be controlled during all plasma operations.

4.3.4.1 Nominal 15 MA target equilibrium

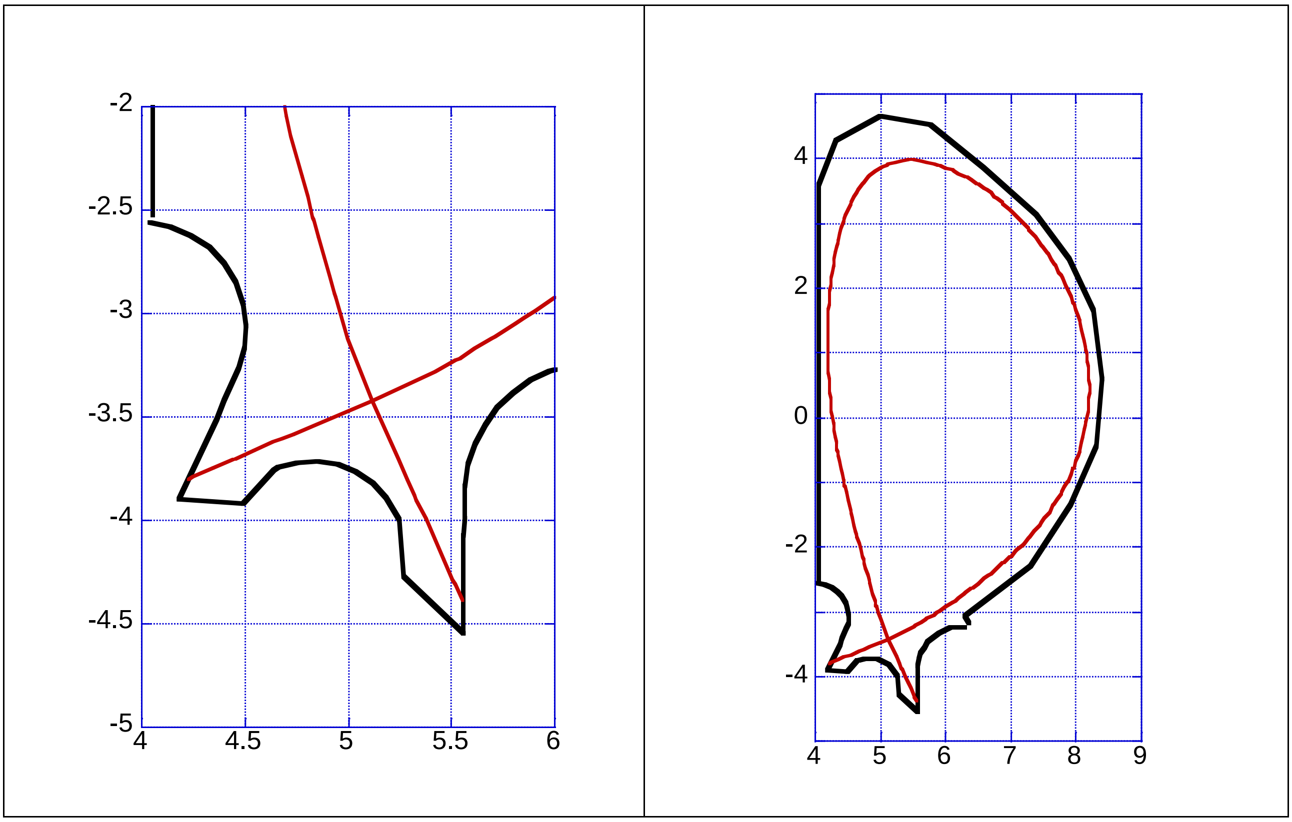
[PR557-R] ITER shall be designed based on the 15 MA target separatrix defined in [A01].

[PR558-I] This target separatrix is designed to satisfy plasma-wall separation, to limit quasi-stationary heat loads on the first wall, and to maintain the location of the divertor strike points, to assure controlled operation of the divertor plasma state as well as avoidance of excessive heat loads beyond the specified high heat flux region of the vertical divertor target.

[PR559-I] Plasma equilibria for Hybrid and Non-inductive scenarios remain the subject of ongoing research.

[PR560-I] Since the reference scenarios defined in **Table 4-1** require operation at currents of less than 15 MA, the specification of requirements for plasma equilibrium control associated with the 15 MA scenario, in particular, at high values of li (about 1.2) provides margin for plasma equilibrium control in the Hybrid and Non-inductive scenarios (see **Figure 4-5**).

Figure 4-5**: Nominal 15 MA target separatrix for analysis of Q = 10 D-T plasma scenarios and equilibrium control (TOSCA code)**



4.3.4.2 Slow timescale (quasi-static) control

[PR563-R] The plasma shape and position shall be controlled to avoid overheating shortening component lifetime through accelerated erosion and ablation of plasma facing surfaces.

[PR2111-I] Quasi-static shape control parameters are specified in **Table 4-2** for all reference scenarios and flexibility scenarios.

[PR564-R] Dynamic control of the separatrix using the Central Solenoid and Poloidal Field coil systems shall be consistent with the recovery time for restoration of the separatrix deviations from their desired quasi-static positions. The special case of plasma-wall contact imposes additional constraints and the requirements are specified in Section 4.3.4.3.

[PR1823-R] During the plasma current flat-top and in the absence of fast disturbances, the plasma current shall be controlled to less than ±2% or ±0.05MA, whichever is less restrictive.

Table 4-2**: Quasi-static shape control parameters (timescale greater than 10 s)**

Parameters	Unit	Value
Maximum downward displacement of the separatrix inner leg relative to the leg of target separatrix	mm	50
Maximum upward displacement of the separatrix inner leg relative to the leg of target separatrix	mm	150
Maximum inward displacement of the separatrix outer leg relative to the leg of target separatrix	mm	50
Maximum outward displacement of the separatrix outer leg relative to the leg of target separatrix	mm	150
Minimum clearance between the separatrix and the inner part of the first wall	mm	≈100 mm at low βp (e.g. at start of heating) ≈150 mm at high βp (e.g. at burn)
Minimum clearance between the 40 mm flux surface (note 1) and the first wall (unless otherwise specified)	mm	80
Minimum distance between the inner and outer separatrices at the outboard equatorial plane (for reliable operation in a single-null divertor configuration.)	mm	40

[PR1638-I] Note 1: The 40 mm flux surface is defined as the flux surface that passes through a point 40 mm outside the separatrix at the outboard equator.

4.3.4.3 Fast timescale control of plasma-wall gap

[PR1824-R] The plasma control system shall minimize the frequency of events causing damage to the first wall and high heat flux components, whether by localized melting, detachment of tiles, or breaching of water cooling pipes.

[PR2112-I] The precise duration of plasma-wall contact leading to such occurrences will depend on the detailed design of the first wall, but can be anticipated to be much less than 1 s. This duration will be determined precisely once the final design of the first wall is specified.

[PR2113-R] To limit this damage the capability to limit transient contact of the separatrix with the first wall surface shall be provided during quasi-static operation and following all large scale plasma disturbances: L- to H-mode transition, H- to L-mode transition, minor disruptions, locked modes, ELMs, as well as during switching-on and switching-off auxiliary heating.

[PR567-I] In cases where the plasma control system is unable to satisfy this requirement, the Disruption Mitigation System specified in Section 4.3.10.3 will be triggered to avoid excessive heat loading of the first wall.

4.3.4.4 Stabilization of plasma vertical displacements

[PR569-R] Elongated plasmas in ITER are vertically unstable and, in the absence of an active control system, drift vertically with a characteristic time determined by the decay time of currents in the vacuum vessel (about 0.1 s). The vertical position of the plasma shall be stabilized by a feedback system typically measuring vertical drift velocity and controlling the horizontal magnetic field created by poloidal field coils.

[PR570-I] A system capable of stabilizing vertical motions of ITER plasmas and restoring the plasma to its preset position will consist of both:

- Ex-vessel Poloidal Field coils (PF2, PF3, PF4, PF5) maintaining the required equilibrium radial field over longer timescales within the current limit specified by IVS1 in Section 4.3.5.3 (designated VS1);
- In-vessel coils, for fast (less than 0.1 s) response (designated VS3).

[PR575-R] The performance of the overall system controlling vertical plasma displacements (VS1+ VS3) shall satisfy:

- The system stabilizing plasma vertical displacements shall be capable of restoring the plasma to its specified vertical position after a maximum uncontrolled vertical drift with target value of 16 cm for a nominal full aperture plasma with li less than 1.2 . The frequency and number of occurrences per pulse of such large amplitude events shall be limited by scenario design to be less than or equal to 0.1 and 3 Hz, respectively. The total number of these events should be no more than 30000 over the lifetime of ITER;
- Uniformly distributed noise in the dz/dt measurement with an RMS value of 0.6 $m.s^{-1}$ and a bandwidth of 1 kHz shall be assumed for vertical stability control assessments. In cases where only VS1 is used, the noise amplitude used in performance assessments should be assumed to be 0.2 $m.s^{-1}$;
- In the absence of specific plasma equilibrium disturbances and over timescales that are long compared with the radial field penetration time for the vacuum vessel, the vertical stabilization system will maintain the plasma vertical position within limits corresponding to the amplitude and bandwidth of noise specified above.

[PR574-R] In the case that the in-vessel coils fail (VS3), the vertical stabilization system based on external coils shall be upgradeable in the following way:

- The necessary busbar connections allowing the possible use of the Central Solenoid coils CS2U and CS2L as a component of the external vertical stabilization circuit (designated VS2) shall be made available;
- The VS1 shall be capable of 9 kV operation;
- The VS2 loop shall be capable of 6 kV operation;
- The VS1 and VS2 circuits alone shall be capable of restoring the plasma to its specified vertical position and avoid separatrix contact with the first wall/divertor dome after a maximum uncontrolled vertical drift with a target value that depends on the plasma li(3) as in the formula:

$$Z_0(cm) = 160\, e^{-3.7\ell_i(3)} + 1.8$$

Where the definitions of l_i and β_p are below:

$$l_i = l_i(3) = \frac{2V\langle B_{pol}^2 \rangle}{(\mu_0 I_p)^2 R}, \qquad \beta_p = \beta_p(1) = \frac{2\mu_0 \langle p \rangle_V}{\langle B_{pol} \rangle_L^2}$$

where the notation $\langle\ \rangle_V$ implies a plasma volume average and the notation $\langle\ \rangle_L$ implies a plasma boundary average:

$$\langle A \rangle_V = \int_V A dV \Big/ \int_V dV, \quad \langle A \rangle_L = \oint A dl_{pol} \Big/ \oint dl_{pol}$$

In these definitions, B_{pol} is the total poloidal magnetic field, dl_{pol} is the poloidal element of the plasma boundary, R is the plasma major radius, V is the plasma volume, p is the plasma kinetic pressure and μ_0 is the permeability of free space.

[PR1802-R] The frequency and number of occurrences per pulse of such large amplitude events shall be limited by scenario design to be less than or equal to 0.1 and 3 Hz, respectively. The total number of these events should be no more than 30,000 over the lifetime of ITER.

4.3.5 Systems for plasma axisymmetric magnetic control

[PR581-I] Plasma axisymmetric magnetic control is provided by the "poloidal field system" that comprises the Central Solenoid, the Poloidal Field coils, the in-vessel, normal conductor, "Vertical Stabilization" (VS) coils and the coil power supplies.

[PR2114-I] Plasma axisymmetric magnetic control relies on measurements of plasma current, position and shape derived from the magnetic diagnostics and possibly other diagnostic systems.

[PR2115-I] Plasma axisymmetric magnetic control acts on currents flowing in the Central Solenoid and Poloidal Field coils to achieve plasma initiation and subsequent control of the plasma current, position and shape according to target waveforms of the controlled parameters.

[PR582-R] Fast control of the plasma vertical position shall be provided by the in-vessel VS coils, while currents flowing in several of the superconducting coils contribute to the stabilization of plasma vertical displacements.

[PR583-I] Analyses of 15 MA Q = 10 Inductive plasma operation scenario defined in Section 4.3.1.1, including the capability for control of the plasma equilibrium following specified disturbances, leads to the following requirements on the performance of the CS and PF coils and their power supplies.

4.3.5.1 Location and dimensions of Central Solenoid and Poloidal Field coils

[PR585-R] The Central Solenoid and Poloidal Field coils position (R, Z co-ordinates of the conductor cross section centre), the size of coil conductor cross sections (ΔR, ΔZ) and the number of turns (N) shall conform to the values in **Table 4-3**. These data are referenced to the tokamak operating temperature in the system of co-ordinate with Z = 0 in the Tokamak Global Coordinate System (TGCS). The TF mid-plane, at operating temperature, is estimated to be at Z=-10mm (TGCS).

Table 4-3**: Location and sizes of the Central Solenoid and Poloidal Field coils [A01]**

Coil	R, m	Z, m	ΔR, m	ΔZ, m	N
CS3U	1.687	5.464	0.740	2.093	554
CS2U	1.687	3.278	0.740	2.093	554
CS1U	1.687	1.092	0.740	2.093	554
CS1L	1.687	-1.072	0.740	2.093	554
CS2L	1.687	-3.258	0.740	2.093	554
CS3L	1.687	-5.444	0.740	2.093	554
PF1	3.943	7.574	0.959	0.984	248.6
PF2	8.284	6.540	0.580	0.715	115.2
PF3	11.992	3.275	0.696	0.954	185.9
PF4	11.992	-2.234	0.638	0.954	169.9
PF5	8.391	-6.727	0.812	0.954	216.8
PF6	4.334	-7.466	1.559	1.107	459.8

[PR587-I] Note: R, Z co-ordinates of the centre of the coil cross-sections.

[PR588-I] Size (ΔR, ΔZ) and number of turns of each coil (4K, without ground insulation).

4.3.5.2 Maximum Central Solenoid and Poloidal Field coil currents and fields

[PR590-R] When individually energized, the CS and PF coils shall be capable of operating anywhere within the range of currents and fields defined by the following points in (I,B) space - (-I_{max}, 0), (-I_{max},-(B@I_{max})), (-(I@B_{max}), -B_{max}), (0, -B_{max}), (0, B_{max}), (I@B_{max}, B_{max}), (I_{max}, B@I_{max}), and (I_{max}, 0) - where the values for I_{max}, I@B_{max}, B_{max}, and B@I_{max} are defined in **Table 4-4**.

Table 4-4**: Maximum individual Central Solenoid and Poloidal Field coil currents and fields**

Coil	Imax (kA)	B (T) @ Imax	I (kA) @ Bmax	Bmax (T)
CS3U	45	12.6	40	13.0
CS2U	45	12.6	40	13.0
CS1U	45	12.6	40	13.0
CS1L	45	12.6	40	13.0
CS2L	45	12.6	40	13.0
CS3L	45	12.6	40	13.0
PF1	48	6.4	41	6.5
PF2	55	4.8	50	5.0
PF3	55	4.8	50	5.0
PF4	55	4.8	50	5.0
PF5	52	5.7	33	6.0
PF6	48	6.4	41	6.5
PF6 (0.4 K subcooling)	52	6.8	41	7.0

4.3.5.3 Required Central Solenoid and Poloidal Field coil current combinations

[PR593-R] Magnet systems shall be capable of operating with combinations of Central Solenoid and Poloidal Field coil currents that are required to support the operating spaces defined by **Figure 4-2** and **Figure 4-3** as exemplified by scenario waveforms defined in the document [A19], with full toroidal field (5.3 T at 6.2 m) subject to the following constraints:

[PR594-I] The maximum current in the VS1 stabilizing circuit, I_{VS1}, does not exceed 22 kA where I_{VS1} is defined as $I_{VS1} = I_{PF2} + I_{PF3} - I_{PF4} - I_{PF5}$.

[PR596-R] The net vertical electromagnetic load on the Central Solenoid coils shall not exceed 60 MN.

[PR597-R] The vertical separating force figure of merit (as described next) on the Central Solenoid assembly, F_{VSF}, does not exceed 120 MN. (The resultant stresses in the CS shall be confirmed by a detailed analysis before proposed scenarios are implemented in operation.)

[PR598-I] F_{VSF} is referred to as a figure of merit because it does not represent the true vertical separating force due to EM loads where the Central Solenoid assembly is supported from the bottom. However, it was used as a constraint in assessing the accessible operating space so it is included here.

[PR599-I] It is defined by:

$$F_{VSF} = \frac{|F_z(Upward)| + |F_z(Downward)|}{2}$$

[PR601-I] Here F_z(*Upward*) is defined as maximum value among the following six values:

- F_z(CS3U),
- F_z(CS3U) + F_z(CS2U),

- F_z(CS3U) + F_z(CS2U) + F_z(CS1U),
- F_z(CS3U) + F_z(CS2U) + F_z(CS1U) + F_z(CS1L),
- F_z(CS3U) + F_z(CS2U) + F_z(CS1U) + F_z(CS1L) + F_z(CS2L),
- F_z(CS3U) + F_z(CS2U) + F_z(CS1U) + F_z(CS1L) + F_z(CS2L) + F_z(CS3L),

[PR609-I] and F_z(*Downward*) is defined as minimum value among the following six values:

- F_z(CS3L),
- F_z(CS3L) + F_z(CS2L),
- F_z(CS3L) + F_z(CS2L) + F_z(CS1L),
- F_z(CS3L) + F_z(CS2L) + F_z(CS1L) + F_z(CS1U),
- F_z(CS3L) + F_z(CS2L) + F_z(CS1L) + F_z(CS1U) + F_z(CS2U),
- F_z(CS3L) + F_z(CS2L) + F_z(CS1L) + F_z(CS1U) + F_z(CS2U) + F_z(CS3U).

[PR617-I] Note that Fz(Downward) has a negative sign.

[PR618-I] The Central Solenoid coils CS1U and CS1L have identical currents.

[PR619-I] The Central Solenoid and Poloidal Field coil currents and fields lie within the operating space defined in Section 4.3.5.2.

[PR620-I] Resultant vertical loads on the Poloidal Field coils lie within the limits specified in **Table 4-5**.

Table 4-5**: Maximum vertical loads on Poloidal Field coils**

Coil	Maximum +ve load (MN)	Maximum -ve load (MN)
PF1	110	-150
PF2	15	-75
PF3	40	-90
PF4	90	-40
PF5	160	-10
PF6	170	-190
PF3+PF4	10	-60

[PR622-I] Note: +ve is upwards vertical in global coordinate system.

4.3.5.4 Target Waveforms

[PR624-R] Representative time-dependent current traces for Inductive scenarios have been generated [A19] and shall be used for design verification purposes.

[PR625-I] Variations in AC losses associated with deviations from the nominal plasma behaviour for these representative cases may be accommodated by changes in the duration of the plasma current flat-top.

4.3.5.5 Power supply voltage requirements

[PR627-R] The Central Solenoid coils CS1U and CS1L shall be connected in series, having identical currents.

[PR629-R] All other Central Solenoid coils and Poloidal Field coils shall have independent power supplies.

[PR2134-I] The VS1 circuit includes up to 6 converters attached to Poloidal Field coils PF2, PF3, PF4, and PF5 for vertical stability control.

[PR2135-I] Voltages required for plasma initiation in the Central Solenoid coils, Poloidal Field coils PF1 and PF6 are produced by Switching Network Units and AC/DC converters connected in series.

[PR630-R] The maximum value of on-load voltage produced by the Switching Network Units shall be 8.5 kV (except for the Central Solenoid CS1U and CS1L modules, for which the maximum value of on-load voltage shall be 6 kV in each coil) and the maximum number of steps in the value of resistors of the Switching Network Units is 2.

[PR2136-I] The Poloidal Field coils PF2, PF3, PF4 and PF5 use only AC/DC converters.

[PR2137-I] The available number of AC/DC converters connected in series in each circuit is shown in **Table 4-6**.

Table 4-6**: Number of converters**

Coil	Configuration for first plasma	Configuration for PFPO-1
CS3U	1	2
CS2U	1	2
CS1U	1	2
CS1L	1	2
CS2L	1	2
CS3L	1	2
PF1	1	2
PF2	3	3
PF3	3	3
PF4	3	3
PF5	3	3
PF6	1	2
VS1 circuit	2	6

[PR2138-I] All the converters are rated for ±1.05kV.

4.3.6 Control of Edge Localized Modes (ELMs)

[PR5397-R] ITER shall provide mean(s) to control ELMs.

[PR633-I] ELMs have the potential of seriously overheating the plasma-facing surfaces of the divertor and other plasma-facing components leading to enhanced rates of Plasma-Facing Component (PFC) erosion and shortening the PFC lifetime. ITER will therefore require an adequate capability for the mitigation of ELM heat loads.

[PR634-I] Resonant Magnetic Perturbations (RMPs) have the potential to eliminate ELMs. Pellet injection has been shown to trigger low energy ELMs frequently enough to be manageable. Other techniques, such as producing regular small vertical plasma displacements, have also been shown to control ELM behaviour. research and development is continuing to investigate all of these techniques with the aim of improving the capability for the quantitative specification of requirements for such techniques to be effective in ITER.

[PR635-I] ITER will make use primarily of two ELM control techniques: application of RMP fields and pellet injection.

[PR637-I] RMPs are calculated to result in overlapping n=3 or 4 islands (Chirikov parameter greater than or equal to 1.1, and is defined as the ratio of the average island size to the island separation) in the edge layer for ELM suppression. ITER will satisfy this condition over the plasma edge region of Y (r) > g, where Y is the normalized poloidal flux and g is in the range g = 0.8-0.9. The precise value of g for each of the reference scenarios remains the subject of research and development.

[PR638-R] It shall be possible to rotate the RMP field distribution at rates up to five periods per second at full RMP amplitude (full coil current oscillations at 5 Hz, each coil current phase shifted according to the distribution of the rotating field with toroidal mode number n greater than 0).

4.3.7 Disruption handling

[PR655-I] A plasma disruption is characterized by a thermal quench phase and a current quench phase. Major disruptions (MDs) result in total loss of thermal energy and plasma current.

[PR656-I] The disruption definition in the Load Specifications [A14] cites an initial plasma current of 15 MA. Disruptions are assumed to occur at the mid-burn in reference Inductive Operation Scenario defined in Section 4.3.1.1.

[PR657-I] Four types of major disruptions are considered. Type I has a slower current quench but a higher likelihood of occurrence. Type II has a faster current quench but a lower likelihood of occurrence. Type III has same current quench as the Type II disruption but a shorter thermal quench time. Type IV has faster current quench time than Type II or III. Another Type IV major disruption is initially slow and finally fast (same quench rate as Type II or III) current quench.

[PR658-I] The runaway electron population reduces the speed of the plasma current quench. The runaway electrons could be generated for all of the major disruptions events.

[PR659-R] All superconducting coils shall be designed not to quench in case of plasma disruption.

[PR660-R] A plasma disruption shall not trigger discharge of the TF superconducting coils.

[PR5398-R] The quench detection system shall not trigger fast discharge of PF and CS coils in more than 90% of MD.

[PR661-R] The cryogenic system shall be designed to maintain the superconducting coils at operating temperature to avoid a quench in case of a major disruption.

[PR669-I] Requirements on the Disruption Mitigation System are specified in Section 4.3.10.3.

4.3.8 Vertical displacement events

[PR663-I] A Vertical Displacement Event (VDE) is characterized by a drift phase, a thermal quench phase and a current quench phase.

[PR664-I] VDEs start with the plasma drifting up or down without significant loss of plasma current and stored kinetic energy. The thermal quench may start between when the plasma first contacts the wall and when the edge safety factor (q_{edge}) drops to 1.5. For conservatism, the current quench is assumed to start when q_{edge} drops to 1.5 for the specification of mechanical load. During the current quench, the plasma is still drifting. Halo currents which flow between the plasma and plasma-facing structures may appear. No runaway electrons are anticipated for VDEs.

[PR665-R] ITER shall be designed to accommodate VDEs as specified in the Load Specifications [A14].

[PR666-R] A VDE shall not trigger discharge of the TF superconducting coils.

[PR5399-R] All superconducting coils shall be designed not to quench in case of VDE.

[PR5400-R] The quench detection system shall not trigger fast discharge of PF and CS coils in more than 90% of VDE.

4.3.9 Plasma heating and current drive

4.3.9.1 Ion Cyclotron Heating and Current Drive (IC H&CD)

[PR672-I] IC H&CD is required to provide heating and centrally-peaked current drive. The system will also be used for wall conditioning between pulses as specified in Section 4.3.14.3.

[PR673-R] The system shall be configured to provide 20 MW of IC power to the plasma.

[PR674-R] The IC power shall be coupled to the plasma through two launchers in two equatorial ports.

[PR675-R] Launchers shall be designed for two-quadrant operation; that is, the toroidal field shall be bi-directional and the plasma current shall always be in the same direction as the toroidal field.

[PR676-R] The IC system shall be capable of operating at any frequency in the range of 40-55 MHz.

[PR1807-R] The IC system shall operate in quasi-CW conditions: pulse lengths of up to 3600 s and a duty cycle of 25%.

4.3.9.2 Electron Cyclotron Heating and Current Drive (EC H&CD)

[PR678-I] EC H&CD is required to provide heating and current drive, control MHD instabilities such as Neo-classical Tearing Modes (NTMs) and the sawtooth instability, assist in plasma initiation, and provide wall conditioning between pulses (pending further study). Requirements for plasma initiation are given in Section 4.3.3. Requirements for wall conditioning between pulses are given in Section 4.3.14.3.

[PR679-R] The EC H&CD system shall provide 20MW of EC power to the plasma at a frequency of 170 GHz for periods up to 3600 s.

[PR680-R] The EC H&CD Power shall be delivered through one equatorial port launcher and four upper port launchers.

[PR681-R] The equatorial port EC H&CD launcher shall be capable of delivering 20MW to the plasma and shall have a toroidal steering with access of $0 < \rho_T \leq 0.4$.

[PR682-R] The upper port EC H&CD launchers shall be capable of delivering 6.7 MW each to the plasma.

[PR683-R] Upper steering mirrors used in EC H&CD launchers shall provide a poloidal steering with approximately a 20° (specific angle determined for optimum control of MHD activity) toroidal inclination between the beam and poloidal cross-section with access of $0.3 < \rho_T \leq 0.8$. (The exact value of the steering angles depends on the specific launching geometry.)

[PR684-R] Lower steering mirrors used in EC H&CD Upper Launchers shall provide a poloidal steering with approximately a 20° (specific angle determined for optimum control of MHD activity) toroidal inclination between the beam and poloidal cross-section with access of $0.6 < \rho_T \leq 0.86$.

[PR685-R] An in-line, automatic, and remotely-controlled switching system to share the RF power between the upper and equatorial EC H&CD launchers shall be provided.

[PR686-R] The EC H&CD system power shall be adjustable with a modulation of 5 kHz.

4.3.9.3 Neutral Beam Heating and Current Drive (NB H&CD)

[PR688-I] The NB H&CD system provides neutral beams for plasma heating and current drive, plasma rotation, fuelling, and plasma current and density profile control. The Diagnostic Neutral Beam System provides a dedicated neutral beam for He ash measurements using Charge Exchange Recombination Spectroscopy (CXRS). The Diagnostic Neutral Beam System also allows localized measurements of various plasma parameters.

4.3.9.3.1 Heating Neutral Beam (HNB)

[PR690-R] The HNB system shall deliver 33 MW to the plasma through two beamlines during D-T operation. Each beamline shall be capable of delivering 16.7 MW with a 1 MeV D0 beam with line-averaged plasma densities (n_e) greater than 0.35×10^{20} /m^3.

[PR691-R] The HNB system shall deliver 33 MW to the plasma through two beamlines during hydrogen (H) operation. Each beamline shall be capable of delivering 16.7 MW with a 0.87 MeV H0 beam with line-averaged plasma densities (n_e) greater than 0.45×10^{20} /m^3.

[PR692-R] Beamlines of the HNB system shall be aimed with a tangency radius of 5.276 m and be adjustable for aiming at any elevation between -0.154 m and -0.420 m at the tangency radius.

[PR693-R] The HNB system shall be capable of operating for pulse lengths up to 3600 s.

[PR694-R] The HNB shinethrough on the blanket first wall during operation at low density plasma shall not exceed power levels defined in the Heat and Nuclear Load Specifications [A15].

[PR695-R] The first-wall surface temperature shall be monitored and the HNB power regulated to avoid overheating the first wall due to NB shinethrough during operation at low plasma density.

[PR696-R] HNB power shall be variable for plasma heating and current drive control.

4.3.9.3.2 Diagnostic Neutral Beam (DNB)

[PR698-R] The DNB system shall deliver 1.4 MW to the plasma through a single beamline with a 100 keV H0 beam with line-averaged plasma densities (n_e) greater than 0.30 x 10^{20} /m^3.

[PR699-R] The DNB shall be aimed 6º from perpendicular to the plasma at the equatorial plane. The vertical aiming angle is 0.89° pointing downwards.

[PR700-R] The DNB shall be modulated at 5 Hz with:

- 1/6 duty factor (3 s ON, 20 s OFF) total on time 3600 s;
- Modulation depth of 100%.

4.3.10 Power handling

[PR711-I] Heat loads on the vacuum vessel and in-vessel components are specified in the Heat and Nuclear Load Specifications [A15]. These loads include power fluxes during the steady and transient phases. Transient phenomena include ELMs, MARFES, major disruptions, VDEs, L-H and H-L transitions, massive gas injection, and loss of control. Some of the specifications for more localized heat loads, such as those resulting from ripple-trapped particles, runaway electrons, NB shinethrough, or the operation of RMP coils, are undergoing refinement with more advanced calculations, taking into account the final tokamak design parameters (such as ripple map, RMP coil distribution, first wall panel shape).

4.3.10.1 Plasma heat loads

[PR714-R] In case of unmitigated transients like VDE, runaway electrons and disruptions, some local damage of the armour material is acceptable. As far as possible, taking into account the other surface heat loads, the armour thickness shall be chosen to maximize the protection of the water cooling channels during the heat deposition due to runaway electrons, so as to minimize the risk of gross damage that could cause a water leak.

4.3.10.2 Plasma-facing surface material

[PR717-R] The initial divertor (to be installed during the construction campaign II, see **Figure 3-3**) shall have tungsten for all its plasma-facing surfaces.

[PR719-R] The blanket first wall shall have beryllium on plasma-facing surface and other materials, such as steel, copper alloy, tungsten may be used in limited areas.

[PR1800-R] The first wall shall be designed to provide limiting surfaces that define the plasma boundary during startup and shutdown.

4.3.10.3 Heat load mitigation

[PR722-I] Plasma loss-of-control events can result in direct plasma contact to the wall or in a major disruption. These can lead to excessive heat flux on the plasma-facing components.

[PR723-R] To mitigate the effects from disruptions and VDEs, a Disruption Mitigation System (DMS) shall be developed to terminate the plasma.

[PR724-I] Potential candidate approaches for the mitigation exist, but additional research and development is needed before final selection, especially concerning the mitigation of runaway electrons.

[PR725-I] The DMS is for investment protection .

[PR726-R] The DMS shall mitigate the most severe effects from electromagnetic and thermal loads as well as from runaway electrons during disruptions and VDEs to minimize the need for intervention and to support routine and reliable operation of the device.

[PR732-R] ITER operation shall be recovered on a timescale of no more than three hours after a disruption.

[PR733-R] The DMS shall be distributed at several locations in the torus and shall include redundancy.

[PR734-R] In case of transients like H-L transition and plasma re-attachments, the plasma control system shall be equipped with the means to prevent physical damage to the in-vessel components and, ultimately, to trigger the disruption mitigation system.

[PR5422-I] To trigger the DMS for mitigating a forthcoming plasma disruption, ITER includes a system to predict and detect disruptions and VDEs with a reliability that ensures the required lifetime of in-vessel components.

4.3.11 Plasma fuelling and pumping

4.3.11.1 Bounding fuelling rates and tritium supply limits

[PR738-R] During the hydrogen and deuterium phases, the bounding fuelling rate (gas puffing plus pellet injection) shall not exceed 200 $Pa.m^3.s^{-1}$ average and 400 $Pa.m^3.s^{-1}$ peak (for durations up to 10 s at an average frequency of 0.01 Hz) when operating with H_2 and D_2.

[PR739-R] During the D-T phase, the T_2 supply (90% T, 10% D) shall be limited to 111 $Pa.m^3.s^{-1}$ average and 222 $Pa.m^3.s^{-1}$ peak (for durations up to 10 s at an average frequency of 0.01 Hz), which is equivalent to 100 $Pa.m^3.s^{-1}$ average and 200 $Pa.m^3.s^{-1}$ peak of pure T_2.

[PR740-R] During the D-T phase, the bounding fuelling rate (gas puffing plus pellet injection) shall not exceed 200 $Pa.m^3.s^{-1}$ average and 400 $Pa.m^3.s^{-1}$ peak (for durations up to 10 s at an average frequency of 0.01 Hz) for burn times up to 400 s when operating with H_2, D_2, and T_2 (subject to T_2 supply limits above).

[PR741-R] During the D-T phase, the bounding fuelling rate (gas puffing plus pellet injection) shall not exceed 160 $Pa.m^3.s^{-1}$average and 320 $Pa.m^3.s^{-1}$ peak (for durations up to 10 s at an average frequency of 0.01 Hz) for burn times between 400 s and 1000 s when operating with H_2, D_2, and T_2 (subject to T_2 supply limits above).

[PR742-R] During the D-T phase, the bounding fuelling rate (gas puffing plus pellet injection) shall not exceed 120 $Pa.m^3.s^{-1}$ average and 240 $Pa.m^3.s^{-1}$ peak (for durations up to 10 s at an average frequency of 0.01 Hz) for burn times between 1000 s and 3000 s when operating with H_2, D_2, and T_2 (subject to T_2 supply limits above).

[PR743-R] During the helium phase, the bounding fuelling rate (gas puffing) shall not exceed 60 $Pa.m^3.s^{-1}$ average and 120 $Pa.m^3.s^{-1}$ peak (for durations up to 10 s at an average frequency of 0.01 Hz) when operating with ^4He.

4.3.11.2 Divertor pumping

[PR745-I] The divertor neutral particle pressure during D-T plasma operations (and during hydrogenic plasma operation in general) is expected to be in range of 1 to 10 Pa when operating with a diverted plasma configuration.

[PR746-I] In He plasmas (including mixtures with H), the neutral particle pressure in the divertor is expected to be in the range 0.25 to 10 Pa when operating with a diverted plasma configuration.

[PR747-R] The divertor pumping system shall provide adequate and controllable pumping speed to maintain a specified pressure under the dome for steady conditions with a variable fuelling rate:

- For He plasma operation (including the simultaneous use of hydrogenic pellet injection):
  - for an under-dome pressure in the range 4 to 10 Pa: throughput up to 120 $Pa.m^3.s^{-1}$
  - for an under-dome pressure less than 4 Pa: throughput less than 120 $Pa.m^3.s^{-1}$ and a minimum pumping speed of 30 $m^3.s^{-1}$.
- For D-T plasma operation:
  - for an under-dome pressure in the range 3 to 10 Pa: throughput up to 200 $Pa.m^3.s^{-1}$;
  - for an under-dome pressure less than 3 Pa: throughput less than 200 $Pa.m^3.s^{-1}$ and a minimum pumping speed of 50 $m^3.s^{-1}$.

[PR755-R] The net pumping speed from the divertor shall be adjustable between 0% and 100% within 10 s.

[PR756-R] During D-T plasma operation, the torus pumping system shall be capable of sustaining flat-top pulse lengths of up to 400 s at the maximum fuel throughput of 200 $Pa.m^3.s^{-1}$.

[PR757-R] The pumping system shall exhaust low concentrations (less than 1%) of extrinsic impurities used to promote divertor radiation, together with gaseous hydrocarbons resulting from chemical sputtering of CFC PFCs. It shall also be capable of pumping, over longer periods, larger quantities of extrinsic impurities used in the course of burn termination or disruption mitigation.

[PR758-R] The pumping speed for the helium produced as a result of a plasma burn shall be close to the pumping speed for fuelling species.

4.3.11.3 Hydrogenic pellet injection

4.3.11.3.1 Common requirements for hydrogenic pellet injection

[PR642-R] The nominal pellet injection frequency shall be adjustable from 4 Hz up to 60Hz.

[PR5405-I] The frequencies specified in PR642-R can be achieved by the combination of several injectors.

[PR643-R] The nominal pellet speed at the injector shall be 300 $m.s^{-1}$ with a maximum of 500 $m.s^{-1}$.

[PR5406-I] The integrity of pellet is not required for injection velocities above 300m/s.

[PR644-R] The pellet injector shall be capable to operate with a D-T mixture containing between 0% T2 and at least 90% T2.

[PR645-R] The capability shall be provided to adjust within the full range the volume of the core fuelling pellet and of the ELM pacing pellet within 3 s during a pulse.

[PR646-R] The capability to select between the core fuelling and ELM pacing functions shall be provided for each injector within one hour between pulses.

[PR647-R] The capability shall be provided to change the pellet injection frequency by a factor of two within 0.25 s during a pulse.

[PR5407-R] The capability shall be provided for each injector to adjust the operating value of pellet throughput by ±20% of the maximum throughput of configuration in use within 0.2 s during a pulse.

[PR761-R] A throughput per injector of up to 120 $Pa.m^3.s^{-1}$ shall be provided for H_2 and D_2 pellets, and of up to 111 $Pa.m^3.s^{-1}$ for T_2 pellets (90% T, 10% D) which equals 100 $Pa.m^3.s^{-1}$ of pure T_2.

4.3.11.3.2 ELM pacing by pellet injection

[PR641-R] The capability to trigger ELMs through Low Field Side (LFS) as well as through High Field Side (HFS) D-T pellet injection (pellet pacing) shall be provided.

[PR650-R] The time averaged injection rate for ELM pacing shall have an accuracy of +/- 5%.

[PR762-I] Pellet injection requirements for ELM suppression (pellet pacing) are provided in Section 4.3.6.

4.3.11.3.3 Core fuelling by pellet injection

[PR760-R] High Field Side (HFS) pellet injection shall be provided for core fuelling.

[PR5408-R] The time averaged injection rate for core fuelling shall have an accuracy of +/- 5%.

4.3.11.4 Impurity pellet injection

[PR764-R] An injection capability of up to five pellets per plasma pulse shall be provided for Ar, Ne and N2 impurity pellets.

4.3.11.5 Gas fuel injection

[PR766-R] Gas fuelling rate shall be within bounding fuelling rates and tritium supply limits given in Section 4.3.11.1.

[PR767-R] The response time of gas fuelling injection from zero to 63% at 20 $Pa.m^3.s^{-1}$ shall be within 1 second.

4.3.11.6 Gas impurity injection

[PR769-R] The capability of injection of impurity gas species such as N_2, Ar and Ne shall be provided.

[PR770-R] The capability for impurity gas injection up to two species at an average rate of 10 $Pa.m^3.s^{-1}$ for each gas species shall be provided.

[PR771-R] The capability for impurity gas injection up to two species at a peak rate of 100 $Pa.m^3.s^{-1}$ for each gas species shall be provided.

[PR772-R] The response time of gas impurity injection from zero to 63% at 5 $Pa.m^3.s^{-1}$ shall be within one second.

4.3.11.7 Neutral Beam Fuelling

[PR774-R] The capability to fuel hydrogen gas at the rate of 49 $Pa.m^3.s^{-1}$ to each of the heating neutral beam injectors shall be provided during hydrogen plasma operation.

[PR775-R] The capability to fuel deuterium gas at the rate of 23 $Pa.m^3.s^{-1}$ to each of the heating neutral beam injectors shall be provided during deuterium and D-T plasma operation.

[PR776-R] The capability to fuel hydrogen gas at the rate of 9 $Pa.m^3.s^{-1}$ to the neutralizer of the diagnostic neutral beam injector shall be provided during hydrogen plasma operation.

[PR777-R] The capability to fuel deuterium gas at the rate of 6 $Pa.m^3.s^{-1}$ to the neutralizer of the diagnostic neutral beam injector shall be provided during deuterium and D-T plasma operation.

[PR778-R] The capability to fuel hydrogen gas at the rate of 8 $Pa.m^3.s^{-1}$ to the high voltage deck of the diagnostic neutral beam injector shall be provided during hydrogen, deuterium and D-T plasma operation.

4.3.12 Plasma diagnostics

[PR780-I] The ITER plasma diagnostics systems are required to provide accurate measurements of plasma behaviour and performance.

[PR781-I] Measurements for ITER plasma diagnostics have four possible roles:

- Machine protection (1.a1);
- Basic machine control(1.a2);
- Advanced plasma control (1.b);
- Evaluation and physics studies (2).

[PR782-R] ITER shall not operate without a working diagnostic providing every measurement for machine protection (1.a1 role) and basic control (1.a2 role).

[PR783-R] ITER shall not operate advanced operation without a working diagnostic providing every measurement for advanced plasma control (1.b role).

[PR784-I] ITER may operate even when a measurement for evaluation and physics studies (2. role) is not provided.

[PR785-R;Defined Requirement] Measurements and diagnostics involved in safety relevant functions concern the plasma current, neutron fluence, fusion power, tritium, and dust. Dust assessment shall be performed as a Protection Important Activity.

[PR786-R] The measurements listed in **Table 4-7** shall be provided.

[PR2359-R] According to their technologies, ITER plasma diagnostics systems may have different contributions to different measurements. The following contributions shall be considered:

- Primary: diagnostic is well suited to the measurement;
- Back-up: diagnostic provides similar data to primary, but has some limitations;
- Supplementary: diagnostic validates or calibrates the measurement but is not complete in itself.

Table 4-7**: Required measurements classified by role**

Measurement	Parameter	Role	Range to cover
1. Plasma Current	I_p	Machine protection 1a.1	0 — 25 MA
2. Plasma Position and Shape	Main plasma gaps, D_{sep}	Basic machine control 1a.2	-
	Divertor channel location (r dir.)	Basic machine control 1a.2	-
	dZ/dt of current centroid	Machine protection 1a.1	0 — 5 m/s
3. Loop Voltage	V_{loop}	Machine protection 1a.1	0 — 500 V
4. Plasma Energy	$Beta_p$	Machine protection 1a.1	0.01 — 5
5. Radiated Power	Main Plasma P_{rad}	Basic machine control 1a.2	0.1 MW — 1 GW
	X-point / MARFE region P_{rad}	1b	30 kW — 0.3 GW
	Divertor P_{rad}	Basic machine control 1a.2	30 kW — 0.3 GW
	Total P_{rad}	Machine protection 1a.1	30 MW — 300 GW
6. Line-Averaged Electron Density	$\int n_e\, dl / \int dl$	Basic machine control 1a.2	10^{18} — $2x10^{22}$ m^{-3}
7. Neutron Flux and Emissivity	Total neutron flux	Machine protection 1a.1	10^{14} — $7.5x10^{20}$ $n.s^{-1}$
	Neutron / a source	Advanced plasma control 1b	10^{14} — $6x10^{18}$ $n.m^{-1}.s^{-1}$
	Fusion power	Basic machine control 1a.2	100 kW — 1.5 GW
	Fusion power density	Basic machine control 1a.2	1 $kW.m^{-3}$ — 1.5 $MW.m^{-3}$
8. Error Field, Locked Mode and RWM	Br/<Bp>	Machine protection 1a.1	10^{-4} — 10^{-2}
9. Low (m,n) MHD Modes, Sawteeth, Disruption Precursors	Btheta(complex, at wall)/<Bp>	Machine protection 1a.1	10^{-4} — 10^{-2}
10. Plasma Rotation	VTOR	Advanced plasma control 1b	1 — 200 $km.s^{-1}$
	VPOL	Advanced plasma control 1b	1 — 50 $km.s^{-1}$
	Tritium concentration	Machine protection 1a.1	10^{20} — $2x10^{24}$ m^{-2}
11. Fuel Ratio in Plasma Core	nT/nD	Basic machine control 1a.2	0.01 — 10
12. Impurity Species Monitoring	Be, C, O rel. conc.	Basic machine control 1a.2	10^{-4} — $5x10^{-2}$
	Be, C, O influx	Machine protection 1a.1	10^{16} — $5x10^{19}$ $m^{-2}.s^{-1}$
	Cu rel. Conc.	Basic machine control 1a.2	10^{-5} — $5x10^{-3}$
	Cu influx	Machine protection 1a.1	10^{15} — $5x10^{18}$ $m^{-2}.s^{-1}$
	W rel. conc.	Basic machine control 1a.2	10^{-6} — $5x10^{-4}$
	W influx	Machine protection 1a.1	10^{14} — $5x10^{17}$ $m^{-2}.s^{-1}$
	Extrinsic(Ne,Ar, Kr) rel. Conc.	Basic machine control 1a.2	10^{-4} — $2x10^{-2}$
	Extrinsic (Ne, Ar, Kr) influx	Basic machine control 1a.2	10^{16} — $2x10^{19}$ $m^{-2}.s^{-1}$
13. Zeff(Line-averaged)	Zeff	Basic machine control 1a.2	1 — 5
14. H-mode: ELMs and2 L-H Transition Indicator	ELM Da bursts	Machine protection 1a.1	-
	ELM density transient	physics studies 2	$5x10^{18}$ — $3x10^{20}$ m^{-3}
	ELM temperature transient	physics studies 2	0.05 — 10 keV

Measurement	Parameter	Role	Range to cover
	L-H Da step	Basic machine control 1a.2	-
15. Runaway Electrons	Emax	physics studies 2	1 — 100 MeV
	Irunaway	physics studies 2	1 — 15 MA
16. Divertor Operational Parameters	Max. surface temperature	Machine protection 1a.1	200 — 3600 °C
	Erosion rate		0.1 – 1 $mm.s^{-1}$
	Net erosion		0 — 3 mm
	Gas pressure (Pdiv)	Basic machine control 1a.2	10^{-4} — 20 Pa
	Gas composition Fuel, He, impurities	Basic machine control 1a.2	10^{-1} — 1 x Pdiv
	Position of the ionisation front	Basic machine control 1a.2	0 — 1 m
17. First Wall (FW) Visible Image & Wall Temperature	FW Surface luminance –	Machine protection 1a.1	40 — 10^{5} $cd.m^{-2}$
	FW Surface temperature	Basic machine control 1a.2	200 — 3600 °C
	FW surface temperature during ELMs	physics studies 2	400 — 3600 °C
18. Gas Pressure and Composition in Main Chamber	Gas pressure (Pmain)	Basic machine control 1a.2	10^{-4} — 1 Pa
	Gas composition Fuel, He, impurities	Basic machine control 1a.2	10^{-4} — 1 x Pmain
19. Gas Pressure and Gas Composition in Ducts	Gas pressure (Pduct)	Basic machine control 1a.2	10^{-4} — 20 Pa
	Gas composition Fuel, He, impurities	Basic machine control 1a.2	10^{-4} — 1 x Pduct
20. In-Vessel Inspection	Wall image	3	100 % coverage of FW and divertor
21. Halo Currents	Poloidal current	Machine protection 1a.1	0 — 3.4 MA (maximum of 17 MA operation)
22. Toroidal Magnetic Field	BT	Basic machine control 1a.2	-5.5 — 5.5 T
23. Electron Temperature Profile	Core Te	Advanced plasma control 1b	0.5 — 40 keV
	Edge Te	physics studies 2	0.05 — 10 keV
24. Electron Density Profile	Core Ne	Advanced plasma control 1b	$3x10^{19}$ — $3x10^{20}$ m^{-3}
	Edge Ne	Advanced plasma control 1b	$5x10^{18}$ — $3x10^{20}$ m^{-3}
25. Current Profile	q(r)	physics studies 2	0.5 — 9
	r(q=1.5,2)/a	Advanced plasma control 1b	0.3 — 0.9
	r(qmin)/a	Advanced plasma control 1b	0.3 — 0.7
26. Zeff Profile	Zeff	physics studies 2	1 — 5
27. High Frequency Instabilities (MHD, NTMs, Aes, turbulence	Fishbone Btheta(mode) / <Bp >	physics studies 2	10^{-4} — 10^{-2}
	TAE Btheta(complex) / < Bp>	physics studies 2	10^{-4} — 10^{-2}
	TAE δN / n, δT/T	physics studies 2	$5x10^{-6}$ — $5x10^{-4}$
	NTM δT / Te (complex. 100ms integration time	Advanced plasma control 1b	$0.1x10^{-2}$ — $5x10^{-2}$
28. Ion Temperature Profile	Core Ti	Advanced plasma control 1b	0.5 — 40 keV
	Edge Ti	physics studies 2	0.05 — 10 keV
29. Core He Density	nHe/ne	Advanced plasma control 1b	1 — 20%
	Profile of 3He concentration	Advanced plasma control 1b	1 — 10%
30. Confined Alphas and Fast Ions	Alpha Energy spectrum	physics studies 2	0.1 — 3.5 MeV
	Alpha Density Profile	physics studies 2	10^{17} — $2x10^{18}$ m^{-3}

Measurement	Parameter	Role	Range to cover
	p,D,T,He3	physics studies 2	0.1 — 1 MeV
31. Escaping Alphas and Fast Ions	First wall flux. Alphas	physics studies 2	0.01 — 20 $MW.m^{-2}$
	First wall flux. Non- Alphas	Advanced plasma control 1b	0.001 — 2 MWm^{-2}
32. Impurity Density Profile	Fractional content, Z<=10	Advanced plasma control 1b	0.5 — 20 %
	Fractional content, Z>10	Advanced plasma control 1b	0.01 — 0.3 %
33. Fuel Ratio in the Edge	nT/nD	physics studies 2	0.01 — 10
	nH/nD	physics studies 2	0.01 — 0.1
34. Neutron Fluence	First wall fluence	Basic machine control 1a.2	0.1 — 1 $MW.m^{-2}.y$
35. Impurity and D,T Influx in Divertor	GBe, GC, GW	Machine protection 1a.1	10^{17} — 10^{22} $atom.s^{-1}$
	GD, GT	Basic machine control 1a.2	10^{19} — 10^{25} $atom.s^{-1}$
36. Plasma Parameters at the Divertor Targets	ne	Advanced plasma control 1b	10^{18} — 10^{22} m^{-3}
	Te	Advanced plasma control 1b	1 — 150 eV
37. Radiation Profile	Main plasma Prad	physics studies 2	100 $W.m^{-3}$ — 1 $MW.m^{-3}$
	X-point/MARFE region Prad	Advanced plasma control 1b	30 $kW.m^{-3}$ — 300 $MW.m^{-3}$
	Divertor Prad	Advanced plasma control 1b	10 $kW.m^{-3}$ — 100 $MW.m^{-3}$
38. Heat Loading Profile in Divertor	Surface temperature	Advanced plasma control 1b	200 — 3600 °C
	Power load	Advanced plasma control 1b	0.1 $MW.m^{-2}$— 5 $GW.m^{-2}$
39. Divertor Helium Density	nHe	Basic machine control 1a.2	10^{17} — 10^{21} m^{-3}
40. Fuel Ratio in the Divertor	nT/nD	physics studies 2	0.01 — 10
	nH/nD	physics studies 2	0.01 — 0.1
41. Divertor Electron Parameters	ne	physics studies 2	10^{19} — 10^{22} m^{-3}
	Te	physics studies 2	0.3 — 200 eV
42. Ion Temperature in Divertor	Ti	physics studies 2	0.3 — 200 eV
43. Divertor Plasma Flow	Vp	physics studies 2	10^{3} — 10^{5} $m.s^{-1}$
44. nH/nD Ratio in Plasma Core	nH/nD	physics studies 2	0.01 — 0.1
45. Neutral Density between Plasma and First Wall	D/T influx in main chamber	Basic machine control 1a.2	10^{18} — 10^{20} $atom.m^{-2}.s^{-1}$
46. Dust Monitoring	Dust accumulation rate	Basic machine control 1a.2	10^{-4} - 10^{-2} $kg.m^{-2}$/pulse
	Dust concentration	Machine protection 1a.1	10^{-2} — 10 $kg.m^{-2}$
47. Tritium Monitoring	H, D, T accumulation rate	Basic machine control 1a.2	2x10^{19} — 2x10^{21} m^{-2} / pulse
	Tritium concentration	Machine protection 1a.1	10^{20} — 2x10^{24} m^{-2}

4.3.13 Fusion power shutdown system

[PR791-R;Defined Requirement] A fusion power shutdown system shall be provided with the capability to inject impurity gases to abruptly terminate a pulse.

4.3.14 Post-discharge operations

4.3.14.1 Data archiving

[PR2175-R] All configuration data and a history of operational data shall be stored, and shall be available in the Main Control Room (see Section 6.10) as needed for the operation of the ITER plant.

[PR794-R] All scientific and replica of operational data shall be kept in archives outside the nuclear island of ITER in a standard data storage facility.

[PR795-R] A remote backup of all ITER configuration-, scientific- and operations- data shall be provided at a location that is at a distance of at least 50 km from the primary storage location.

[PR1769-R] Some computational resources shall be provided to all ITER Members to enable efficient pre-processing of the data and reduce the need of data transfer to all Members.

4.3.14.2 Vacuum base pressure

[PR797-R] A base pressure of less than 5 x 10^{-4} Pa (for hydrogenic species) shall be achieved by the end of the dwell periods between pulses when operated at maximum duty cycle.

[PR798-R] A base impurity pressure of less than 10^{-7} Pa (the sum of partial pressures of impurity gases) shall be achieved by the end of the dwell periods between pulses when operated at maximum duty cycle.

4.3.14.3 RF wall conditioning

[PR800-I] The purpose of RF wall conditioning is to limit the release of hydrogen isotopes and non-hydrogenic gas impurities during plasma operation and to limit tritium inventory in plasma facing components.

[PR803-R] The capability to use the existing IC heating and current drive system for wall conditioning between pulses with up to 20% of nominal power shall be provided.

[PR804-R] Diagnostics for IC antenna protection shall be provided for IC wall conditioning.

[PR806-I] There are indications that the EC H&CD system can be used for wall conditioning, typical duty cycles being about 1 second ON / about 10 seconds OFF mode.

[PR807-R] The capability to use the existing EC heating and current drive system for wall conditioning between pulses shall be assessed.

[PR808-R] A poloidal magnetic field of about 0.1 T (possibly rotating in about 5 seconds) shall be provided for EC wall conditioning to improve uniformity.

4.4 Upgrade requirements

4.4.1 Divertor upgrades

[PR812-R] The divertor design shall accommodate replacement of the divertor cassettes during operations.

4.4.2 Resistive wall mode control upgrades

[PR815-I] Resistive wall modes (RWM) may become unstable in cases of very high β_N (about 3.0) at low rotation speeds.

[PR817-R] ITER design shall be upgradeable to provide a system that is capable of stabilizing RWMs.

[PR5351-I] This upgrade may be implemented if regular RWM instabilities interfere with ITER operations. This stabilization may be achieved with a feedback system that is capable of monitoring the poloidal field amplitude of the resonant RWM with n=1, and of producing helical magnetic field of the same structure and appropriate phase shift with the ELM control coils.

[PR818-I] The characteristic frequency response that is required for RWM feedback stabilization is about 10 Hz, and the amplitude of the helical field produced by the stabilizing coils depends on the amplitude of low frequency plasma noise on the magnetic sensors used. It will be measured before the upgrade is implemented.

4.4.3 Heating and current drive upgrades

[PR5426-R] The heating and current drive systems shall be upgradable to provide the maximum power of 130 MW, as specified in **Table 4-9.**

[PR821-I] The initial configuration for DT operations already supports the upgrade of IC and EC H&CD systems to 40 MW each (no change to the port allocations, as specified in **Table 5-1**, will be required to implement these upgrades).

[PR822-R] The design of ITER shall not preclude the possibility of accommodating the combinations of heating and current drive upgrades up to the maximum power specified in **Table 4-9.**

Table 4-9: **Heating and current drive power upgrade**

	INITIAL CONFIGURATION FOR DT OPERATIONS		MAXIMUM POWER UPGRADE	
	POWER (MW)	EQUATORIAL PORTS	POWER (MW)	EQUATORIAL PORTS
NB	33	2	50	3
IC	20	2	40	2
EC	20	1	40	1
TOTAL	73	5	130	6

[PR1783-I] One IC antenna will allow to couple 10 MW in a broad range of plasma scenarios, with provision for the large uncertainties existing in the plasma edge density profiles. The capability of the ICRF system to deliver 20 or 40 MW through two antennas will depend on the plasma-loading range effectively achieved, to be assessed after acquisition of sufficient experimental information.

[PR825-R] The IC H&CD system shall be upgradable (with additional investment) to 40 MW of ICRF power to the plasma through two launchers in two equatorial ports.

[PR827-R] The EC H&CD system shall be upgradable (with additional investment) to 40 MW of ECRF power to the plasma through the existing launchers available at the initial configuration for DT operations (one equatorial and four upper port launchers).

[PR832-R] The NB H&CD system (HNB) shall be upgradable (with additional investment) to deliver 50 MW through three ports.

[PR2094-R] The power upgrades for the EC and IC H&CD systems shall be located in one of the following areas: the Assembly Building, the RF Heating Building and the Cleaning Facility Building.

4.4.4 Auxiliary system upgrades for hybrid and non-inductive scenarios

[PR834-R] ITER auxiliary (non-tokamak) systems shall be upgradable (with additional investment) to meet the requirements of the Hybrid and Non-inductive scenarios that are defined in Section 4.3.1. Parameters for the Hybrid and Non-inductive scenarios are shown in **Table 4-1**.

4.4.5 Tritium breeding blanket modules

[PR839-I] The capability to install tritium breeding blankets on the outboard side of the Vacuum Vessel, as a future upgrade, should not be precluded.

4.4.6 High duty cycle

[PR842-R] The ITER tokamak and facility shall be capable of being upgraded to accommodate operation with a time-averaged fusion power of 133 MW for each of the design scenarios that are specified in Section 4.3.1.2.

4.4.7 Fuelling upgrades

[PR845-R] The pellet injection system shall be upgradable (with additional investment) to a six-injector configuration.

4.5 Deactivation

[PR847-R;Defined Requirement] ITER Organization shall provide the site Host Member with all records, "as-built prints", information and equipment pertinent to dismantling after deactivation.

[PR848-R;Defined Requirement] ITER Organization shall develop a plan to put the plant in a safe, stable condition while it awaits dismantling.

[PR849-R;Defined Requirement] Residual tritium that is present at the end of ITER operations shall be recovered to secure storage and/or shipping containers.

[PR850-R;Defined Requirement] Residual mobile activation products and hazardous materials that are present at the end of ITER operations shall be recovered to secure storage and/or shipping containers so that they can be shipped to a repository as soon as practical.

[PR851-R;Defined Requirement] ITER deactivation shall include the removal of in-vessel components and their packaging for long-term storage.

[PR2096-R;Defined Requirement] Removal of in-vessel components from the vacuum vessel, during ITER de-activation, shall be performed by remote handling tools and personnel who have been trained for maintenance during the previous ITER normal operation.

[PR852-R;Defined Requirement] Liquids that are used in ITER systems may contain activation products, which shall be removed before the liquids can be released into the environment or solidified as waste. All liquids shall be rendered to a safe, stable form during the deactivation phase, further cooling shall be unnecessary.

[PR853-R;Defined Requirement] During the deactivation and decommissioning phase, the components of ITER shall be protected against corrosion, to prevent spreading of contamination or unacceptable hazards to the public or workers.

5 LAYOUT REQUIREMENTS

[PR4963-I] This chapter identifies the overall layout requirements that ITER must achieve in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

5.1 Configuration Management Model

[PR857-R] The CMM shall be used to assure consistency between all components and with the buildings of the Tokamak Complex:

- Collision analysis;
- Interface constraint definition and checking between systems;
- Space allocations for systems to be designed considering supports and penetrations;
- Tolerance studies;
- Assembly and RH maintenance simulations.

[PR864-I] For information, equipment of other buildings that are outside the scope of the CMM is managed according to the Design Integration and Configuration Control responsibilities for buildings and areas on the ITER site [R06].

[PR865-R] The minimum gap between in-cryostat different PBS components shall be 50 mm, unless other value is specified in the relevant SRDs or Interface Sheets.

[PR866-R] ITER system elements within the Tokamak Complex (Tokamak Building, Diagnostics Building, and Tritium Plant Building) shall conform to the space envelope constraints and interface characteristics specified in the CAD assemblies, parts, and drawings in the CMM.

5.2 Site Master Plan

[PR868-R] The layout of buildings on the ITER site shall comply with the ITER Site Master Plan [A13].

5.3 Port allocations

[PR870-R] The port numbering scheme shall comply with the ITER Coordinate Systems [A04] document.

5.3.1 Equatorial port allocations

[PR874-R] The allocation of equatorial ports in DT plasma shall be in accordance with the column labeled “Initial configuration” in **Table 5-1**.

[PR875-R] ITER shall be capable of accommodating the heating and current drive upgrade specified in Section 4.4.3 with the equatorial port allocations specified in **Table 5-1.**

Table 5-1**: Equatorial port allocations**

Port	Initial configuration for DT operations	Maximum power upgrade
1	Diagnostics	Diagnostics
2	Diagnostics / DMS	Diagnostics / DMS
3 (RH port)[2]	Diagnostics / GDC Electrode	Diagnostics / GDC Electrode
4 (small rad.)	DNB	DNB
4 (tangential)	HNB	HNB
5 (tangential)	HNB	HNB
6 (tangential)	Torus Leak Detection	HNB (incl. Torus Leak Detection)
7	Closed	Closed
8 (RH port)[2]	Diagnostics / GDC Electrode/ DMS	Diagnostics / GDC Electrode/ DMS
9	Diagnostics	Diagnostics
10	Diagnostics	Diagnostics
11	Diagnostics[3]	Diagnostics
12 (RH port)[2]	Diagnostics / GDC Electrode	Diagnostics / GDC Electrode
13	IC	IC
14	EC	EC
15	IC	IC
16	Test Blanket	Test Blanket
17 (RH port)[2]	Diagnostics / GDC Electrode / DMS	Diagnostics / GDC Electrode / DMS
18	Test Blanket	Test Blanket

[PR1665-R] Note 1: Any components belonging to systems in remote handling port plugs (3, 8, 12 and 17) shall be removable to allow access for remote handling operation.

5.3.2 Upper port allocations

[PR878-R] The allocation of upper ports in DT plasma shall be in accordance with **Table 5-2**.

Table 5-2**: Upper port allocations**

Port	Port plug	In Port	
1	Diagnostics	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold Blanket Instrumentation
2	Diagnostics / DMS	In-Vessel Diagnostics Upper ELM coil feeder	Blanket water manifold
3	Diagnostics / GDC	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold Gas Injection (including FPSS)
4[1]	Diagnostics / Roughing filters	In-Vessel Diagnostics Upper ELM coil feeder	Blanket water manifold
5[1]	Diagnostics / Roughing filters	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold
6[1]	Diagnostics / Roughing filters	In-Vessel Diagnostics Upper ELM coil feeder	Blanket water manifold Blanket Instrumentation
7[1]	Diagnostics / Roughing filters	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold Blanket Instrumentation
8	Diagnostics / DMS / GDC	In-Vessel Diagnostics Upper ELM coil feeder	Blanket water manifold Gas Injection
9	Diagnostics	In-Vessel Diagnostics	Blanket water manifold Mid and Lower ELM coil feeders
10	Diagnostics	In-Vessel Diagnostics Upper ELM coil feeder	Blanket water manifold Gas Injection (including FPSS)
11	Diagnostics	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold
12	EC	In-Vessel Diagnostics Upper ELM coil feeder Upper VS coil feeder	Blanket water manifold Blanket Instrumentation
13	EC	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold Blanket Instrumentation
14	Diagnostics / GDC / DMS	In-Vessel Diagnostics Upper ELM coil feeder Upper VS coil feeder	Blanket water manifold Gas injection
15	EC	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold
16	EC	In-Vessel Diagnostics Upper ELM coil feeder Upper VS coil feeder	Blanket water manifold
17	Diagnostics	In-Vessel Diagnostics Mid and Lower ELM coil feeders	Blanket water manifold
18	Diagnostics	In-Vessel Diagnostics Upper ELM coil feeder Upper VS coil feeder	Blanket water manifold Blanket Instrumentation

[PR1669-I] Note 1: No port cell. Access is through the NB cell, with higher radiation levels (Zone C) and less hands-on access.

5.3.3 Lower port allocations

[PR882-R] The allocation of lower ports in DT plasma shall be in accordance with **Table 5-3**.

[PR2177-R] No removable lower port plugs shall be provided at the odd numbered port positions.

[PR883-R] Some fixed penetrations (for in-vessel viewing, ELM-VS coil feeders, and divertor cooling manifolds) shall be accommodated as shown in **Table 5-3**.

[PR884-R] Divertor diagnostics, and diagnostics electrical services, shall be accommodated at even numbered port positions.

[PR885-R] There shall be no Vacuum Vessel penetrations crossing the field joints between sectors.

Table 5-3**: Lower port allocations**

Port	Type	Content
1	Cryostat access flange	Large cryostat access flange
2	Divertor Remote Handling port	Vacuum Vessel In-Service Inspection Divertor Rails Divertor remote Handling System Diagnostics Rack
3	In-vessel viewing port	IVVS
4	Divertor pumping port	Blanket water manifold Fuelling Pellet Injection System Gas Injection Torus cryopump
5	In-vessel viewing port	IVVS Cryostat access flange
6	Divertor pumping port	Vacuum Vessel In-Service Inspection Blanket water manifold Blanket Instrumentation Gas Injection Torus Cryopump Dust Filtering System
7	Cryostat pumping flange	Cryostat Cryopump
8	Divertor Remote Handling port	Vacuum Vessel In-Service Inspection Divertor Rails Divertor remote Handling System Diagnostics Rack
9	In-vessel viewing port	IVVS Cryostat access flange
10	Divertor pumping port	Blanket water manifold Fuelling Pellet Injection System Gas Injection Torus cryopump
11	In-vessel viewing port	IVVS
12	Divertor pumping port	VS Coil Feeders Vacuum Vessel In-Service Inspection Blanket Instrumentation Gas Injection Torus Cryopump Dust Filtering System
13	Cryostat pumping flange	Cryostat Cryopump
14	Divertor Remote Handling port	Vacuum Vessel In-Service Inspection Divertor Rails Divertor remote Handling System Diagnostics Rack
15	In-vessel viewing port	IVVS Cryostat access flange
16	Divertor pumping port	Blanket water manifold Fuelling Pellet Injection System Gas Injection Torus cryopump
17	In-vessel viewing port	IVVS
18	Divertor pumping port	VS Coil Feeders Vacuum Vessel In-Service Inspection Blanket Instrumentation Gas Injection Torus Cryopump

[PR1676-I] Divertor cooling manifolds are located in every lower port.

[PR1678-R] Diagnostics systems shall not affect the pumping conductance.

5.4 Location of diagnostics

[PR889-R] Diagnostics mounted in ports shall be located in accordance with **Table 5-4** whereas the location of the diagnostics plugs is defined in **Table 5-1**.

[PR890-R] Diagnostics located in the vacuum vessel shall be located in accordance with **Table 5-5**.

Table 5-4**: Distribution of diagnostics mounted in the ports**

	Diagnostics mounted in port *(greyed cells not used by diagnostics as per Tables 5-1 to 5-3)*		
Port No	**Equatorial ports**	**Upper ports**	**Lower ports (and in divertor cassettes)**
1	E4: Impurity Influx Monitor (Div. Vis/UV) EB: MSE Based On Heating Beam G3: Pressure Gauges B1: Radial Neutron Camera B7: Radial Gamma Ray Spectrometers BB: High Resolution Neutron Spectrometer D1: Bolometers B4.C0: NFM DD Eq#01	D1: Bolometers E4: Impurity Influx Monitor (Div. Vis/UV) F3: Plasma position reflectometry	
2	E5: Core Imaging X-Ray Spectrometer (CIXS)	GA: IR Cameras: Vis/IR TV (Upper) GL: In Vessel Lighting	BC: Divertor Neutron Flux Monitors G2: Thermocouples AL: Divertor Equilibrium Coils AM: Divertor Shunts AN: Rogowski (Divertor) AO: Toroidal Coils (Divertor) G7: Langmuir Probes E4: Impurity Influx Monitor (Div. Vis/UV)
3	EB: MSE Based On Heating Beam EC: CXRS Based On DNB (Edge) C5: Toroidal Interferometer/Polarimeter-[Reflector] FA: Line Averaged Density Diagnostic - [Reflector] G1: IR Cameras, Vis/IR TV (Midplane) GL: In Vessel Lighting	B3: Microfission Chambers E1: CXRS Based On DNB (Core)	
4			AL: Divertor Equilibrium Coils AM: Divertor Shunts AN: Rogowski (Divertor) AO: Toroidal Coils (Divertor) B9: Lost Alpha Monitor (LAM #B0) G3: Pressure Gauges G4: Residual Gas Analyzers-[Pass through space reservation only]
5			
6			D1: Bolometers G3: Pressure Gauges G4: Residual Gas Analyzers-[Pass-through space reservation only]] G9: Dust Monitor [Optical]
7	B4.D0: NFM DD Eq#07		
8	B4.A0:NFM DT Eq#08 B9: Lost Alpha Monitor BE: Tangential Neutron Spectrometer F9: HFS Refractometer (Main Plasma, HFS) FA: Density Interferometer Polarimeter - [Perpendicular LOS] E6: Visible Spectroscopy Reference System FA: Density Interferometer Polarimeter - [Tangential LOS] GE: Boundary Flow Monitor	F9: Reflectometer (Main Plasma, HFS) GA: IR Cameras: Vis/IR TV (Upper) GL: In Vessel Lighting B4.D0: NFM DD Eq#07	BC: Divertor Neutron Flux Monitors AL: Divertor Equilibrium Coils AM: Divertor Shunts AN: Rogowski (Divertor) AO: Toroidal Coils (Divertor) G3: Pressure Gauges G7: Langmuir Probes C4: Thomson Scattering (Divertor, Outer) EA: Laser-Induced Fluorescence G8: Erosion monitor
9	G1: IR Cameras, Vis/IR TV (Midplane) GL: In Vessel Lighting F1. ECE C5: Toroidal Interferometer/Polarimeter	EI:X-Ray Crystal Spectroscopy Edge Imaging F9: Reflectometer (Main Plasma, HFS)	
10	C2: Thomson Scattering - Edge	C6:Polarimeter Poloidal	D1: Bolometers

	Diagnostics mounted in port *(greyed cells not used by diagnostics as per Tables 5-1 to 5-3)*		
Port No	**Equatorial ports**	**Upper ports**	**Lower ports (and in divertor cassettes)**
	C6:Polarimeter Poloidal C1: Core Plasma Thomson Scattering F3: Plasma position reflectometry G3: Pressure Gauges		C6:Poloidal Polarimeter Reflector - [Reflector] AL: Divertor Equilibrium Coils AM: Divertor Shunts AN: Rogowski (Divertor) AO: Toroidal Coils (Divertor) G2: Thermocouples G3: Pressure Gauges
11	F2: Reflectometer (Main Plasma, LFS) G4: Residual Gas Analyzers E2: H-Alpha (+ visible spectroscopy) E8: Neutral Particle Analyser incl. Gamma and Neutron Spectrometer B8: Activation System E3: VUV Survey ED: X-Ray Crystal Spec Survey EG: Divertor VUV Spectroscopy	B3: Microfission Chambers B8: Activation System-[Activation System Head] GA: IR Cameras: Vis/IR TV (Upper) GL: In Vessel Lighting	
12	E2: H-Alpha (+ visible spectroscopy) G1: IR Cameras, Vis/IR TV (Midplane) GL: In Vessel Lighting E7: Radial X-ray Camera EE: Hard X-ray Monitor (H-phase) C7: Collective Thomson Scattering		B8: Activation System D1: Bolometers G3: Pressure Gauges G4: Residual Gas Analyzers G9: Dust Monitor – [Optical]
13			
14		F3: Plasma position reflectometry GA: IR Cameras: Vis/IR TV (Upper) GL: In Vessel Lighting	BC: Divertor Neutron Flux Monitors G7: Langmuir Probes AL: Divertor Equilibrium Coils AM: Divertor Shunts AN: Rogowskis (Divertor) AO: Toroidal Coils (Divertor) B9: Lost Alpha Monitor (LAM #B0) B2: Vertical Neutron Camera
15			
16			D1: Bolometers AL: Divertor Equilibrium Coils AM: Divertor Shunts AN: Rogowskis (Divertor) AO: Toroidal Coils (Divertor) G2: Thermocouple G3: Pressure Gauges
17	G1: IR Cameras, Vis/IR TV (Midplane) GL: In Vessel Lighting G6: IR Thermography (divertor) GC : Tritium Monitor B4.B0: NFM DT Eq#17 B8: Activation System	D1: Bolometers F9: Reflectometer (Main Plasma, HFS) GA: IR Cameras: Vis/IR TV (Upper) GL: In Vessel Lighting	
18		B2: Vertical Neutron Camera B8: Activation System EH: VUV Edge Imaging	D1: Bolometers B8: Activation System G3: Pressure Gauges G4: Residual Gas Analyzers – [Pass-through space reservation only]

Table 5-5: **Distribution of diagnostics mounted in the vacuum vessel**

		VV sector								
Diagnostic	**System**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Diagnostic systems with interfaces with the Vacuum Vessel PBS 15 (outside the VV)									
55.A3	Tangential Coils Outer			X			X			X
55.A4	Normal Coils Outer			X			X			X
55.A5	Tangential Steady State Sensors		X			X			X	
55.A6	Normal Steady State Sensors		X			X			X	
55.A7	Continuous Flux Loops	Continuous toroidal loops								
55.A8	Fibre Optic Current Sensor (FOCS)		X			X			X	
55.A9	Diamagnetic Coils Outer	X			X			X		
	Diagnostic systems with interfaces with the Blankets (PB 16)									
55.C1	Core Thomson dumps					X				
55.C2	Edge Thomson dumps					X				
55.C5	Toroidal Interferometer Polarimeter retroreflectors			X	X	X	X			
55.C6	Poloidal Polarimeter retroreflectors					X				
55.E2	H-alpha dumps			X		X	X			
55.FA	Density Interferometer Polarimeter retroreflectors				X					
55.G1	Vis/IR black bodies	X	X		X	X	X	X	X	X
55.GD	First Wall Samples	X	X	X	X	X	X	X	X	X
55.B3	Microfission Chambers	X	X			X	X			
55.B8	Activation System						X			X
	Diagnostic systems with interfaces with the Vacuum Vessel PBS 15 (inside the VV)									
55.AA	Tangential Coils Inner	X		X	X		X	X		X
55.AB	Normal Coils Inner	X	X		X	X		X	X	
55.AC	Toroidal Coils Inner	X	X	X	X	X	X	X	X	X
55.AD	Partial Flux Loops	X	X		X	X		X	X	
55.AE	Continuous Flux Loops Inner	Continuous toroidal loops								
55.AF	Diamagnetic Loop		X			X			X	
55.AG	Diamagnetic Coils Inner		X			X			X	
55.AH	Diamagnetic Saddles		X			X			X	
55.AI	MHD Saddles	X	X	X	X	X	X	X	X	X
55.AJ	HF Sensors	X	X	X	X	X	X	X	X	X
55.AP	Blanket Rogowskis	X	X	X	X	X	X	X	X	X
55.B3	Micro Fission Chambers	X	X			X	X			
55.B8	Neutron Activation System						X			X
55.BC	Divertor Neutron Flux monitor	X			X			X		
55.C4	Divertor Thomson		X							
55.D1	Bolometers	X		X	X		X		X	X
55.E4	Div. Imp. Monitor (lower port)				X					
55.F3	Plasma Position Reflectometry							X		X
55.F9	High Field Side Reflectometry				X	X				X
55.FA	Density Interferometer Polarimeter				X					
55.G3	Pressure Gauges		X	X			X			X
55.G8	Erosion Monitor				X					

		VV sector								
Diagnostic	**System**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
55.G9	Dust Monitor			X			X			
55.GB	ECH Detectors					X	X	X	X	X
55.GF	TF Mapping	X	X	X	X	X	X	X	X	X
55.Lx	Lower ports	X			X			X		
55.NE	Electrical Services	X	X	X	X	X	X	X	X	X
55.Qx	Equatorial Ports	X	X		X	X	X		X	X
55.Ux	Upper Ports	X	X	X	X	X	X	X	X	X

6 OPERATIONAL REQUIREMENTS

[PR4964-I] This chapter identifies the overall operational requirements that ITER must achieve in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

6.1 Design life

[PR895-R] ITER shall be designed for an operating lifetime no less than 20 years.

[PR1827-R] The design life of systems (including buildings) that are required to be operational during commissioning and/or deactivation periods shall be specified accordingly.

[PR896-R] The Tokamak Complex and Hot Cell Building shall be designed for a 70 year life.

6.2 Number of pulses

[PR904-R] ITER shall be capable of operating for at least 30,000 pulses in order to satisfy the overall requirement specified in the Project Specification document [R01].

6.3 Progressive start-up

[PR898-I] Progressive start-up is assumed in the RPrS [R08].

[PR899-R] Operating parameters shall be progressively increased during different plasma operations in order to verify the integrated systems perform safely and in accordance with operational design intent as defined in ITER Research Plan [R07] as updated by [R37] - see also Chapter 10.

6.4 Site electrical power constraints

[PR901-I] High-level design assumptions and constraints, applicable at the ITER/RTE interface (also known as Prionnet) unless otherwise noted are given in **Table 6-1**.

Table 6-1**: Site electrical power constraints**

Voltage	400kV +/-5%
Frequency	50Hz +/-1%
Minimum short circuit power at 400kV Under normal operating conditions	10GVA
Maximum voltage deviation	+/-3%
Maximum active power of SSEN	120MW
Maximum reactive power of SSEN	48MVAR
Maximum active power of PPEN	500MW
Maximum reactive power of PPEN	200MVAR
Maximum active power derivative of PPEN	280MW/s
Maximum active power step of PPEN	60MW

[PR1775-I] The limit on active power derivative and step is a pending issue currently under discussion between ITER Organization and RTE.

6.5 Plasma pulse duration and repetition

[PR5352-R] ITER shall be capable of executing plasma pulses with duration of up to 3600 s.

[PR907-R] ITER shall be capable of executing the next pulse after a duration not exceeding three times the duration of the previous pulse or 1800 s whichever is longer.

6.6 Design operating schedule

[PR910-R] ITER shall be designed for an active (D-T) phase lasting at least 14 years.

[PR912-R] ITER shall be designed to be capable of operating for periods of 11 consecutive days while accommodating three-shift daily plasma operation, followed by 3 days of routine maintenance.

[PR911-R] ITER shall be designed so that plasma operation can be conducted for periods of up to 16 months continuously in three 8h work-shift daily operating mode to perform the following actions: plasma operations, test, conditioning, routine maintenance.

6.7 Neutron production

[PR914-I] Annual neutron fluence limit was derived from operation at 400 MW (Design Scenario 3 with 1000 s pulse length) for one year at an availability close to unity (very limited unscheduled downtime).

[PR915-I] The maximum instantaneous neutron flux, for nominal operation, corresponds to a peak fusion power of 500 MW. Note that the ITER design includes appropriate provisions to cover the maximum instantaneous neutron flux that would result from the potential flexibility scenario of 700 MW for 100 s (see Section 4.3.1.2), and to include a safety margin.

[PR916-R] ITER shall be designed to provide an average neutron fluence of 0.30 $MW.y.m^{-2}$ in the active phase in order to satisfy the overall requirement specified in the Project Specification document [R01].

[PR917-R] ITER shall accommodate a maximum instantaneous average neutron flux of at least 0.5 $MW.m^{-2}$ in order to satisfy the overall requirement specified in the Project Specification document [R01].

6.8 Containment of water in the cryostat

[PR1828-R] The length and number of pipes inside the cryostat shall be minimised.

[PR919-R] Cooling pipes within the cryostat vacuum boundary shall be double-contained with guard pipes to ease leak detection and reduce risk of water leaks from the TCWS piping into the cryogenic environment.

[PR1829-R] All TCWS pipes in the cryostat shall be contained within restrained guard pipes. This is to reduce the risk of pipe-whip in the case of a break that could damage a neighbouring pipe or anything else in the cryostat systems.

[PR1830-R] The number of cryostat vacuum penetrations for TCWS needs shall be minimised.

6.9 Procedures of operation

[PR921-I] Global operating states and sub-states and transitions between them are described in the Operations Handbook [A08].

[PR922-R] ITER shall be operated in accordance with the Operations Handbook [A08].

[PR2189-R;Defined Requirement] Procedures shall be developed for all ITER operations (including maintenance and decommissioning). These procedures shall describe the appropriate organization to guarantee their application, the authorization required as well as actions to be taken in event of an emergency such as in case of a fire, an equipment failure or ITER On-Site Emergency.

6.10 Plant operation

[PR924-R] ITER Organization, as Operator of the ITER machine, shall be responsible for all actions inside the perimeter of the Nuclear Installation (INB).

[PR925-R] No ITER system shall be controlled or configured by personnel outside of the Nuclear Installation (INB) perimeter. For this purpose, a Plant Operation Zone (POZ) is defined, which geographically almost equals the perimeter of the INB.

[PR5303-I] The Plant Operation Zone is a collection of computer or hardwired networks, and of plant system equipment connected to those networks, required for integrated plant operation.

[PR935-R] There shall be no automatic transfer of data of any type onto the Plant Operation Zone (POZ) from any other computer networks.

[PR2190-R] There shall be a physical separation between the Plant Operation Zone network and any other networks to ensure that there can be no unauthorized transfer of data.

[PR2191-R] All data transfers between the Plant Operation Zone network and any other networks shall be executed through dedicated secure mechanisms.

[PR936-R] Transfers onto the Plant Operation Zone (POZ) network shall be initiated manually, and all parameters, pulse schedules and other data that are so loaded onto the POZ network shall be verified by, and under the responsibility of, an authorized individual located in the control room as if they had themselves created this data.

[PR926-R] There shall be a single Main Control Room and supporting facilities within the Control Building (71), and a Backup Control Room located within the Personnel Access Control Building (24).

[PR927-R] Control or configuration of ITER systems shall only be made from this Main Control Room except where control of individual systems from local control panels is specifically and exceptionally authorized.

[PR928-R] Remote handling and Hot Cell Facility activities shall be controlled by the RH Control Suite located close to these installations.

[PR929-R] The tritium plant shall be managed from a Tritium Plant Control Room within the protected area inside the Main Control Room (MCR, in Building 62-71). The Tritium Plant shall be capable of limited operations from the ITER Backup Control Room (BCR, in Building 62-24).

[PR930-R] The Sites Services Building shall have an appropriate local control area to facilitate the management and maintenance of non-pulse related systems.

[PR931-R] Health physics personnel shall be located within the Personnel Access and Control Building to ensure appropriate controls of persons entering and leaving controlled areas.

[PR932-I] There may be industrial areas, with limited facilities and air conditioning, for task-related activities such as maintenance facilities within the Diagnostic Building (74).

[PR933-R] Other than the above cases, there shall be no other permanent occupation by personnel of plant areas, that is, offices or control rooms, within the INB perimeter.

[PR934-R] In all cases working within the INB perimeter (and in other areas where specified) shall be subject to a Permit to Work system.

6.11 Remote participation

[PR938-R] Experimental data and information on plant system status shall be copied from the plant network in order to make it available on the ITER general network for analysis and remote collaboration.

[PR939-R] There shall be technological means, including video conferencing and remote data access, to enable collaboration between Main Control Room personnel and remote participants regarding the execution of the experimental program.

6.12 Instrumentation and control of ITER systems

[PR941-R] Required measurements shall be developed through the interface control process.

[PR942-R] Plant systems shall contain adequate instrumentation to ensure the following functions:

- To ensure human safety/security;
- To enable control of the plant system;
- To ensure equipment integrity and interlock;
- To monitor the system state;
- To record all system control actions;

- To control tokamak system operations;
- To prepare plasma pulses;
- To ensure plasma discharge quality;
- To monitor and record system performance.

[PR953-R] ITER systems shall contain instrumentation to measure all parameters that may affect their system, availability or which may predict failures or indicate the need of maintenance.

[PR954-R] Instrumentation and Control (I&C) of ITER systems shall be designed in accordance with the Plant Control Design Handbook [A02].

6.13 Reliability, Availability, Maintainability and Inspectability

[PR956-R] The Reliability, Availability, Maintainability and Inspectability (RAMI) requirements shall be an input in the specifications, design, testing, operation and maintenance of the ITER systems.

[PR2216-I] They integrate availability and reliability objectives to match the machine operation requirements and the ITER RAMI Analysis Program [R13] by using the rules defined in terms of the failure criticality level.

[PR2215-I] The main drivers to define the ITER facility reliability and availability targets are the pulse number defined in Section 6.2 and the neutron fluence defined in Section 6.7 requirements, along with the mean scheduled maintenance/upgrade down-time necessary to be able to conduct the ITER research program with the expected availability.

6.13.1 ITER functional breakdown

[PR2219-I] Reliability and availability are characteristics that are assigned to the functions of the system.

[PR959-I] Knowledge of its hardware architecture is usually not enough. Functional analysis methods are used to determine the reliability.

[PR2217-I] The main functions identified for RAMI requirements, derived from the RAMI analyses performed on the ITER systems, are regrouped in different functional groups:

- **Machine Operation** regroups the Safety and Investment Protection functions, the functions related to structures, the utilities functions necessary to sustain the activity of the plant as well as main functions (components) of the tokamak.
- **Physics Programme** gathers the functions required for physics experiments which are not specifically required for machine operation.
- **Maintenance** relates to the functions that are not necessary for performing a plasma pulse but are nevertheless essential to keep ITER in working order: wall conditioning, remote handling, the hot cell facility, the port plug test facility and the radwaste treatment and storage.

[PR2220-I] To be able to allocate separately RAMI objectives to each function, the systems (PBS) have been broken down as a hierarchy of functions on multiple levels, from the main operational functions fulfilled by the system to the basic functions performed by the components.

6.13.2 Availability

[PR2221-I] One of the main objectives for ITER is its availability in order to deliver sufficient plasma time for the research programme.

[PR970-I] Availability is defined as the ratio of operating time to the sum of operating time and downtime during experimental campaigns, assuming that the required external resources needed are provided.

[PR2222-I] Availability can be further defined as either inherent availability or operation availability.

[PR2223-I] The inherent availability is defined as the ratio of the operating time (or Mean Up Time: MUT) to the sum of operating time (or MUT) and not-scheduled downtime due to corrective maintenance (or Mean Down Time not-scheduled: MDTns). It does not take into account the loss of operating time due to the planned preventive maintenance or upgrade periods, but only the loss of operating time due to failures of the system.

[PR2224-I] The operational availability is defined as the ratio of the operating time (MUT) to the sum of operating time (MUT), downtime due to corrective maintenance (MDTns) and downtime due to preventive maintenance, tests and upgrades (or Mean Down Time scheduled: MDTs). Operational availability is thus lower than inherent availability as it is also reduced by time lost without any failure of the system.

[PR971-I] When allocating availability and reliability objectives to the systems or their main functions, it is better to use inherent availability, which is only related to the design and is not impacted by the preventive maintenance rhythm that does not result from failures.

[PR2225-I] To assess the overall availability of the machine for plasma operation and for the execution of the scientific programme, it is better to use operational availability, as it takes into account management decisions such as the operation rhythm and the planned maintenance programme.

6.13.2.1 Main functions inherent availability objective

[PR982-I] While using the definition previously given, the inherent availability is defined as:

$A_i = MUT / (MUT + MDT_{NS})$

[PR981-R] To allow the machine to reach the ITER machine operational availability target (60% in H-phase), the systems and/or main functions required to achieve "basic" plasma operation shall be designed to reach the Inherent Availability objectives given in **Table 6-2**.

[PR983-I] The availability AI of a group of Systems/Functions can be approximated with a series system/function logic:

$A_i = 1 / (1 + \Sigma I=1 \text{ to } n\ \lambda(I)\ MDT_{NS}(I))$

where n is the number of systems/functions, λ(I) is the failure rate of the System/Function, I, which causes a Mean Down Time of MDTNS(I).

Table 6-2**: Inherent availability objectives for the main functions necessary for Machine Operation**

System	PBS	A_H (%)	A_{D-T} (%)	Main Function	A_H (%)	A_{D-T} (%)
Magnet	11	96.1	92.2	To provide magnetic confinement	99.0	98.0
				To induce current plasma and provide stabilization control	99.0	98.0
				To provide field for plasma equilibrium	99.0	98.0
				To provide corrective field	99.0	98.0
Vacuum Vessel	15	99.7	98.7	To provide vacuum and first confinement barrier	99.7	98.7
Blanket Modules	16	91.8	90.0	To exhaust power & provide thermal & nuclear shielding	91.8	90.0
Divertor	17	92.8	91.0	To exhaust power & to control particles	92.8	91.0
Fuelling & Wall Conditioning	18	99.5	97.2	To inject gas	99.9	99.4
VVPSS	24	99.9	99.9	To prevent overpressure in the VV	99.9	99.9
Cryostat		99.4	99.4	To protect the magnets from thermal loads	99.4	99.4
Cooling Water System	26	94.0	94.0	To reject the heat loads	98.9	98.9
				To cool & bake components	98.7	98.7
				To produce chilled water	98.5	98.5
				To cool & bake Tokamak components	97.8	97.8
Thermal Shields	27	99.9	99.9	To provide thermal shielding	99.9	99.9
Vacuum Pumping	31	99.3	97.6	To provide fluids for cryopump operations	99.9	99.9
				To provide vacuum	99.4	97.7
Tritium Plant*	32	N/A	80	To recycle Tritium and provide Tritium fuel	N/A	80.0

System	PBS	A_H (%)	A_{D-T} (%)	Main Function	A_H (%)	A_{D-T} (%)
Cryoplant & cryodistribution	34	91.2	91.2	To provide cooling power	96.0	96.0
				To distribute cooling power	96.0	96.0
				To transport cryogenic fluids	99.0	99.0
CPSD	41	85.4	92.8	To supply and distribute power to the pulsed loads	92.0	92.0
				To supply and distribute power to the coils	93.0	93.0
				To ensure proper grounding of the coils	99.9	99.9
				To ensure fast discharge of stored energy	99.9	99.9
SSEN	43	99.2	99.2	To provide Class I, II power supply	99.9	99.9
				To provide Class III power supply	99.9	99.9
				To provide Class IV power supply	99.4	99.4
CODAC	45	98.8	98.8	To perform Control, Data Acquisition & Communication	98.8	98.8
Central Interlock System	46	99.9	99.9	To protect the investment	99.9	99.9
Plasma Control System	47	98.8	98.8	To control the plasma	98.8	98.8
Central Safety System	48	99.9	99.9	To protect people & environment with SIC components	99.9	99.9
ECH&CD	52	88.2	84.5	To assist plasma start-up with EC	98.0	96.0
Diagnostics	55	79.1	77.3	To measure parameters for IP functions	98.5	98.5
				To measure parameters for basic control	98.0	98.0
Reinforced Concrete Buildings	62	99.3	99.3	To shelter activities within nuclear buildings	99.3	99.3
Steel Frame Buildings	63	99.9	99.9	To shelter activities within non-nuclear buildings	99.9	99.9
Radiological & Environmental Monitoring	64	99.9	99.9	To monitor radiology & environment	99.9	99.9
Liquid & Gas Distribution	65	97.8	97.8	To provide fire protection water	99.9	99.9
				To provide breathing air	99.8	99.8
				To provide demineralized water	99.9	99.9
				To provide potable and hot water	99.8	99.8
				To provide compressed air	99.0	99.0
				To provide GHe and N2	99.4	99.4
Access Control & Security Systems	69	99.8	99.8	To provide real-time security functions	99.9	99.9
				To provide Security-Relevant Communications Between Staff, Security Officers & Guards. (COM)	99.9	99.9

[PR2376-R;Defined Requirement] Note *: The Detritiation System shall have an availability of 98.72%.

[PR2228-R] To allow the machine to reach the ITER research programme operational availability target, the main functions of ITER systems, required to perform the physics programme shall be designed to reach the Inherent Availability objectives given in **Table 6-3**.

Table 6-3**: Inherent availability objectives for the additional main functions necessary for the Physics Programme**

System	PBS	A_H (%)	A_{D-T} (%)	Main Function	A_H (%)	A_{D-T} (%)
In-Vessel Coils	15	98.7	96.7	To control VDEs	99.5	98.5
				To control ELMs	99.2	98.2
Fuelling & Wall Conditioning	18	-	-	To inject pellets	99.8	97.8
ICH&CD	51	87.3	83.6	To perform IC heating or current drive	90.0	88.0
ECH&CD	52	-	-	To perform EC heating, current drive or control MHD instabilities	90.0	88.0
NBH&CD	53	90.0	85.0	To perform NB heating or current drive	90.0	85.0
Diagnostics*	55	-	-	To measure parameters for advanced control	91.0	90.0
				To measure parameters for performance and physics	90.0	89.0
Test Blanket System	56	80.0	75.0	To demonstrate the feasibility of Tritium breeding and electricity production	80.0	75.0

[PR2231-R] To allow the machine to reach its operational availability targets, the systems and/or main functions used for maintenance shall be designed to reach the Inherent Availability objectives given in **Table 6-4**. Those targets are set in **Table 6-4** to address first the preventive maintenance and planned upgrades expected to be performed during the 6-month Long-Term Maintenance shutdowns and then the corrective maintenance operations that might happen during the experimental campaign in Plasma Operation States, Test and Conditioning States or Short-Term Maintenance.

Table 6-4**: Inherent availability objectives for the main functions necessary for Maintenance**

System	PBS	A_H (%)	A_{D-T} (%)	Main Function	A_H (%)	A_{D-T} (%)
Fuelling & Wall Conditioning	18	-	-	To perform Glow Discharge Cleaning	99.8	97.8
Remote handling	23	79.8	71.8	To ensure cask transfers	97.0	95.0
				To remotely handle and refurbish port plugs	96.0	94.0
				To remotely handle blanket modules	95.0	93.0
				To remotely handle divertor cassettes	95.0	93.0
				To remotely handle NBH&CD system	95.0	93.0
ICH&CD	51	-	-	To perform IC wall conditioning	97.0	95.0
Port Plug Test Facility	58	99.0	97.0	To test the port plugs	99.0	97.0
Rad-waste Treatment & Storage	66	N/A	90.2	To treat and store Type A & TFA waste	N/A	94.0
				To treat and store Type B and to store PTW	N/A	96.0

[PR2234-I] In addition to the availability targets, a margin is given, equal to ±0.1% for an availability target of 99% or more, ±0.2% for an availability target between 95% and 99% and ±0.5% for an availability target lower than 95%.

6.13.2.2 Overall machine operational availability objective

[PR2235-I] While using the definition previously given, the operational availability is defined :

$$A_o = MUT / (MUT + MDT_S + MDT_{NS})$$

[PR974-R] Taking into account 365 working days per year and 24 working hours per day, ITER shall be designed for an operational machine availability of at least 32% on average over ITER H-phase (up to 40% over one month of operation) in a three-shift operating mode with a Mean Scheduled Down Time (MDTS) not greater than 11.3 months over every two-year experimental campaign.

[PR2237-I] An eight month scheduled down time, including two months for preparatory activities for opening the vacuum vessel and getting the machine back on line, will be allocated on average every two years as major shutdown (long-term maintenance state, LTM) for maintenance and/or upgrades of all the systems.

[PR2236-R] In-vessel activities involving remote handling shall not exceed six months every two years.

[PR978-R] For out-vessel maintenance/upgrade activities, there shall be no planned outages additional downtime outside these defined periods unless it can be performed during normal plasma operation (hidden maintenance).

[PR979-I] The scheduled periods for machine inspections and maintenance tasks are defined in detail in the ITER Operations Plan (to be issued).

[PR980-I] To reach that overall machine operational availability objective while taking into account this scheduled downtime for planned inspection, maintenance and upgrades, the machine must meet an inherent machine availability of 60% for "basic" plasma operation. This translates into a list of inherent availability targets for the main functions performed by the ITER systems.

[PR989-R] In order to optimize their availability, ITER systems shall be designed in such a way that the time to repair is reduced as much as possible.

[PR2238-R] Recommendations for spare parts provisioning shall be provided following the RAMI requirements analysis of the systems, both for scheduled and unscheduled maintenance and taking into account the operating conditions, the benefits of using as many standard parts as possible and the risk of components obsolescence over the lifetime of ITER.

[PR2239-R] Standardization shall be privileged when selecting multiple numbers of similar components that can be used by several systems throughout ITER in order to reduce the number of required spare parts, tools, skills, procedures, storage spaces and associated costs.

[PR2240-R] Procedures and training documents shall be provided to ITER Organization for operation, test and maintenance of the systems equipment on site, both as paper and electronic media, and shall be complete, updated and easily available.

[PR2241-R] All tools and test equipment needed for packaging, handling, storage, transportation, test and maintenance of the systems equipment on site must be provided to IO. Assembly tools shall be designed in such a way as they may be modified later to be used for maintenance during the operation phase of ITER, and shall thus be resilient and multi-purpose.

[PR2242-R] The supplier shall identify any facility requirements for the equipment that needs to be tested and maintained outside the Hot Cell Facility (control cubicles for instance).

[PR2243-R] A Major Risk Register shall be prepared using the Functional Analysis, Reliability Block Diagrams and Failure Mode, Effects, and Criticality Analysis described in the ITER RAMI Analysis Programme [R13].

[PR2244-R] The severity scaling of the failure modes shall be oriented towards machine availability with an objective to reach the overall machine availability targets.

[PR2245-I] The Criticality (severity x occurrence) value leading to a major technical risk for the ITER machine will be defined by the Project.

[PR2246-R] For each major risk, a detailed analysis shall be made of causes via their occurrence and effects via their severity.

[PR996-R] For every credible major technical risk that would compromise the required operational capability of ITER, mitigation actions and/or provisions for recovery shall be decided in terms of design changes, tests, operation procedures and/or maintenance/spares plan with the objective to mitigate the risk or reduce its criticality level below the limit defined for the major risks.

[PR2247-R] In cases where the risk level cannot be sufficiently reduced, specific provisions shall be defined for recovery including failure detection, localization repair and verification, in addition to an inspection plan to be able to prevent the failures.

[PR2248-R] The supplier shall demonstrate that the availability of the function performed by its design can meet the allocated availability requirement given in **Table 6-2, Table 6-3 and Table 6-4**.

6.13.3 Reliability requirements

[PR2249-I] The reliability is the ability that an item will perform its intended function without failure in a specified time interval under given conditions and without including a maintenance period. It is thus one of the levers with which ITER can reach its availability objective, the other being the maintainability.

[PR960-R] As part of the qualification process, the supplier demonstrates that the reliability characteristics shall be consistent with the calculations that were performed during the RAMI analysis .

[PR2250-R] The warranty period shall be used as a validation period for the reliability characteristics of the system equipment.

[PR2251-R] Deviations from requirements shall be identified and compensating/correcting actions identified and implemented.

6.13.4 Maintainability and Inspectability

[PR998-I] The objective of Maintainability is to develop equipment and systems which can be maintained in the least time, at the least cost, with a minimum expenditure of support resources, without adversely affecting the item's performance or/and its safety characteristics.

[PR2252-I] Inspectability is defined as that characteristic of design and integration that allows in-situ monitoring of equipment performance with regard to the amount of usable lifetime remaining.

[PR999-I] Inspectability includes the accessibility to equipment to evaluate the material degradation and diagnostics to determine incipient failure. It is one of the characteristics of maintainability with a preventive objective.

[PR1000-R] Accessibility to the physical interface points shall be taken into account as a way to improve the maintainability and inspectability of the concerned components, and thus ultimately the availability of the systems.

[PR1001-R] The maintainability shall ensure the minimum time to recognize, isolate and correct a malfunction, to understand and apply technical procedures, to gain access to faulty items, to repair or replace faulty items and to test and verify accuracy and adequacy of the maintenance actions.

[PR2253-R] The maintainability shall require the lowest amount possible of required facilities, tools, tests, support requirements and maintenance staff training to enable the fulfillment of maintenance requests.

[PR1002-R] As a general rule, the systems and their components shall be designed in such a way as to reduce the time to detect, identify, locate and repair any failure, or sign of impending failure.

[PR2254-R] Components and subsystems shall be as much as possible integrated in such a way that those requiring the most frequent maintenance shall be the more readily accessible.

[PR2255-R] Test engineering as a provision and access of test points, shall be involved at an early stage to define test requirements and design test approach.

[PR2256-R] As this consideration is mostly specific to the components themselves, inspectability requirements shall be addressed in detail in the SRDs specific to each system.

6.14 Inspection

[PR2192-R] Periodic inspections shall be performed during installation and maintenance periods to detect metallic equipment that is potentially left or loose in a magnetic zone.

6.14.1 In-vessel viewing

[PR1005-R] An In-Vessel Viewing System (IVVS) shall be provided which is capable of viewing and inspecting the Blanket and Divertor plasma-facing surfaces and providing their dimensional measurements.

[PR1006-R] The IVVS shall be designed to operate with the vacuum vessel under vacuum.

[PR1007-R] The IVVS shall be designed to operate with the in-vessel components at temperatures in the range of 20°C to 120°C.

[PR1008-R] The IVVS shall be designed to operate in a radiation environment up to 1500 Gy/hr.

[PR1009-R] The IVVS shall be capable of being deployed in 4 hours and stowed in 4 hours.

6.14.2 Leak localization

[PR1011-R] The capability to localize all vacuum leaks that affect or have the potential to affect operations shall be provided.

[PR1012-R] The precision of leak localization shall be such as to minimize component repair/replacement operations and for each leak shall give certainty of position to a single replaceable or repairable section of a component.

[PR2193-R] When multiple leaks occur on different components or in different locations these shall also be individually-localizable down to individually-replaceable components or repairable sections.

[PR1013-R] The methods applied for leak localization shall minimize the time required to locate leaks. A good level of confidence of the position of leaks shall be obtained within one week of leaks being detected and effecting operations.

[PR2194-R] Should mitigation of the leak require major intervention (such as coil warm-up, or blanket module replacement) then techniques giving further precision and certainty of the leak position shall be applied as part of this intervention but shall not add more than one week to this intervention.

[PR1014-R] The design of components and systems which form a vacuum boundary or feed fluid or gas to such a component or system shall give due consideration to integrate the methodologies of leak localization which are to be applied.

[PR2195-R] The techniques of localization shall be appropriate to the potentially-leaking vacuum boundary, the leak size, the leak type, the leak accessibility, and risk of the leak.

[PR2196-R] The methods of leak localization shall be designed and performed following the ALARA principle with respect to worker dose.

[PR2197-I] A leak localization strategy is formed following research and development into techniques.

6.15 Maintenance conditions

[PR1016-R] Maintenance plans shall be developed for all maintenance scenarios with a probability of occurrence greater than 10^{-6}, over the 20-year life of ITER.

[PR2198-R] Maintenance procedures and tools shall be provided for maintenance scenarios with a probability exceeding 10^{-1} over the 20-year life of ITER.

[PR2199-R] For maintenance scenarios with a probability of occurrence lower than 10^{-1}, but for which serious feasibility concerns exist, such as machine sector replacement in the case of a TF coil failure, maintenance plans shall be developed and the required tooling conceptualized.

[PR2200-I] TF and PF coil replacement after the activation phase is not considered.

[PR2201-R] Handling equipment (including transfer and lifting systems) shall be designed and operated so to prevent any injury to the personnel and any damage to the handled equipment or surrounding components (especially SIC components and systems containing effluents). This includes the optimization of the required number of handling activities, the transfer trajectory and lifting height as well as protection measures to be put in place in the event of the failure (direct or indirect) of the handling system or an operation error.

[PR2202-R] Appropriate measures of quality control shall be implemented for the manufacturing, installation and operation of handling equipment (including transfer and lifting systems) - including periodic qualification tests for lifting equipment.

[PR2203-R] In the event of the failure of a handling system, appropriate recovery systems and procedures shall be available (as necessary).

[PR1018-R] The preparatory works, including the time to reach the required environmental conditions that enable hands-on maintenance activities inside the Vacuum Vessel and inside the Cryostat, shall not exceed 2 weeks, and 4 weeks, respectively, after reaching the acceptable dose rate for personnel defined in PR1130-R.

[PR1019-R;Defined Requirement] Before the first deuterium-tritium starts, the ITER device and facility shall be capable of being upgraded to provide personnel access to the interior of the vacuum vessel in the presence of Be dust for hands-on maintenance.

[PR1021-I] Requirements for remote handling are provided in Section 6.16.

[PR1022-R;Defined Requirement] The vacuum vessel or cryostat shall be vented with dry nitrogen or humidity-controlled air prior to introducing personnel or remote handling equipment as appropriate.

[PR2204-I] Remote handling equipment is required to operate in dry air.

[PR1032-R] The capability shall be provided to vent the cryostat with dry air or nitrogen from vacuum to atmospheric pressure within 48 hours.

[PR1023-R] ITER coils shall be de-energized prior to providing access for personnel or remote handling equipment in the vacuum vessel or cryostat.

[PR2205-R] The residual magnetic field in the volume within the vacuum vessel that can be accessed by remote handling equipment during remote handling operation shall not exceed 1 mT.

[PR1024-R] Remote handling equipment shall be designed to operate in the environment conditions of the locations where the tasks for which they have been designed are to be carried out.

[PR1025-R] The temperature of the vacuum vessel shall be maintained in the range of 20°C to 50°C when remote handling equipment is present

[PR5404-R] For personnel access to the vacuum vessel or cryostat, the temperature shall be maintained in the range authorized by IO Health and Safety.

[PR5416-I] In compliance with the French Labour Code, the size of the corridor for human access is defined according to the type of environment.

[PR5417-R] For non-hostile environment, the passage width shall be at least 800 mm (Article R4323-12 of the French Labour Code).

[PR5418-I] For hostile environment, the Article R4323-7 of French Labour Code applies and the analysis of the references [R39] and [R40] provides the minimum passage width.

[PR5419-R] For hostile environment, the passage width shall be at least 900 mm.

6.15.1 In-vessel tritium inventory control

[PR2370-I] The requirements for the tritium inventory are detailed in Section 7.4.1.

[PR1034-R;Defined Requirement] In-vessel tritium inventory shall be monitored through periodic measurement.

[PR1035-R;Defined Requirement] Taking into account measurements uncertainties on in-vessel tritium inventory, tritium shall be removed before the inventory approaches the safety limits.

[PR1036-R] In-vessel tritium inventory estimates shall rely on physical inventory taking and a validated procedure to determine the difference between the amount of tritium injected or bred and the amount of tritium extracted or burned.

[PR1037-R] Local tritium monitoring and sampling during in-vessel intervention shall provide another support for the estimate of in-vessel tritium inventory measurements.

[PR1038-I] The tritium removal relies on:

- The capability to bake all VV and in-vessel components as described in Section 4.2.5;
- Wall-cleaning techniques.

[PR1042-R;Defined Requirement] Baking shall be carried out:

- Before any planned venting of the machine to limit the spread of tritium;
- In any other circumstance where the tritium inventory build-up in the vacuum vessel will approach the safety limits considering the uncertainties.

[PR1046-R] The duration of baking shall be commensurate with the tritium desorption rate; see Section 4.2.5.

6.15.2 In-vacuum vessel dust inventory control

[PR1048-R] The in-vessel dust inventory shall be monitored through periodic measurements.

[PR1049-R;Defined Requirement] The in-vessel dust shall be removed before the inventory approaches the safety limits having considered the measurement uncertainties.

[PR1050-R;Defined Requirement] Methods to assess the global erosion in the vacuum vessel shall be provided (IVVS).

[PR1051-R;Defined Requirement] Methods to perform local monitoring and sampling to assess local dust erosion and deposition in the vacuum vessel shall be provided.

[PR1052-R;Defined Requirement] Removal of dust from accumulation areas in the vacuum vessel shall be provided at any divertor replacement and on every other occasion where in-vessel maintenance operations are carried out.

[PR1053-R;Defined Requirement] The possibility of dust removal via vacuum cleaning of the plasma-facing component surfaces shall be provided using the in-vessel remote handling systems.

6.15.3 Refurbishment and disposal of in-vessel components

[PR1055-R] Facilities shall be provided in the Hot Cell Building for refurbishment of failed or worn in-vessel components which are designed for refurbishment (including remote handling equipment). Test facilities to confirm refurbishment shall be provided.

[PR1056-R;Defined Requirement] Personnel access shall be provided to the Hot Cell Building when dose rates permit, and with adequate protection and measures to limit the personnel exposure to and spread of radioactive substances.

[PR1057-R] Personnel access to the Beryllium zones (see Section 7.9.4) within the Hot Cell Building shall require adequate protection and measures to limit the personnel exposure to and spread of beryllium.

[PR1058-R;Defined Requirement] Transfer casks shall be provided for transport of activated or contaminated in-vessel components between the Tokamak Complex and the Hot Cell Building.

[PR1059-R;Defined Requirement] Facilities shall be provided for storage of replacement parts of in-vessel components (including activated or contaminated components that have been refurbished) and for storage of associated equipment, such as RH tools and transfer casks.

[PR2206-R;Defined Requirement] Appropriate measures (for example, confinement, monitoring, decontamination, exposure limitation, access control) shall be implemented in order to minimize worker exposure to beryllium and beryllium compounds throughout ITER lifetime (including ITER construction and its non-nuclear phase).

6.15.4 Processing of radioactive waste

[PR1061-R;Defined Requirement] Facilities and equipment to process activated and contaminated components (including appropriate process, pre-packaging, packaging, and temporary storage) shall be provided.

[PR1062-R;Defined Requirement] Facilities to process low-level and very-low-level radioactive waste for periods up to six months before disposal shall be provided.

[PR1063-R;Defined Requirement] Facilities to store intermediate-level radioactive waste for periods up to 20 years prior to disposal by the Host country shall be provided.

[PR1064-R;Defined Requirement] Facilities and equipment to treat radioactive liquid waste shall be provided.

[PR1065-R;Defined Requirement] No radioactive material processing shall lead to a high-level radioactive waste stream.

[PR2207-R;Defined Requirement] Solid radioactive waste shall be transported (if required) from its source location to the treatment facility using appropriate containers and transport systems that ensure the maintenance of the required level of confinement and radiation shielding.

[PR2208-R;Defined Requirement] Solid waste packages shall be controlled prior to transport and disposal.

[PR2209-R;Defined Requirement] Suitable management routes shall be implemented for all radioactive waste generated throughout ITER lifetime.

6.15.5 Safety drain tank

[PR1067-R;Defined Requirement] It shall be possible to process the contaminated water discharged to safety drain tank(s) following an in-vessel water leak.

[PR1068-R;Defined Requirement] It shall be possible to process the water and to clean the safety drain tank(s) to allow the restart of the ITER plant within one year.

[PR1776-R;Defined Requirement] It shall be possible to process the contaminated water from the VVPSS to allow the restart of the ITER plant within one year.

6.15.6 Types of maintenance equipment

[PR3078-I;Defined Requirement] Three types of maintenance equipment are required from a viewpoint of the Control Scheme and Man Access into the work area.

6.15.6.1 Remote handling equipment (RHE)

[PR3080-I;Defined Requirement] This type of maintenance equipment is to operate where man access is not allowed, both during normal maintenance operations and rescue operations of the RH equipment.

[PR3081-R;Defined Requirement] Generally, the RHE is very complex, expensive equipment and its use requires special attention with regards to RH compatibility of the maintained components. Therefore, any request by the system designers for use of RHE for maintenance of a system’s components shall be timely and deeply studied, well justified and highly optimized from a viewpoint of project integration, cost and schedule.

[PR3082-I;Defined Requirement] For information, the ITER RHE is the baseline equipment under the responsibility of PBS 23 “Remote Handling Equipment”.

Table 6-4a: **RHE type of maintenance equipment**

Control Scheme	Man Access in the work area
Centralized remote control. Specially trained RHE Operator(s) control(s) the equipment remotely from the RH Control Room	No man access in the work area during any RHE operations, both normal and rescue

6.15.6.2 Human-assisted equipment (HAE)

[PR3086-I;Defined Requirement] This type of maintenance equipment is to operate where man access is restricted and very limited in time. Therefore, man access is dedicated to completion of complex tasks for a limited amount of time, such as deployment of HAE or rescue operations.

[PR3087-I;Defined Requirement] One of the essential differences between HAE and RHE is that the HAE is dedicated equipment that is not integrated with any RHE. The HAE could be either off-the-shelf industrial equipment (for example, a robotic arm) or first-of-a-kind equipment developed for ITER.

Table 6-4b: **HAE type of maintenance equipment**

Control Scheme	Man Access in the work area
Local remote control. Specially trained HAE Operator(s) control(s) the equipment from a control station/board installed close to the target plant but protected from the direct hazards present in the work area	Time limited man access during HAE operations. Nominally, the operations are performed without workers in the area. Exceptionally, the presence of workers in the work area could be required for some specific tasks that cannot be done remotely, such as HAE deployment or HAE rescue operations

6.15.6.3 Hands-on tool (HTL)

[PR3091-I;Defined Requirement] This is the name given to any other maintenance equipment that is not identified as RHE or HAE.

Table 6-4c: **HTL type of maintenance equipment**

Control Scheme	Man Access in the work area
Direct control. A well trained Operator controls the tool directly in the work area	Full time man access during hand-on operations. The operations are performed with workers in the area, according to approved maintenance procedures and with appropriate personal protection

6.15.7 Maintenance classification

[PR3095-I;Defined Requirement] An ITER Maintenance Classification is applicable to any maintenance task that is defined by an ITER Designer or by the ITER Operator.

[PR3096-R;Defined Requirement] The Maintenance Classification is intended to support the performance of relevant engineering analyses, and an adequate implementation of the ITER limit for annual collective radiation dose exposure, as established in [PR1129-R]. Therefore, this classification is maintenance environment oriented, and shall be assigned to any maintenance task that is defined by the ITER Designer or ITER Operator.

[PR3097-R;Defined Requirement] Maintenance tasks are identified from RAMI analysis and Safety Analysis in order to meet the Project's safety and availability requirements. They shall be specified and verified as part of the design process for ITER systems, under the responsibility of their TRO.

6.15.7.1 Maintenance class 1

[PR4965-I;Defined Requirement] Maintenance Class 1 (MC1) includes any planned or unplanned maintenance activities that must be performed in environment of radiation exposure and/or radioactive contamination. Such a maintenance environment is expected in the Nuclear Buildings.

[PR3099-R;Defined Requirement] The natural background radiation at the ITER site shall not be considered as a contributor to the annual collective radiation dose exposure until otherwise decided by the ITER Operator.

[PR3100-R;Defined Requirement] Maintenance Class 1 shall be associated to any maintenance task which requires use of RHE or HAE.

[PR3101-R;Defined Requirement] In order to manage the ITER maintenance planning in a proper way, MC1 is divided into three sub-classes as follows:

- Maintenance Class 1-1 (MC1-1) shall be defined for any maintenance task which represents 1% or more of the ITER annual collective radiation dose exposure limit;
- Maintenance Class 1-2 (MC1-2) shall be defined for any maintenance task which is in the range from 0.1% to 1% of the ITER annual collective radiation dose exposure limit;

- Maintenance Class 1-3 (MC1-3) shall be defined for any maintenance task which represents less than 0.1% of the ITER annual collective radiation dose exposure limit.

6.15.7.2 Maintenance class 2

[PR3103-I;Defined Requirement] Maintenance Class 2 (MC2) includes any planned or unplanned maintenance activities that must be performed in environment of toxic and/or other hazardous but without risk of radiation exposure or radioactive contamination.

[PR3104-R;Defined Requirement] Maintenance Class 2 shall be associated to any maintenance task which is not classified as MC1 and which requires special PPE (Personal Protective Equipment) for workers, such as air suit or breathing mask.

In order to manage the ITER maintenance planning in a proper way, MC2 is divided into two sub-classes as follows:

- Maintenance Class 2-1 (MC2-1) shall be defined for any maintenance task which deals with Beryllium and require Beryllium waste management;
- Maintenance Class 2-2 (MC2-2) includes any other MC2 maintenance tasks that are not classified as MC2-1.

6.15.7.3 Maintenance class 3

[PR3106-I;Defined Requirement] Maintenance Class 3 (MC3) includes any planned or unplanned maintenance activities that are not classified as MC1 or MC2.

6.16 Remote maintenance requirements

[PR1075-I] The ITER Organization policy regarding maintenance provision is to balance risk and cost by assigning a remote handling (RH) classification for maintenance tasks according to the likelihood of them having to be carried out, and to define the level of provision to be made for each classification.

[PR1071-R] The ITER remote handling system (PBS-23) shall be designed in accordance with the guidelines provided in the ITER Remote Maintenance Management System document [A17].

[PR1073-R;Defined Requirement] Provisions for remote maintenance shall be made for all environments where hands-on maintenance would result in ITER administrative limits (less than 100 µSv/h) being exceeded.

Table 6-5**: Remote Handling (RH) Classification**

Classification	Task	RH Provision
RH Class 1	Scheduled maintenance tasks (upgrades, predictable refurbishment)	Plant designed to be RH-compatible for maintenance. Maintenance equipment procured and operation sequences planned in detail prior to machine operations. Maintenance tasks verified on physical mock-ups before design is finalized.
RH Class 2	Task probability > 3.10^{-1} but not scheduled tasks (in 20-year period)	Plant designed to be RH-compatible for maintenance. Maintenance equipment procured and operation sequences planning in detail prior to machine operations. Novel aspects of maintenance tasks verified on physical mock-ups before design is finalized.
RH Class 3	Task probability > $3.\ 10^{-2}$ but < 3.10^{-1} (in 20-year period)	Plant designed to be RH-compatible for maintenance. Maintenance equipment and operation sequences designed prior to machine operations.
Unclassified	Task probability < $3.\ 10^{-2}$ or no credible need for remote maintenance (in 20-year period) (For Example) TF coil, Lower PF coil	No provision

[PR1078-R] All equipment in the in-vessel, Neutral Beam cell, and Hot Cell controlled areas shall be analyzed for their RH classification defined in **Table 6-5**, as described in the ITER Maintenance Management System document [A17].

[PR1079-R] All ITER systems with an RH classification shall be designed for RH compatibility. Guidelines for designing for RH compatibility are provided in the RH Code of Practice [R19].

[PR1081-R] The remote maintenance tasks shown in **Table 6-6** shall comply with the scheduled shutdowns defined in the ITER Operations Plan (to be issued).

[PR1082-R] The ITER maintenance facilities shall ensure execution of the scheduled remote maintenance tasks (RH Class 1) within the scheduled maintenance time (**Table 6-6**).

[PR5420-I] The RH maintenance activities and the duration provided in **Table 6-6** are design constraints. The detailed list of RH activities and their duration is refined as required along with the ITER design and the ITER Operations Plan (to be issued).

Table 6-6**: Scheduled remote handling maintenance tasks**

Task	Maintenance Time (note 1)
Divertor Cassette Exchange (54 units)	6 months
Blanket Replacement of all First Wall Panels	24 months
Test Blanket Modules (2 units)	2 months
NB caesium oven	1 month
VVPSS maintenance	6 months
Vacuum Vessel In-Service Inspection	(to be defined)

[PR1690-I] Note 1: This time excludes ITER stop/start time.

[PR1084-R] Unscheduled remote maintenance tasks (failures that did not require an unscheduled shutdown or system upgrades) shall be performed during the remaining available time of a scheduled shutdown. The number of unscheduled tasks performed will depend on the time required to perform each task, their priority, and the possibility to carry out parallel remote handling operations (see **Table 6-7**).

[PR1087-R] The remote maintenance systems (PBS-23) shall be capable of processing, in parallel, tasks from the different columns (pools) shown in **Table 6-7**.

Table 6-7**: ITER maintenance task pools**

Pool A Tasks (est. 3 months each)	Pool B Tasks (est. 3 months each)	Pool C Tasks (est. 2 months each)	Pool D Tasks (est. 2 months each)	Pool E Tasks (est. 2 months each)
1 x Equatorial Diagnostic Plug maintenance	1 x Upper Diagnostic Plug maintenance	3 x Test Blanket exchange	18 x Divertor cassette exchange	1 x NB caesium oven change
1 x Equatorial ECH antenna upgrade	1x Upper port EC antenna upgrade	2 x Diagnostic rack exchange	37 x Blanket module replacements (based on a complete blanket replacement 2-year campaign)	1 x NB Fast Shutter maintenance (unplanned maintenance)
1 x Equatorial ICH antenna upgrade		1 x IVVS exchange		1 x NB ion source caesium cleaning
	1 x Torus cryopump maintenance			

[PR1089-R] For pools A and B, the maintenance systems shall be capable of processing, in series, two tasks in a six-month maintenance period.

[PR1090-R] For pools C, D, and E, the maintenance systems shall be capable of processing, in series, three tasks in a six-month maintenance period.

6.17 Human factor engineering

[PR2210-R;Defined Requirement] Human performance and human error can have a major impact on the safety of a nuclear installation, as well as in operability, availability, and maintainability and inspectability aspects. Human and Organizational Factors shall be considered within the ITER Project.

[PR1093-R;Defined Requirement] ITER Organization will retain responsibility for Human and Organizational Factors at the overall system level and will assure and integrate the HF inputs from suppliers. The ITER Human Factors Integration Plan (HFIP) [R22] was established in order to:

- Ensure that human and organizational factors risks across and within the ITER project are competently identified and managed all along the entire design and supply chain;
- Ensure that all systems and design shall satisfy the requirements set out in this document and meet regulatory requirements;
- Derive, manage and assure ITER Human Factors requirements to the entire system design and supply chain;
- Develop and provide detailed Human Factors guidance for suppliers (such as checklists, methods, and guidance on standards);
- Provide ITER with Human Factors acceptance criteria and assurance of supplier Human Factors activities;
- Oversee the integration of Human Factors output across the overall ITER Project;
- Oversee and guide ITER design, development and implementation teams on Human Factors issues with systems interfaces (support for systems integration);
- Oversee and guide human and organizational factors within ITER Organization to ensure proper integration and delivery of human factors within and across the entire system design and supply chain.

[PR1092-I;Defined Requirement] The HFIP defines a systematic and reasonable application of Human and Organizational factors throughout the ITER Project, from concept to decommissioning with reference to all systems and activities where Human Factors plays an important role from a safety and availability point of view (particularly in view of operation and maintenance optimization). This application takes into consideration the specifity of ITER as a prototype and in terms of its safety nature.

[PR2211-R;Defined Requirement] All systems shall be designed in accordance to the *ITER Human Factor Integration Plan (HFIP)* [R22].

6.18 Investment protection requirements

[PR2213-I] Investment Protection is a function referring to any form of prevention or guarantee that an unacceptable loss of investment or operational time will not occur due to any fault or failure in Structures, Systems or Components (SSC). Such failure may be direct, through the action of other SSC or due to events related to the operation of the plant or the plasma, or through external influence such as earthquake. The policy on investment protection is defined in MQP Policy for ITER Investment Protection [R24].

[PR2214-R] Risks to investment categorised as Severe or above shall be mitigated as defined in the Investment Protection Strategy.

[PR2356-R] Each system design shall take into account possible impact on other SSC, for example due to collapse, debris, leaks and deflagration.

[PR1310-R;Defined Requirement] In compliance with the requirements for Investment Protection, the ITER facility shall be designed to be reasonably expected to restart and operate in normal situation after an SL-1 event without special maintenance or tests in particular for ESPN components.

6.19 Site signage requirements

[PR3214-R;Defined Requirement] In order to improve safety on the ITER site, all identification, labelling and signage shall be standardised to reduce the likelihood of error.

[PR3215-R;Defined Requirement] Use of signage shall show information in both English and French to reflect the international project culture and its host country.

[PR3216-I] Labelling, colour coding, signage and display material at ITER is to serve the following primary functions:

- Health and Safety;
- Operational;
  - Pipeline Identification;
  - Plant Item Tagging;
  - Electrical Component Labelling;
  - Colours for Electrical Equipment Surfaces;
  - Operator Aids;
- Way finding;
- Information.

[PR3217-R;Defined Requirement] All labelling, colour coding and signage installed on the ITER site shall comply with the ITER Site Signage and Graphics Standards [R33].

7 ENVIRONMENTAL, SAFETY, AND HEALTH REQUIREMENTS

[PR4966-I;Defined Requirement] This chapter identifies the overall environmental, safety and health requirements that ITER must achieve in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

7.1 Natural environment

[PR1105-R;Defined Requirement] The design of all ITER systems, and subsystems, and the planning of the shipping, storage, construction and machine operation, shall take into account the meteorological conditions, and the risks of abnormal conditions. The meteorological conditions, and some Cadarache-specific criteria that are imposed by French and European norms, are reported in [A20].

[PR1987-R;Defined Requirement] The weather conditions shall be monitored continuously.

[PR1106-R;Defined Requirement] Records of the meteorological conditions shall be kept for the whole duration of the project.

[PR1107-R;Defined Requirement] Records of the meteorological conditions shall be used for the preparation and implementation of the ITER site emergency plan.

[PR1108-R;Defined Requirement] A secure weather-warning system shall be set up to warn against abnormal weather conditions that can impact the construction of ITER, or limit the operation of ITER systems and/or create risks for the personnel on site, or for the investment.

[PR1988-R;Defined Requirement] The ITER rainwater management system (taking account of rainwater run-off) shall be designed to protect the ITER installations against a 100-year return period rainfall plus 20% margin.

[PR1989-R;Defined Requirement] The ITER installations shall be designed to withstand a 100-year return flood.

[PR1990-R;Defined Requirement] All nuclear buildings shall be designed to prevent ingress of rainwater and groundwater, in combination with the Precipitation Water Drainage System.

[PR1991-R;Defined Requirement] ITER buildings shall be designed to withstand wind gusts of 166.6 km/h at 50 m above ground level [A11 and A20].

[PR1992-R;Defined Requirement] The ITER installations shall be designed to withstand extreme permanent winds up to 29 m/s at 10 m above ground level [A11 and A22].

[PR1993-R;Defined Requirement] The ITER installations shall be designed to withstand extreme cold conditions; that is, air temperatures down to -25ºC and temperatures of -15ºC for concrete structures and isolated structures [A11 and A22].

[PR1994-R;Defined Requirement] The ITER installations shall be designed to withstand extreme heat conditions; that is, air temperatures up to +45ºC and temperatures of +40ºC for buildings [A11 and A22].

[PR1995-R;Defined Requirement] The ITER installations shall be designed to withstand extreme snow conditions; that is, a normal loading up to 80 daN/m2, an exceptional loading up to 150 daN/m2 [A11 and A22].

7.2 General safety objectives

[PR1110-R;Defined Requirement] ITER shall be designed, constructed, and operated in accordance with the French safety regulations as provided for in Article 14 of the ITER Agreement [R18].

[PR1111-R;Defined Requirement] The potential for the public and workers to be exposed to radiological and other hazards shall be limited by design, construction, operation, and preparation for decommissioning. (Decommissioning is the responsibility of the Host country, France, not of ITER Organization, so requirements during that phase are not covered by ITER project documents.) The policy shall be to ensure that exposures are As Low As Reasonably Achievable (ALARA) and to provide defence-in-depth for potential incidents and accidents.

[PR1112-R;Defined Requirement] For radiological hazards, the dose objectives that are presented in **Table 7-1** shall be respected during normal operation and off-normal events (incidents and accidents) with the following definitions and guidelines:

- **Normal Operation situations** (including operation, testing, and maintenance): events and plant conditions that are planned and required for ITER normal operation, including some faults, events or conditions that can occur as a result of ITER's experimental nature (for example, disruption type I);
- **Incidental situations:** deviations from normal operation, event sequences or plant conditions that are not planned but that are likely to occur due to failures one or more times during the life of the plant;
- **Accidental situations:** postulated event sequences or conditions that are not likely to occur during the life of the plant;
- **Hypothetical events:** beyond the design basis. These are studied to assure that the design has an adequate ultimate safety margin, and are based on the analysis of postulated event sequences that are considered to be implausible, or of extremely low frequency.

[PR1996-R;Defined Requirement] The ITER design shall be failure-tolerant, and no single failure of components shall result in significant consequences to the personnel, public and/or environment.

[PR1118-R;Defined Requirement] No cliff-edge effect: this shall be demonstrated by showing that the magnitude of the consequences of a postulated event is bounded, and that there is no large increase as the safety functions are progressively degraded.

[PR1119-I;Defined Requirement] Counter measures limited in time and space should be addressed by considering consequences in relation to guidelines such as:

- The avoidance of the need for public evacuation, for which a guideline is 50 mSv of avertable dose in a period of no more than one week, according to IAEA recommendations and French regulations;
- The limitation of the need for short-term sheltering, for which a guideline in French regulations is 10 mSv;
- The limitation of the need to ban the consumption of food products, by studying the likely contamination levels and predicting the extent (in space and time) of such banning, if any.

Table 7-1**: Radiological safety objectives**

General safety objectives		
	For personnel	For the public and environment
Situations in design basis		
Normal situations	As low as reasonably achievable, and in any case less than: Maximum individual dose <= 10 mSv/yr Average individual dose for workers classified for radiation exposure <= 2.5 mSv/yr	Releases less than the limits authorised for the installation Impact as low as reasonably achievable and in case less than: <= 0.1 mSv/yr
Incidental situations	As low as reasonably achievable and in any case less than: 10 mSv per incident	Release per incident less than the annual limits authorized for the installation. ≤ 0.1 mSv
Accidental situations	Take into account the constraints related to the management of the accident and post-accident situation	No immediate or deferred counter-measures (confinement, evacuation) < 10 mSv No restriction of consumption of animal or vegetable products
Situations beyond design basis		
Hypothetical events	No cliff-edge effect; possible counter-measures limited in time and space	

7.3 Safety-important systems, structures, and components

7.3.1 General criteria

[PR2377-R;Defined Requirement] ITER Systems, Structures and Components (SSC) that play an important role in the protection of ITER and its environment, shall be classified as Protection Important Components, as considered in the INB order of the 7th February 2012 [R30].

[PR1256-R;Defined Requirement] PIC that play an important safety role, and that contribute in respecting ITER Generic Safety Objectives during an abnormal event, shall be classified as Safety Importance Class (SIC) 1 or 2 or Safety Relevant (SR), following the criteria and methodology that is described in ref [A23], based on the consequences of their failure. The top-level criteria for the identification are:

- Criterion A: their failure can directly initiate an incident or accident leading to significant risks of exposure or contamination;
- Criterion B: their operation is required to limit the consequences of an incident or accident that leads to significant risks of exposure or contamination;
- Criterion C: their operation is required to ensure the functioning of the other SIC components.

[PR2046-R;Defined Requirement] ITER nuclear pressure equipment (ESPN) shall comply with the safety requirements that are associated with its ESPN class for design, manufacture, qualification, installation and operation, testing and inspection [A06].

7.3.2 Auxiliary safety systems

[PR1262-R;Defined Requirement] Support services for systems that provide safety functions shall be designed and operated such that the intended safety function can be fulfilled when required.

7.3.2.1 Safety-relevant power supply systems

[PR1264-R;Defined Requirement] The Class I, II and III safety-relevant power supply systems shall have sufficient generating or stored energy capacity to power SIC loads when necessary, even if one of the safety-relevant emergency generators fails to start, or starts and fails to accept loads [A07].

[PR1265-R;Defined Requirement] The maximum power interruption times shall be:

- Class I: no time delay
- Class II: full load transfer within one-half cycle of the degraded power-sensing signal
- Class III: full load transfer within a specified time of the degraded power-sensing signal (30 s or more, depending on the startup sequence of the electrical consumers that are supplied by the emergency diesel generators).

[PR1270-R;Defined Requirement] The electrical power for all safety control systems shall be non-interruptible.

[PR1271-R;Defined Requirement] Steady-state power supplies shall provide remote-controlled breakers and switchgear, such that all major non-safety loads may be disconnected by the plant electrical control centre.

[PR1272-R;Defined Requirement] The Class I and II safety-relevant power supply systems shall provide power for at least one hour to safety loads.

[PR1273-R;Defined Requirement] The Class I and II safety-relevant power supply systems shall have a reliability that exceeds 0.999 per hour.

[PR1274-R;Defined Requirement] The Class III safety-relevant power supply systems shall have a reliability that exceeds 0.99 per loss of power event.

[PR1275-R;Defined Requirement] The Class III safety-relevant power supply systems shall have sufficient on-site fuel to maintain full safety loads for 3 days.

[PR1276-R;Defined Requirement] Provisions shall be made to auto/manual-synchronize each emergency/backup power source to its bus, for periodic testing.

7.3.2.2 Ancillary fluids

[PR1278-R;Defined Requirement] The compressed air supply or demineralised water supply or SIC nitrogen supply, for instruments that are needed to maintain confinement barriers in accidental situations, shall be separated from other non-SIC supply systems.

7.3.3 Guidelines related to safety importance class (SIC) components

[PR1301-R;Defined Requirement] The design of SIC systems, structures, and components shall include all loading events for which the components may be required to perform a safety function.

[PR1302-R;Defined Requirement] Design rules and standards shall be selected for each system or component, in consideration of SIC, using the guidelines in **Table 7-2**.

[PR2047-R;Defined Requirement] ITER shall be designed to provide redundant and, where appropriate, diverse systems, as necessary to achieve the required reliability.

[PR1311-R;Defined Requirement] Operation, inadvertent actuation or damage to components that are not SIC, shall not prevent SIC systems, structures, or components from accomplishing their safety functions when required.

[PR2048-R;Defined Requirement] ITER shall include appropriate systems to enable the removal of accumulated heat (from electrical equipment) under any design basis situations, in order to protect the personnel and SIC components.

Table 7-2**: Guidelines related to Safety Importance Class (SIC) components**

Issue	Guideline for Safety Important Class components
1. Design (use of codes and standards, degree of conservatism, margins, etc.)	a. Code and regulatory requirements for design, fabrication, testing etc. shall be followed. Deviations from code requirements shall be documented. b. Where an appropriate design code does not exist, an agreed surrogate developed specifically for ITER may be used. c. Testing, proven and documented manufacturing process, control of materials, etc. shall be provided for prototype/non-code items. d. Standard commercial components shall be acceptable if appropriate to conditions of use.
2. Materials (restrictions on which materials can be used, extent of testing, sources of data, margins in data, etc.)	a. Materials to be specified and compliance ensured. b. Materials in standard commercial component may be acceptable if appropriate to conditions of use.
3. Fabrication and Installation (manufacturing process qualification, weld types, welding procedures and welder qualification, etc.)	a. Manufacturing, assembly and installation process/procedures to be specified and compliance ensured. b. Compliance with design code and regulatory requirements (if applicable). c. Standard, proven, commercial component fabrication may be acceptable.
4. Examination (extent of inspection, third party or owner, non-destructive examination, etc. prior to operation.)	a. Examination and acceptance tests during fabrication/construction as needed to ensure safety function to be specified and compliance ensured. b. Compliance with design code and regulatory requirements (if applicable).
5. Testing (pressure testing, performance testing, etc. prior to operation)	a. Testing required to demonstrate safety function to be specified and compliance ensured. b. Compliance with design code requirements (if applicable).
6. In-Service or Periodic Inspection (inaugural, frequency and extent of in-service tests)	a. In-service inspections, monitoring and/or tests or compensatory measures taken to ensure that the equipment can continue to provide its safety functions with the required level of reliability. b. Test records, calibration records, personnel training requirements, etc. to be specified as part of the normal maintenance procedures. c. Compliance with the regulatory requirements
7. Equipment qualification	a. Justification to be provided that component can withstand the normal and abnormal environmental conditions that may arise from an accident at the end of their service life for which their operation is needed. For equipment which is required in the event of an earthquake, this includes seismic qualification.
8. Reliability	a. System to perform its credited safety function even with single active fault/failure (or alternative system available to provide the safety function). b. Use of proven, good industrial quality components may suffice as a justification.
9. Independence, physical separation	a. Safety function shall not be undermined by underlying common cause or cascading failures. b. Protective I&C for a system should be separate and functionally isolated from process instrumentation for that system (separate signal channels appropriately de-coupled and shielded), and with physical separation between redundant channels.
10. Equipment status indication	a. Status under normal conditions and functioning of system under emergency use as appropriate available to operators, possibly at remote location.

7.3.4 System seismic requirements

[PR1305-I;Defined Requirement] SL-1 (Seismic Level-1) response spectra are defined as one-third of the envelope of the SMS and the PALEO-earthquake response spectra. SL-1 corresponds to an event with a probability of the order of 10^{-2} per year, and represents an investment protection earthquake level (following the Nuclear Pressure Equipment regulation, it corresponds to a foreseeable event).

[PR1306-I;Defined Requirement] SL-2 response spectra (also called SSE, Safe Shutdown Earthquake) are defined by the envelope of two spectra: SMS and PALEO-earthquake response spectra. SMS and PALEO-earthquake are calculated in accordance with the ITER Seismic Nuclear Safety Approach [R12].

[PR2178-I;Defined Requirement] SMHV (Séismes Maximaux Historiquement Vraisemblables, or Maximum Historically Likely Earthquakes) are the most penalising earthquakes that are liable to occur over a period of about 1000 years.

[PR1307-I;Defined Requirement] Peak ground accelerations and design response spectra for seismic events are defined in the Load Specifications [A14].

[PR2049-R;Defined Requirement] Those SIC components that are required to perform safety functions during, or after, a SL-2 earthquake, shall be designed such that their capabilities are maintained.

[PR1308-R;Defined Requirement] The collapse, falling, dislodgement or any other spatial response of a component, as a result of an earthquake, shall not jeopardize the functioning of other components that provide a safety function during or after the earthquake.

[PR1309-R;Defined Requirement] The combination of loads from earthquakes with other loading events shall be considered.

[PR2050-R;Defined Requirement] The ITER installation shall be equipped with a seismic detection system to provide a warning notification of a seismic event.

Table 7-3: **System seismic requirements**

PBS	System	Safety Requirements during and following SL-2 earthquake
11	Magnet Systems	No damage to vacuum vessel or cryostat confinement barriers.
15	Vacuum Vessel	Leakage from vacuum vessel no greater than that assumed in safety analysis
16 17	Blanket Divertor	No damage to vacuum vessel
18	Fuelling and Wall Conditioning	No significant leakage of activity from system to rooms Vent detritiation systems (Normal and Standby systems) continue to function; interruption during earthquake acceptable; must be able to be restarted. Able to reach safe storage state for tritium. Maintain confinement (DS) function.
23	Remote Handling Equipment	No significant leakage of activity from system to rooms
24	Cryostat	No damage to vacuum vessel Vacuum vessel pressure suppression system functional
26	Cooling Water System	No significant leakage from system Chilled water to DS continues; interruption during earthquake acceptable; must be able to be restarted.
31 32	Vacuum Pumping and Leak Detection Tritium Plant	No significant leakage of activity from system to rooms Vent detritiation systems (Normal and Standby systems) continue to function; interruption during earthquake acceptable; must be able to be restarted. Able to reach safe storage state for tritium. Maintain confinement (DS) function.
34	Cryogenics System	No impact on SIC and SR components
41	Coil Power Supply & Distribution	Ability to switch off PF coil power supplies remains functional during and after earthquake;
43	Steady State Power Supplies	Ability to provide power to systems providing safety function retained; interruption during earthquake acceptable; must be able to be restarted.
46	Central Interlock System	Not required to remain operational. No impact on SIC and SR components
48	Central Safety System	Safety system remains operational
51 52 53 55	Ion Cyclotron H&CD Electron Cyclotron H&CD Neutral Beam H&CD Diagnostics	No significant leakage of activity from system into rooms
56	Test Blankets	No significant leakage of activity (or lithium, if applicable) from system into rooms
62	Tokamak Complex Hot Cell	Integrity of the main structure is to be maintained Vent and clean-up systems are functional Detritiation systems Fire detection capability remains operational for fire sensitive rooms
64	Radiological Protection	Ability to monitor (estimate) releases from site retained Radiation protection monitoring (possibly portable) available
65	Liquid Distribution	Fire protection available following earthquake

7.3.5 Fire protection for SIC electrical, instrumentation and control components

[PR2052-R;Defined Requirement] The components of two redundant SIC-1 systems shall be located in independent and separate fire sectors (fire sectors are defined in Section 7.9.7).

[PR2367-R;Defined Requirement] Each train (A and B) of the electrical supply and the I&C cabling of the SIC-1 cubicles shall be routed through independent and separate fire sectors.

[PR2053-R;Defined Requirement] The SIC-1 cubicles shall be located in dedicated rooms that do not contain SIC-2 or SR or non-SIC cubicles.

[PR2179-R;Defined Requirement] The SIC-1 cubicles shall be equipped with automatic fire detection and suppression systems.

[PR2054-R;Defined Requirement] The components of SIC-2 systems for which there is a redundancy requirement shall be located in two independent and separate fire sectors.

[PR2055-R;Defined Requirement] The redundancy SIC-2 cubicles can be implemented with the SR, and non-SIC cubicles at dedicated and separate places in the same room. The minimum distance between SIC-2 and non-SIC cubicles shall be 2 m. This room (and not the cubicles themselves) shall be equipped with automatic fire detection and suppression systems.

[PR2056-R;Defined Requirement] Each train (A and B) of the electrical supply and of the I&C cabling of the SIC-2 cubicles, shall be routed through different fire sectors.

[PR2057-R;Defined Requirement] Concerning the SIC-2 cubicles for which there is no redundancy requirement, their implementation in the same room as SR and non-SIC cubicles shall be possible if all the cubicles (SIC-2, SR and non-SIC) are equipped with automatic fire detection and suppression systems.

[PR2058-R;Defined Requirement] In any given room, all the SIC-1 cubicles shall be on the same Train (A or B) for power supply and I&C cabling.

[PR2059-R;Defined Requirement] In any given room, all the SIC-2 cubicles shall be on the same Train (A or B) for power supply and I&C cabling.

[PR2379-R;Defined Requirement] All cables shall be installed in steel cable trays and conduits, which shall provide adequate physical protection and ensure reliable support to the cables during and after installation. In addition, in all nuclear buildings, all cable trays shall have a metallic cover to minimize the risk of fire propagation.

7.4 Inventory control guidelines

[PR1142-R;Defined Requirement] All ITER systems shall be designed and operated so that radioactive and hazardous inventories are maintained as low as reasonably achievable and within the limits that are authorized for the site, plants, zones, systems and components.

[PR2007-R;Defined Requirement] This shall include inventories of all hazardous substances and fuel that is stored on site, as well as radioactive and hazardous waste and effluents that are generated during ITER operation and decommissioning.

[PR2008-R;Defined Requirement] Both the quantity and level of toxicity of such inventories shall be minimized, controlled and monitored.

7.4.1 Tritium inventory

[PR1149-R;Defined Requirement] The total site tritium inventory shall not exceed 4 kg.

[PR1144-R;Defined Requirement] The tritium inventory shall be tracked, with measurement uncertainties estimated to assure that inventory limits are respected.

[PR2009-R;Defined Requirement] Tritium accountancy shall be undertaken on ITER site in accordance with the international obligations related to non-proliferation and export control.

[PR1145-R;Defined Requirement] The mobilizable tritium inventory within the vacuum vessel and extensions, that is, the vacuum boundary (including the Neutral Beam enclosures, Neutral Beam cryopumps, torus crypopumps, and measurement uncertainties) shall not exceed 1000 g.

[PR1146-R;Defined Requirement] The tritium inventory in a fire sector (see Section 7.9) shall be limited to 70 g, with some exceptions that are individually authorized.

[PR1147-R;Defined Requirement] The maximum tritium concentration in the vacuum vessel PHTS cooling water shall not exceed 0.21 $mg.m^{-3}$ (76 MBq/kg), including measurement uncertainties.

[PR1148-R;Defined Requirement] The maximum tritium concentration in the PHTS cooling water of in-vessel components shall not exceed 0.32 $mg.m^{-3}$ (114 MBq/kg), including measurement uncertainties.

7.4.2 Activation products

[PR1153-R;Defined Requirement] The total inventory of in-vessel, activated dust (such as beryllium dust and tungsten dust) shall not exceed 1000 kg, including measurement uncertainties.

[PR1152-R;Defined Requirement] The inventory of beryllium dust and tungsten dust, on surfaces that become sufficiently hot to be reactive with steam or air during incidents, shall not exceed 11 kg for beryllium dust or 76 kg for tungsten dust, or a linear combination of the two species, taking into account that 11 kg beryllium or 76 kg tungsten is the quantity which, if fully reacted with steam, leads to 4 kg hydrogen in the vessel. Deflagration of more than this quantity exceeds 0.2 MPa peak dynamic pressure, the limit for the first confinement barrier (see **Table 7-4**).

[PR1151-R;Defined Requirement] There shall be provisions for measuring or estimating the inventory of activation products to assure that inventory limits are not exceeded.

[PR1154-R;Defined Requirement] The level of activated corrosion products in cooling systems shall be minimized, for example through the selection of materials in systems.

7.5 Confinement of radioactive and hazardous materials

7.5.1 Number of radioactive and hazardous materials confinement systems

[PR1157-R;Defined Requirement] Two confinement systems shall be provided for each principal inventory of radioactive or hazardous material, unless formal project approval for a single confinement system is given.

[PR2018-R;Defined Requirement] Each confinement system shall include one or more static barriers, or dynamic components, to confine the inventory at risk. Static barriers require no moving parts to fulfill their confinement function (such as vacuum vessel, process piping) whilst dynamic components require moving parts (such as isolation devices or detritiation systems).

[PR2017-R;Defined Requirement] Formal project approval for a single confinement system may be given by ITER Organization if justified by analyses that shall show that the failure of this single confinement system results in small consequences.

[PR1158-I;Defined Requirement] In some foreseen normal operations or off-normal events, a confinement system may be temporarily removed from service, or become inoperable. These include: in-vessel maintenance, confinement testing, confinement maintenance; and single system failure.

[PR1164-R;Defined Requirement] When a confinement system is removed, compensatory measures shall be taken to limit the risk in the unlikely event of a challenge to the remaining confinement system. These compensatory measures shall include, as necessary:

- Limiting the mobilizable source term:
    - 350°C baking of the divertor, to reduce the tritium inventory in co-deposited layers, shall be performed;
    - Baking of the Vacuum Vessel and the in-vessel components to reduce the tritium inventory in co-deposited layers, shall be performed;
    - In-vessel dust removal shall be performed, for example vacuuming of dust;
    - The vessel atmosphere shall be detritiated prior to port opening, to obtain a low tritium concentration in the vacuum vessel;
    - Inventories shall be segregated or stabilized to a safe state.
- Limiting the energy that is available to mobilize inventories:
    - Processes shall be shut down;
    - Cooling water systems servicing in-vessel components shall be depressurized.
- Confinement measures:

- o In-vessel maintenance and transfer of in-vessel components shall be carried out, at pressures that are below adjacent room pressures;
- o Filtration and/or detritiation shall be maintained;
- o Leak-tight, fire-resistant transfer casks shall be used to transfer activated components, and components that are contaminated with toxic or radioactive contaminants, between the tokamak and the Hot Cell Building;
- o Alternate, temporary systems and/or barriers (like tents) shall be provided.

7.5.2 Requirements to ensure the radioactive and hazardous materials confinement function

[PR2016-R;Defined Requirement] Rooms that may become contaminated with beryllium aerosol shall be equipped with a confinement system to ensure a minimum beryllium removal efficiency of 99.9% prior to release into the environment.

[PR1181-R;Defined Requirement] The allowable leak-rates for confinement barriers shall be as specified in **Table 7-4**.

[PR1183-R;Defined Requirement] The confinement systems shall be capable of returning the confined volume to below atmospheric pressure within a specified period, following an accident.

[PR1184-R;Defined Requirement] The confinement systems shall be provided with a detritiated, filtered, controlled and monitored pathway, to control any release that follows an incident or accident, until releases without their operation are acceptable.

[PR1185-R;Defined Requirement] Exhaust from ventilation zones shall be routed to filtration/detritiation systems (as required) in order to limit releases to the outside, and to prevent backdraught phenomena occurring from one area to another.

[PR1186-R;Defined Requirement] Pressures within buildings that may receive radioactive leakages shall be kept lower than atmospheric pressure for any weather conditions that are considered in the design.

[PR1187-R;Defined Requirement] Air flow within the buildings shall be directed from lower to higher zones of contamination.

[PR1188-R;Defined Requirement] Ventilation exhaust shall go through controlled and monitored release points.

[PR1189-R;Defined Requirement] Valves that are part of a confinement boundary shall operate within required periods after detection of the onset of an incident or accident.

[PR1190-R;Defined Requirement] The confinement isolation valves shall assume their safe position on loss of power.

[PR1191-R;Defined Requirement] Designated areas within the buildings shall have passive and active features that prevent, detect, retard or extinguish fire that threaten or degrade safety-related components or worker safety.

[PR1244-R;Defined Requirement] If the atmospheric concentration of tritium exceeds 10^8 Bq/m^3, the ventilation of the affected zone shall be automatically isolated, and its depressurization and exhaust management shall be performed by the Detritiation System until the radiological levels are acceptable again, and the HVAC is running.

[PR1192-R;Defined Requirement] The confinement systems shall be designed to ensure their function in all conditions and events for which their function is credited in the safety analysis.

[PR1193-R;Defined Requirement] The confinement systems shall be capable of withstanding all loads and conditions that result from accident sequences.

[PR1194-R;Defined Requirement] Designated areas within the buildings shall resist the effects of accidents such as pressurization failure, explosion, loss of secondary confinement for radioactive inventory, pipe whip, and fire, if failure threatens safety equipment or workers.

[PR1195-R;Defined Requirement] Fire loading shall be minimized, and shall be such as to prevent the spread of fire between fire sectors.

[PR1196-R;Defined Requirement] Emergency power and SIC compressed air shall be provided to dynamic systems/components so as to maintain mitigation function even postulating the loss of off-site power.

[PR1197-R;Defined Requirement] Penetrations through a confinement system shall be justified with respect to their impact on the effectiveness of the confinement system.

[PR1198-R;Defined Requirement] The penetrations through a confinement system shall neither increase the likelihood or consequences of failure of the confinement system, nor introduce new failure modes beyond those that are addressed in the safety analysis: a penetration crossing a fire or a confinement barrier shall reconstitue the barrier properties. Provision of adequate reliability may require the use of such items as double barriers, double bellows, double windows, double isolation valves, and robust sealing.

[PR1199-R;Defined Requirement] Analyses shall be performed to identify credible failure modes, and to provide assurance of reliable performance of credited safety functions.

[PR1200-R;Defined Requirement] Structural integrity of buildings shall be ensured in case of underpressure, for example due to failure of vacuum boundaries (even in worst-case scenarios).

[PR1201-R;Defined Requirement] Systems/components to ensure the confinement function shall be independent, and physically separated, to avoid common mode failure that could lead to loss of both systems.

[PR1202-R;Defined Requirement] The routing/piping of confinement barriers shall be such as to avoid potential damage to confinement systems by movement of equipment during maintenance.

[PR1204-R;Defined Requirement] Systems shall provide the capability for testing and for monitoring parameters, as necessary, to ensure availability and function, as credited in the safety analysis.

[PR1205-R;Defined Requirement] Signals that are associated with parameters, such as pressure or radiation level, shall be provided to actuate safety actions, such as isolation of confinement.

[PR1206-R;Defined Requirement] Confinement systems shall be designed and constructed to allow testing, inspection, monitoring, and maintenance, as needed, to assure the initial and continuing performance that is assumed in the safety analysis.

[PR1207-R;Defined Requirement] In all situations, the Main Control Room (see Section 6.10), or the Backup Control Room, that both have the capability to monitor and to control SIC components and to put the plant in a safe state, shall remain habitable.

7.5.3 Assessment values for confinement of radioactive and hazardous materials

[PR1210-R;Defined Requirement] The values in **Table 7-4** were used in the safety analyses. These design constraints shall be used to ensure that the design stays within the basis of safety analyses.

Table 7-4**: Safety Assessment values for confinement systems**

Component	Parameter	Safety Assessment Value
Components of the vacuum vessel and its extensions providing the 1st barrier of 1st confinement system	Range of design pressure	0 to 0.2 MPa absolute
	Leak rate	<= 1 volume %/day at 0.1 MPa pressure differential
TCWS piping	Max. Pressure Leak rate	5 MPa (FW/BLK) 5.1 MPa (DIV) 2.6 MPa (VV) 3 MPa (NBI) ≤ 1 kg/hr (total for all loops)
VVPSS (activated in case of vacuum vessel overpressure)	Max. Pressure Leak rate	0.17 MPa ≤ 1 volume %/ day at 0.1 MPa pressure differential
Safety drain tank(s) (in case of in-vessel pipe break)	Max. Pressure Leak rate	0.2 MPa <= 1 volume %/ day at 0.1 MPa pressure differential

Component	Parameter	Safety Assessment Value
Vault area (including TCWS vault, CVCSs area and TCWS vault annex, pipe shafts, upper and lower pipe chases, guard pipes	Max. Pressure Leak rate	0.2 MPa < 100 volume %/day at 0.1 MPa pressure differential < 5.5 volume %/day at 300 Pa pressure differential
Gallery rooms (all galleries at all levels, volumes containing piping for fuelling and vacuum pumping between port cells and Tritium Plant Building, rooms containing vacuum vessel pressure suppression system, cryostat space room)	Max. Pressure Leak rate	0.12 MPa < 100 volume %/day @ 300 Pa overpressure < 820 volume %/day at 0.02 MPa pressure differential
Drain tanks room	Max. Pressure Leak rate	0.2 MPa < 100 volume %/day at 0.1 MPa pressure differential < 5.5 volume %/day at 300 Pa pressure differential
Fuel processing systems	Leak rate	No leakage outside guard pipes
Isotope Separation System (ISS) process piping	Leak rate	No leakage assumed outside first confinement
Hot Cell Building C4***, C4** and C3 areas	Max. Pressure Leak rate	0.105 MPa ≤ 1 volume %/hour at normal operating negative pressure (from -0.2 kPa to -0.1 kPa relative to atmosphere) ≤ 5.8 volume %/hour at 5kPa pressure differential
Hot Cell buildings (C2 areas)	Max. Pressure Leak rate	0.105 MPa <100 volume %/day for C2-2 areas at normal operating negative pressure (-0.05 kPa relative to atmosphere) <=240 volume %/day for C2-1 areas at normal operating negative pressure (-0.05 kPa relative to atmosphere)
NBI cell	Max. Pressure Leak rate	0.2 MPa absolute <= 100 volume %/day at 0.1 MPa pressure differential <= 5.5 volume %/day at 300 Pa pressure differential
Port cell	Max. Pressure Leak rate	0.16 MPa absolute <=100 volume %/day at 300 Pa pressure differential <= 1420 volume %/day at 0.06 MPa pressure differential
Detritiation systems	Detritiation efficiency	> 99 % (normal) > 90 % (during a fire)
	HVAC isolation and switching time	< 30 s (between detection at trigger point and isolation)
	HVAC isolation set point	10^8 Bq.m^{-3}
High Efficiency Particulate Air (HEPA) filters	Filter efficiency	> 99.9 % (normal and during a fire)
Tritium Plant (fire sectors)	Max. Pressure Leak rate	0.105 to 0.31 MPa absolute (note 1) < 100 volume % /day at 300 Pa pressure differential < 410 volume % /day at 5 kPa pressure differential
Tritium Plant (outer wall)	Max. Pressure Leak rate	0.105 to 0.19 MPa absolute (notes 1&2) < 24 volume % /day at 300 Pa pressure differential < 100 volume % /day at 5 kPa pressure differential

[PR2279-I;Defined Requirement] Note 1: Depends on location (see [R21]).

[PR2368-R;Defined Requirement] Note 2: Leakage rate limitation at pressure higher than 5 kPa shall consider the following extrapolation law:

Leak rate (volume%/day) = 1.413 x $(\text{Pint-Pext})^{1/2}$

with internal and external pressures Pint and Pext in Pa.

7.5.4 Protection of radioactive and hazardous materials confinement systems

7.5.4.1 Heat removal

[PR2020-R;Defined Requirement] The design of all ITER systems shall provide reliable means to remove the heat that is generated during normal operation, as well as the decay heat of activation products after shutdown, and the heat from potential chemical reactions, if this heat could lead to a challenge to a confinement barrier including indirectly (for example, by elevated temperatures causing a higher rate of a hydrogen-producing chemical reaction).

[PR1214-R;Defined Requirement] The reliability of all ITER systems shall be commensurate with the potential impact on the confinement barrier, using passive means as a back-up, where possible.

[PR1215-R;Defined Requirement] Reliable, long-term, post-accident cooling shall be available to remove the maximum power that is transferred to the vacuum vessel under such conditions.

7.5.4.2 Control of confinement pressure

[PR2021-R;Defined Requirement] ITER shall be equipped with appropriate devices to prevent plasma transients from challenging confinement barriers.

[PR1217-R;Defined Requirement] All ITER systems, structures and components shall provide means to accommodate the pressure loads that are due to unplanned release of coolants, in particular those that are used for in-vessel components, vacuum vessel and superconducting magnets.

[PR2022-R;Defined Requirement] A pressure suppression system shall be incorporated reliably to maintain the pressure rise below the design pressure of the vacuum vessel in the case of an off-normal event such as the ingress of coolant from a failed in-vessel component.

[PR2023-R;Defined Requirement] Passive devices (such as rupture disks) shall be used in the flow path between the vacuum vessel and the Vacuum Vessel Pressure Suppression system (VVPSS) tank.

[PR2024-R;Defined Requirement] A drain line shall be provided to drain water from the vacuum vessel to drain tanks, to limit long-term steam formation.

[PR2025-R;Defined Requirement] The VVPSS and drain tanks shall be de-pressurised, and the gas vented through the Vent Detritiation System.

[PR1218-R;Defined Requirement] The VVPSS shall be provided with a means (Suppression Tank Vent System, ST-VS) to remove non-condensable gases, if present in off-normal events.

[PR1219-R;Defined Requirement] The Tokamak Cooling Water System (TCWS) vault shall be designed to maintain its confinement function in case of a hypothetical double-ended guillotine break of the largest coolant pipe during pulsed operation and baking, with some means to relieve pressure if necessary.

[PR1220-R;Defined Requirement] Overpressure relief to a closed vessel or process shall be provided for liquefied or solidified tritiated gases in the Tritium Plant.

[PR2026-R;Defined Requirement] The system that supplies liquid helium to ITER systems shall limit the potential release of helium within the vacuum vessel to 50 kg (protection measure to guarantee the confinement function of the VVPSS).

[PR2027-R;Defined Requirement] Systems (such as systems of high energy fluid piping/containers, and systems with risks of explosion or with potential failure of moving parts) that could impact SIC systems or confinement, shall be designed to prevent the generation of a missile or to limit the consequences associated with this hazard. This shall include periodic testing and inspection in order to detect precursor signs of associated missile risks.

[PR2028-R;Defined Requirement] Systems that transport high energy fluids (with a pressure greater than 20 bar absolute, or a temperature greater than 100ºC) shall be designed to prevent pipe whipping, or to limit the consequences that are associated with this hazard. This shall include periodic testing and inspection, to detect precursor signs of associated pipe whip risks.

[PR2029-R;Defined Requirement] SIC components shall be protected against the risk that is associated with potential missiles from high energy fluid circuits (pressures greater than 20 bar absolute, or temperatures greater than 100ºC) or other potential sources for missiles (such as internal explosion, failure of a machine with moving parts).

[PR2030-R;Defined Requirement] SIC components shall be protected against the risks that are associated with potential pipe whipping from high energy fluid circuits (pressures greater than 20 bar absolute, or temperatures greater than 100ºC).

7.5.4.3 Control of chemical energy

[PR1225-R;Defined Requirement] The design of all ITER systems shall be such that chemical energy inventories are controlled to avoid energy and pressurization challenges to confinement.

[PR1223-R;Defined Requirement] ITER shall be designed to minimize hydrogen production, to avoid explosive mixtures of hydrogen with air/oxygen with the potential to challenge a confinement barrier, and to minimize the release of chemical energy as heat.

[PR1224-R;Defined Requirement] The total quantity of hydrogen inside the vacuum vessel and connected volumes (HNBI, DNBI, cryopumps) including the hydrogen contained in the circuits or the cryopanels and the one that is produced by chemical reactions (such as between beryllium and coolant water or steam that leaks from a failed in-vessel component) shall be limited to below 4 kg H_2 (that is, the quantity at which deflagration would lead to a maximum pressure exceeding the vacuum vessel safety assessment pressure value, 0.2 MPa). This limitation implies the need to avoid elevated temperatures that would accelerate the beryllium/steam reaction, including the termination of plasma power in the event of loss of cooling of plasma-facing components, and the limitation of dust accumulation on hot surfaces.

[PR1226-R;Defined Requirement] The quantity of air that could enter the vessel (such as through a failed penetration line, or a cooling pipe that has fully drained) shall be limited to below 50 kg of air (that is, the quantity at which a hydrogen or dust detonation could result in a maximum pressure exceeding the vacuum vessel safety assessment pressure value, 0.2 MPa). This limitation may be satisfied by limiting the size of penetrations, and/or by the provision of isolation valves.

[PR1227-R;Defined Requirement] Reliable separation, typically provided by two barriers, shall be provided between volumes that may contain air and hydrogen, including during off-normal conditions.

[PR1228-R;Defined Requirement] Isolation 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.

[PR2031-R;Defined Requirement] Cryogenic needs at locations where there may be a neutron flux or other ionizing radiation shall be met by helium, not liquid nitrogen.

[PR1229-R;Defined Requirement] The use of nitrogen in any region that is subject to radiation shall be justified by an analysis of the possible generation of C14 through activation and of ozone through radiochemical conversion of trace levels of oxygen.

7.5.4.4 Control of halogenated materials

[PR1231-I;Defined Requirement] Halogenated materials include all solids liquids and gases that contain fluorine, chlorine, bromine or iodine. In industrial applications, halogenated materials are often present in such items as process gases, electrical cable insulation, floor and wall coatings, paints and cleaning solvents.

[PR1232-R;Defined Requirement] The use of halogenated materials is forbidden in areas or volumes that are served by the Detritiation System (DS) or by the Tokamak Exhaust Processing System (TEPS). Exceptions shall require a formal project approval. (The procedure for formal project approval shall include approval of the Nuclear Safety and Tritium Plant Responsible Officers.)

[PR2032-R;Defined Requirement] The annual limit for the release of SF_6 gas into the environment shall be maintained at below 0.5% of the overall SF_6 volume that is present on site.

7.5.4.5 Control of magnetic energy

[PR2033-R;Defined Requirement] The superconducting coils shall be designed to avoid quench during plasma operation, including plasma disruptions.

[PR2034-R;Defined Requirement] The magnet system shall be equipped with devices to detect any loss of superconductivity.

[PR1234-R;Defined Requirement] To ensure that failures in magnets do not damage systems that provide safety functions, a means shall be provided to detect a quench in a toroidal field coil, and rapidly to discharge its energy.

[PR1235-R;Defined Requirement] A means shall be provided to detect short circuits in the poloidal and central solenoid coils, and to close the Explosive-actuated Protective Make Switch (EPMS) at the output of the converters that will avoid further delivery of electrical energy.

7.5.4.6 Design provision for internal and external aggressions

[PR1237-R;Defined Requirement] The design of all ITER systems shall include provisions to minimize the potential for other hazards that could challenge confinement systems. These include internal aggressions, such as fire or flooding, and external aggressions, such as earthquakes or extreme weather conditions.

[PR2035-R;Defined Requirement] The ITER installation shall be designed, and appropriate measures taken, to minimize the risk of external fire around the installation and, if such an event were to occur, to prevent its propagation inside the nuclear buildings.

[PR2036-R;Defined Requirement] In the event of an aircraft crash, the design and layout of the radiologically controlled buildings, and of the buildings that contain Protection Important Components (PIC), shall protect all PIC that they contain.

[PR2037-R;Defined Requirement] In the event of an aircraft crash, Protection Important Components (PIC) that are located outside the radiologically controlled buildings shall be provided with sufficient redundancy, and shall be separated in such a way that, if one should be destroyed, the other would remain available and allow the safe state of the facility to be maintained (such as emergency diesel generators).

[PR2003-R;Defined Requirement] The ITER facility shall be sited at an appropriate distance from the site boundary, to mitigate the impact of the overpressure wave and projectiles that are induced by a potential explosion involving an installation that is located close to the ITER site boundary fence.

[PR2004-R;Defined Requirement] The ITER buildings that contain Protection Important Components (PIC) shall be able to withstand an overpressure wave of 50 mbar from whatever direction it comes, for example, due to an explosion on the road close to ITER site boundary fence.

7.6 Radiation protection

[PR1997-R;Defined Requirement] The As Low As Reasonably Achievable (ALARA) principle shall be applied to minimize occupational doses.

[PR1126-R;Defined Requirement] The ALARA procedure shall be applied before work in a radioactive zone is authorized.

[PR1127-R;Defined Requirement] An assessment shall be made of the work that is to be performed during operation, maintenance, and repair so that the design may ensure that worker exposures to radiological and other hazards are ALARA and in all cases within the General Safety Objectives, Section 7.2 and the guidelines for exposure to such hazards.

[PR1128-R;Defined Requirement] Habitable space shall provide safe ingress and egress paths.

[PR1998-R;Defined Requirement] In event of an emergency, appropriate evacuation routes, and associated auxiliary systems, shall enable the safe evacuation of the personnel. This includes but is not limited to evacuation paths and exits, emergency lighting, and communication and warning systems.

[PR1129-R;Defined Requirement] The collective annual worker dose, averaged over the operational life time of ITER, shall be ALARA and in any case shall not exceed an annual target of 0.5 person.Sv.

[PR1130-R;Defined Requirement] Where hands-on maintenance activities in port cells and in other locations in the ITER facility requiring human access are performed, dose rate shall be as low as reasonably achievable.

[PR5355-R;Defined Requirement] Where hands-on maintenance activities in port cells and in other locations in the ITER facility requiring human access are performed, dose rate shall not exceed 100 μSv/h in yellow zones and 10 μSv/h in green zones, at 10^6 s (about 12 days) after shutdown without formal project approval. The dose will be estimated 30 cm from the nearest accessible surface and must take into account the surface contamination, airborne tritium as well as activated materials.

[PR1782-R;Defined Requirement] To minimize radiation exposure to the workers in port cells (with the exception of the Neutral Beam injectors cell), with the bioshield plug in place, the dose rate shall be as low as reasonably achievable, and shall not exceed 10 micro-Sv/hr at 24 hours after shutdown, without formal project approval. The dose rate will be estimated 30 cm from the nearest accessible surface.

[PR1131-R;Defined Requirement] The dose rate and the level of atmospheric and surface contamination, in the rooms that are accessible to personnel, shall be monitored using fixed and/or mobile equipment, depending on the potential or proven hazards.

[PR1132-R;Defined Requirement] Fixed radiation monitoring equipment shall display readings at a central control location, and at points of access to the monitored rooms, so that personnel can assess the radiological status of the rooms before entering.

[PR1133-R;Defined Requirement] First confinement system shall be such that there is no need to wear individual protection equipment in routine operations. The necessity (if any) to wear individual protection equipment in a regulated zone shall be clearly indicated.

[PR1134-R;Defined Requirement] Food, drinks, tobacco, personal cosmetics, handkerchiefs shall not be allowed when a contamination risk may exist.

[PR1135-R;Defined Requirement] The changing rooms shall be separated in two parts, one for civil clothes, the other for work clothes. Showers and sinks shall be available.

[PR1136-R;Defined Requirement] If there is a risk of contamination, the surfaces of habitable room equipment shall be made of materials that are easy to decontaminate.

[PR1137-R;Defined Requirement] Physical measures (such as interlocks, and wearing of protective clothing) and/or administrative measures (such as warning signs, and sound messages) shall be set up to restrict access to rooms that have atmospheric contamination or a dose rate that is higher than the green-zone limit (see Radiological Zoning, Section 7.9.2) and to take account of temporary changes in the classification of rooms, in accordance with the operating mode.

[PR1138-R;Defined Requirement] For radiological zones, other than orange and red (see Section 7.9.2), the individual sources of radiation shall be clearly indicated, and shall be communicated to workers prior to entry.

[PR1139-R;Defined Requirement] Human access shall be forbidden in radiological red and orange zones (see Section 7.9.2), without special authorization from the ITER Director-General.

[PR1140-R;Defined Requirement] Human access to radiological yellow zones (see Section 7.9.2) shall be subject to specific authorization procedures.

[PR1999-R;Defined Requirement] Shielding against ionizing radiation shall be maintained during all design basis situations (including maintenance).

[PR2000-R;Defined Requirement] Radiation protection (fixed or mobile shielding in conjunction with access control for the radiological zone) shall be provided between sources of ionizing radiation and the personnel, in order to limit dose rates to levels that are As Low As Reasonably Achievable (ALARA).

[PR2001-R;Defined Requirement] Temporary access areas or changing rooms for workers to put on and remove any protective equipment that is required to protect against internal/external exposure to ionizing radiation or hazardous substances (such as beryllium) shall be provided, as needed, especially for maintenance operations on ventilation and filtration components. They shall be implemented as close to the working area as possible, and shall include waste collection areas.

[PR2002-R;Defined Requirement] If personnel must enter a zone that is contaminated by radioactive or hazardous substances, they shall wear appropriate personal protective equipment, as required for their protection and to limit the spread of contamination.

7.7 Monitoring

7.7.1 Radiological protection of workers

[PR1241-R;Defined Requirement] ITER Organization shall develop and implement a suitable Radiation Protection Program (RPP) that will include worker classification and access control as well as a system of authorization and associated procedures.

[PR2357-R;Defined Requirement] The ITER RPP shall be reviewed periodically to check its efficiency, and to optimize it where possible.

[PR2005-R;Defined Requirement] Personnel exposure to ionizing radiation shall be monitored via a network of detectors that are located in rooms together with, as appropriate, active and passive dosimeters that are worn by the personnel and individual medical surveillance. This includes but is not limited to monitoring of tritium, neutron, gamma, radon gas, particles, and ^{14}C.

[PR1242-I;Defined Requirement] The personnel access in rooms with airborne contamination is controlled depending on the level and nature of the potential contamination that would result in workers dose, taking into consideration the effectiveness of personnel protection equipment and any other protection measures put in place. Airborne contamination level in a room is expressed in Derived Air Concentration (DAC). DAC is defined as the airborne concentration that leads to the maximum allowed dose for workers (20 mSv), if breathed during the maximum annual work duration (2000 hours), without any external dose. For tritium only exposure, 1 DAC is equal to 3.4×10^5 Bq/m^3.

[PR1243-R;Defined Requirement] Where personnel access is authorized in rooms with airborne contamination, the airborne contamination level shall be monitored with alarms to:

- Alert the personnel when the room contamination level has reached a specified fraction of the defined DAC limit for that room (usually 10%);
- Evacuate personnel when the room DAC limit is reached.

7.7.2 Radiological and environmental monitoring

[PR1246-R;Defined Requirement] The ITER Installation shall include means for monitoring and controlling radioactive or hazardous material releases (gaseous or liquid), as well as dose rates to the public around the site and in areas that are accessible to site staff as well as the impact of the ITER facility on the environment. The necessary provisions will be defined to ensure that ITER meets the related regulatory requirements.

[PR1247-R;Defined Requirement] The design of all ITER systems shall provide systems assuring reliable information on all operational events and accidents, and for monitoring the performance of the confinement and its protection during accidents.

[PR1248-R;Defined Requirement] Protection Important Components (PIC) shall be subject to monitoring, as needed to ensure that safety functions are being performed, as assumed in the safety analysis. The monitoring program may require parameters to be displayed in the Main and Backup Control Rooms (Section 6.10) to ensure the assumed operability and reliability.

[PR1250-R;Defined Requirement] The environmental monitoring system shall be capable of monitoring levels, to ensure respect of the authorized release limits.

[PR1251-R;Defined Requirement] The Radiological and Environmental Monitoring system shall provide monitoring and warnings for chemical and radiological hazards, and for ionizing radiation fields.

[PR1252-R;Defined Requirement] Monitoring shall be provided in rooms/areas that are under access control, and shall confirm or override the logic of the Access Control and Security System to allow or deny access, based on actual measured conditions.

[PR1253-R;Defined Requirement] The Fixed Area Monitors (tritium-in-air, gamma, neutron, radioactive gas, ^{14}C) shall have a minimum detectable level that is consistent with the radiological zoning for the area.

[PR2044-R;Defined Requirement] ITER shall have an environmental monitoring system that is able to operate in cooperation with the CEA site at Cadarache [R23].

[PR2045-R;Defined Requirement] Oxygen levels in zones that are accessible to personnel, where there is a potential risk of anoxia, shall be monitored, with appropriate alarm systems.

[PR1249-R;Defined Requirement] The release monitoring system shall provide measurement of all the release types (including tritium, beryllium, radiological particulate emissions and effluents, ^{14}C, ^{41}Ar, NO_X, CO, CO_2, SO_2).

[PR2039-R;Defined Requirement] The hydrogen atmospheric concentration, in areas with a potential risk of accumulation of tritium, deuterium, protium and/or mixtures of these isotopes, shall be monitored, with appropriate alarm systems provided.

[PR2040-R;Defined Requirement] Rooms, areas or systems that contain or that may contain an explosive atmosphere (such as hydrogen, dust, or ozone) shall be equipped with an appropriate monitoring system to detect the potential explosive atmosphere.

[PR2041-R;Defined Requirement] Prior to opening the double confinement of a hydrogen-bearing system, measures shall be taken to avoid the presence of potentially explosive conditions.

[PR2042-R;Defined Requirement] Appropriate measures shall be taken to minimize and control the in-cryostat ozone inventory, to prevent or minimize the risk of ozone explosion.

[PR2043-R;Defined Requirement] The strength of magnetic fields shall be monitored with fixed and/or portable detectors, as required, with appropriate alarm systems provided.

7.8 Safety requirements for the Test Blanket Modules System

[PR1315-R;Defined Requirement] All ex-vessel parts of the cooling system, and other auxiliary systems of the Test Blanket Modules System, shall be considered part of the first confinement system.

[PR1316-R;Defined Requirement] Decay heat removal shall be achieved by thermal radiation and conduction from the Test Blanket Modules System to the Tokamak.

[PR1317-R;Defined Requirement] Chemical reactions between coolant, air and breeder/multiplier material shall be limited, so that the confinement function of the Test Blanket Modules System is not challenged.

[PR1318-R;Defined Requirement] Self-sustaining chemical reactions shall be precluded by design of the Test Blanket Modules System.

[PR1323-R;Defined Requirement] Hydrogen production by each Test Blanket System (TBS) shall be limited to 2.5 kg hydrogen, to limit the explosion hazard.

[PR1319-R;Defined Requirement] Special consideration for lithium fires shall be made for the Test Blanket Systems that contain a liquid lithium loop.

[PR1320-R;Defined Requirement] Intermediate cooling loops shall be provided for Test Blanket Systems that contain a liquid lithium loop.

[PR1321-R;Defined Requirement] Gaseous leaks of helium from each Test Blanket System to the vacuum vessel shall be limited to 45 kg helium, to assure reliable functioning of the VVPSS.

[PR1322-R;Defined Requirement] Specific provisions shall be implemented to control additional radioactive source terms due to the activation of the Test Blanket Modules.

7.9 Zoning

[PR1325-R;Defined Requirement] Zoning shall be established in the nuclear buildings, to protect people, equipment, and the environment from the effects of perceived hazards during all phases of the facility life cycle. For the ITER facility, zoning applies to: Ventilation, Radiological, Anti-deflagration, Beryllium, Magnetic, Radiofrequency, Fire, Waste.

7.9.1 Ventilation zoning

[PR1336-R;Defined Requirement] Ventilation zones shall be established, based on the estimated atmospheric contamination, consistent with **Table 7-5**.

Table 7-5**: Ventilation zoning standards**

Permanent contamination (DAC) (1)	Accidental contamination (DAC) (1)	Confinement class	Application for ITER ventilation zoning
0	0	C1	Normal HVAC
<= 1	<= 80	C2	Nuclear HVAC with filtered exhaust and able to be detritiated/filtered
<= 1	<= 4000	C3	Filtered exhaust and detritiated depending upon contamination expected
<= 80 < 4000 > 4000	<= 4000 >= 4000 >= 4000	C4* C4** C4***	Recirculated (note 1) filtered and detritiated with filtered and detritiated exhaust stream.

[PR1708-I;Defined Requirement] Note 1: Recirculation is included for enhanced tritium recovery, and does not significantly impact confinement.

[PR1338-R;Defined Requirement] Note 2: The derived air concentration (DAC) shall be used as defined in PR1242 for considering internal exposure hazard and ventilation zoning definition.

7.9.2 Radiological zoning

[PR1340-R;Defined Requirement] Radiation zones shall be established in accordance with the risks of internal exposure (through inhalation of airborne contamination and skin transfer) and of direct external exposure, considering that the workplaces are continuously occupied (according to the planned maximum occupancy rate for each workplace). Each zone corresponds to a dose rate range, and has associated time and access conditions.

[PR1342-R;Defined Requirement] As presented in **Table 7-6**, the radiological zoning shall be based on the total effective dose for the whole body or on equivalent doses to the skin or extremities (hands, forearms, ankles and feet) and/or radon dose

[PR1343-R;Defined Requirement] The radiological zoning shall be defined for each plant operation state, following the criteria of **Table 7-6**.

[PR2060-R;Defined Requirement] The marking (signing) of the radiological zones from blue to red (and for radon/extremities zones) shall follow the applicable norms (ISO361) and shall be clearly posted on all access routes to the zones. The marking of the radiological zones shall be modified according to every change to the zoning.

[PR1344-R;Defined Requirement] Access conditions for the personnel to the radiological zones shall be as given in **Table 7-7**.

[PR2378-R;Defined Requirement] The tunnel for cask transfers between the Tokamak Building and the Hot Cell Building shall be designed and constructed to avoid needing an exclusion zone outside the nuclear buildings during the cask transfers [R32].

Table 7-6**: Radiological zoning**

<table>
<tr><th>Zone</th><th>Control type (2)</th><th>Radiological Zone Identification</th><th>Total effective dose for the entire body - external and internal exposure (1)</th><th>Maximum total equivalent dose on extremities or skin</th><th>Maximum effective dose from radon</th></tr>
<tr><td>Unregulated zone</td><td></td><td>White zone</td><td>< 80 µSv/month</td><td>< 4 mSv per month</td><td>< 6 mSv per year</td></tr>
<tr><td>Supervised zone</td><td>Specially regulated</td><td>Blue zone</td><td>1.25 mSv integrated on a month</td><td rowspan="6">Extremities/skin zone: > 4 mSv per month</td><td rowspan="6">Radon zone: > 6 mSv per year</td></tr>
<tr><td>Controlled zone</td><td>Specially regulated</td><td>Green zone</td><td>4 mSv integrated on a month</td></tr>
<tr><td>Controlled zone</td><td>Specially regulated</td><td>Yellow zone</td><td>2 mSv integrated on one hour</td></tr>
<tr><td>Controlled zone</td><td>Forbidden</td><td>Orange zone</td><td>< 100 mSv integrated on one hour
AND
< 100 mSv averaged over a second</td></tr>
<tr><td>Controlled zone</td><td>Forbidden</td><td>Red zone</td><td>≥ 100 mSv integrated on one hour
OR
≥ 100 mSv averaged over a second</td></tr>
</table>

[PR1347-R;Defined Requirement] Note 1: Total dose rate shall be the sum of external dose rate and internal dose rate. Internal dose rate can be calculated, using airborne concentration, as a ratio of “Derived Air Concentration” (DAC) (see definition of DAC in PR1242).

[PR1348-R;Defined Requirement] Note 2: See **Table 7-7.**

Table 7-7**: Access conditions for personnel**

Radiological Zone identification	Required signage	Access for classified workers	Access for non-classified workers
Blue zone or radon / extremities / skin zones	Trefoil sign indicating risk of external exposure (blue)	Permitted to type A and B workers	Specific authorization required from the employer
Green zone or radon / extremities / skin zones	Trefoil sign indicating risk of internal or external exposure (green) (1)	Permitted to type A and B workers	Specific authorization required from the employer
Yellow zone or radon / extremities / skin zones	Trefoil sign indicating risk of internal or external exposure (yellow) (1)	Limited to only type A and B workers who need to operate in these zones	Specific authorization required from the employer, with additional provisions and information
Orange zone or radon / extremities / skin zones	Trefoils indicating: • risk of external exposure (orange) • risk of internal exposure (orange)	Prohibited except with consultation and authorization	Prohibited
Red zone or radon / extremities / skin zones	Trefoils indicating: • risk of external exposure (red) • risk of internal exposure (red)	Prohibited except with consultation and authorization based on a nominative register at every entrance in such zone	Prohibited

[PR1354-R;Defined Requirement] Note 1: Under normal situations, with no detectable atmospheric contamination permitted in green or yellow zones, the trefoils shall only indicate the risk of external exposure.

[PR1355-R;Defined Requirement] Note 2: French regulations classify workers as Type A and Type B and defines specific provisions for non-classified workers, pregnant women, less than 18 years old workers or for exceptional emergency situations. Type A workers shall include those whose exposure to ionizing radiation may lead to a dose greater than 6 mSv during 12 consecutive months, and Type B workers include those that are not type A and whose exposure to ionizing radiation may lead to a dose greater than 1 mSv during 12 consecutive months. Other constraints on skin, extremities or crystalline apply for workers likely to be exposed.

7.9.3 Anti-deflagration zoning

[PR1357-I;Defined Requirement] Anti-deflagration zoning provides a means of locating explosion risks in the buildings, in order to implement suitable risk prevention measures, both in terms of building design and of the use of their systems and equipment.

[PR1358-R;Defined Requirement] In accordance with the European Directive 94/9/EC (ATEX), hazardous locations shall be classified, and anti-deflagration zones established, according to the frequency with which an explosive atmosphere may form, and the length of time for which this atmosphere lasts:

- Zone 0: location where an explosive atmosphere consisting of a mixture of air and inflammable gases, vapours or mist is present permanently, frequently or during long periods;
- Zone 1: location where an explosive atmosphere consisting of a mixture of air and inflammable gases, vapours or mist is liable to be present occasionally under normal operation;
- Zone 2: location where an explosive atmosphere consisting of a mixture of air and inflammable gases, vapours or mist is not likely to be present under normal operations or, if present, only for short periods;
- Zone 20: location where explosive atmosphere in the form of combustible dust cloud is present in the air permanently, frequently or during long periods;
- Zone 21: location where explosive atmosphere in the form of combustible dust cloud is liable to be present occasionally under normal operation;
- Zone 22: location where explosive atmosphere in the form of combustible dust cloud is not likely to be present under normal operation or, if present, only for a short period.

[PR1366-R;Defined Requirement] Ventilation shall provide sufficient air renewal to avoid hydrogen concentration in rooms where there is an explosion risk.

[PR2061-R;Defined Requirement] The concentration of hydrogen in air (tritium, deuterium, protium and/or mixtures of these isotopes) shall not exceed 1% in explosive areas to stay below 1/4 of the inferior inflammability limit.

[PR1367-R;Defined Requirement] If there is no potential for an explosive mixture, the area shall be defined as having "no zoning".

[PR1369-I;Defined Requirement] "Normal operation" means situations where facilities and equipment are used in accordance with their design parameters.

7.9.4 Beryllium zoning

[PR1373-R;Defined Requirement] Beryllium zones shall be established in accordance with the zoning criteria that are listed in **Table 7-8**.

[PR1374-R;Defined Requirement] Access to beryllium zones shall be restricted in accordance with **Table 7-8**.

[PR1375-R;Defined Requirement] Proper signage shall be placed in areas, to be consistent with **Table 7-8** beryllium zoning requirements.

Table 7-8**: Beryllium zoning criteria and access control**

Beryllium zone	**Beryllium zoning criteria**		**Access and control conditions for personnel**
	Beryllium atmospheric concentration (µg/m³)	Beryllium surface contamination (µg/m²)	
Beryllium non-controlled zone	< 0.01	< 0.1	No plausible risk of presence of beryllium, no access limitation.
Beryllium controlled zone	0.01 < [Be] < 0.2	0.1 < [Be] < 10	No risk of dispersal of beryllium aerosols, vapour, and dusts. Possible presence of beryllium, in concentrations below the detection limits of monitoring equipment. Access limited to 'beryllium' qualified personnel. Stay times and possible safeguards adapted to the risk of exposure, depending on the operations to be performed.
Beryllium breathing protection zone	> 0.2	> 10	Presence of contamination and/or potential overshooting of controlled beryllium zone limit values. Access limited to 'beryllium' qualified personnel, Confined and ventilated zone requiring use of respiratory protection gear.

7.9.5 Magnetic zoning

[PR1378-R;Defined Requirement] Thresholds and conditions of exposure of personnel to magnetic fields shall be established as per **Table 7-9**.

[PR1379-R;Defined Requirement] Preventive actions (including signage) shall be taken in areas where the magnetic thresholds that are identified in **Table 7-10** might be exceeded.

[PR1380-R;Defined Requirement] Magnetic field zones and access and control conditions shall be established as per **Table 7-11**.

Table 7-9**: Exposure limit values (ELVs) for magnetic fields**

Frequencies	**Sensory effects**		**Health effects**		
	Localised head exposure	**Localised limbs exposure**	**Entire body**	**Localised head exposure**	**Localised limbs exposure**
Static EMF	2 T	8 T	8 T	-	-
0 Hz ≤ f < 1 Hz	2 T	8 T	8 T	-	-
1 Hz ≤ f < 10 Hz	0.7/f V/m	-	1.1 V/m	-	-
10 Hz ≤ f < 25 Hz	0.07 V/m	-	1.1 V/m	-	-
25 Hz ≤ f < 400 Hz	0.0028 V/m	-	1.1 V/m	-	-
400 Hz ≤ f < 3 kHz	-	-	1.1 V/m	-	-
3 kHz ≤ f < 100 kHz	-	-	$3.8\ 10^{-4}$ f V/m	-	-
100 kHz ≤ f < 10 MHz	-	-	$3.8\ 10^{-4}$ f V/m	10 W/kg	20 W/kg
10 MHz ≤ f < 0.3 GHz	-	-	0.4 W/kg	10 W/kg	20 W/kg
0.3 GHz ≤ f < 6 GHz	10 mJ/kg	-	0.4 W/kg	10 W/kg	20 W/kg
6 GHz ≤ f < 300 GHz	-	-	50 W/m^2	-	-

Table 7-10**: Thresholds for other areas that should be properly signed**

Interference risk with active implanted devices (e.g. pacemakers)	0.5 mT
Attraction and projectile risk in the fringe field of high field strength sources (missile effect) (>100mT)	3 mT

Table 7-11**: Magnetic field zones and access conditions**

Zone Name	**B [mT]**	**Access and Control Condition for Personnel**
Non-controlled magnetic zone	< 3 mT (access granted to pacemakers holders also if < 0.5 mT)	No access limitation Warning signs for persons wearing a cardiac stimulator
Controlled magnetic zone	3 mT ≤ B < 200 mT	Access limited to 8 hours per day
Prohibited magnetic zone	≥ 200 mT	Access prohibited, except under exceptional circumstances or in case of duly certified temporary access

7.9.6 Radiofrequency zoning

[PR1385-R;Defined Requirement] The radiofrequency exposure for personnel who are working in areas that are adjacent to sources of hazard shall comply with the following limits that are recommended by the International Commission on Non-Ionizing Radiation (ICNIR).

[PR1386-R;Defined Requirement] The exposure limit for workers expressed as Equivalent Power density for EC H&CD waves shall not exceed 5 $mW.cm^{-2}$ (in free space; that is areas accessed by workers and not in transmission lines).

[PR1387-R;Defined Requirement] The exposure limit for workers expressed as Equivalent Power density for IC H&CD plane waves shall be less than 1.0 $mW.cm^{-2}$ (in free space).

7.9.7 Fire zoning

[PR1396-R;Defined Requirement] Fire zoning shall be set up to limit the spread of fire and fumes, and to confine the fire within predefined volumes, to allow enough time to extinguish the fire. Fire zoning shall be based on fire sectors and confinement sectors in accordance with regulations.

[PR1394-I;Defined Requirement] Note that the two defined areas (Fire Sectors and Confinement Sectors) can be congruent.

7.9.7.1 General requirements

[PR1390-I;Defined Requirement] A fire sector is a volume that is composed of a room or group of rooms that are delimited by walls that are designed to keep an internal fire (within the volume) from spreading outside (or to keep an external fire from spreading inside) for a duration that is sufficient to extinguish the fire.

[PR1392-I;Defined Requirement] A confinement sector is a volume that is composed of a room or group of rooms with characteristics that are designed to limit the dispersal of toxic or radioactive materials outside this volume in the event of fire.

[PR2260-R;Defined Requirement] Confinement sectors are associated with fire sectors when there is an identified risk of radioactive substances being released and leading to a dose of 10 mSv to the site boundary. These sectors shall be designed to prevent and limit the release of such substances to the environment.

[PR2062-R;Defined Requirement] To prevent or limit the propagation of fire within the ITER installation, each room that has, or may have, a potential fire risk shall be classified into fire sectors, according to the level of this risk.

7.9.7.2 Fire sector boundaries and characteristics

[PR1398-R;Defined Requirement] Fire sector boundaries shall ensure there is no spread of radioactive or hazardous substances to a room or zone in which these substances cannot be confined and kept from spreading to the environment.

[PR1400-R;Defined Requirement] Fire sector boundaries shall ensure there is no loss of safety function through failure of SIC components.

[PR1401-R;Defined Requirement] The radioactive inventory shall be controlled in the fire sectors of the buildings by physical means, administrative means, or both, in order to limit the radioactive inventory that is potentially vulnerable to a single fire.

[PR1403-R;Defined Requirement] Fire loading and fire resistance shall be controlled in the fire sectors of the buildings, to avoid damage, such that at least one confinement barrier remains intact.

[PR1404-R;Defined Requirement] Fire sectors shall be surrounded by physical, fire-resistant barriers, with a fire resistance rating of at least two hours.

[PR1405-R;Defined Requirement] Doors and penetrations through fire barriers shall offer the same degree of fire resistance as the rest of the fire barrier. In the event of an internal fire, doors shall maintain their integrity, insulation and leak tightness with a pressure difference equal to +/-0.05 bar between the affected fire sector and the adjacent areas.

[PR1406-R;Defined Requirement] Openings through fire barriers shall be filled-in using a material that guarantees the same degree of fire resistance as the rest of the fire barrier, using a process that is verified by an approved organization.

[PR1407-R;Defined Requirement] Electric cables and other materials that run through a fire sector shall not contribute to the spread of fire (C1 cables, or cables that are protected by a flame-retardant material for a radiologically-controlled building).

[PR1408-R;Defined Requirement] Electric cables, and other materials that run through a fire sector, and that are required to operate in the event of fire, shall be fire-resistant (CR1 cables, or cables that are protected by a fire-resistant material for radiologically-controlled buildings).

[PR1409-R;Defined Requirement] Ventilation ducts and pipes that run through a fire sector shall be protected by a fire-resistant material.

[PR1410-R;Defined Requirement] Ventilation ducts that open into a fire sector shall be equipped with fire valves or dampers. These valves or dampers shall be installed as near as possible to the fire sector walls. The piping between the valve or damper and the fire sector boundary shall be protected by a fire-resistant material.

[PR1412-R;Defined Requirement] HEPA filters shall be fire-resistant (minimum efficiency of 99.9% during a fire).

7.9.8 Waste zoning

[PR1420-R;Defined Requirement] Waste zones shall be established within the nuclear facilities, and shall include:

- "Radioactive waste zones" (Zones de Déchets Nucleaires, ZDN, in French) within which the waste that is produced is liable to be contaminated or activated. This waste consists of very low-level (TFA, in French), low-level (FAVC, in French), intermediate-level (MAVL, in French) as the ITER facility does not generate high-level (HA, in French) waste.

- "Non-radioactive waste zones" (Zones de Déchets Contrôlés, ZDC, in French) within which the waste that is produced is not liable to be contaminated or activated.

[PR1424-R;Defined Requirement] Waste from a radioactive waste zone shall be processed in a radioactive treatment facility.

[PR1425-R;Defined Requirement] Waste from a non-radioactive waste zone shall be processed in a non-radioactive treatment facility.

7.10 Effluents

[PR1427-R;Defined Requirement] All effluents (airborne and waterborne) shall be identified, and their quantity and characteristics shall be estimated for normal operation and maintenance. This shall include, as a minimum, radioactive materials, hazardous materials, direct radiation, magnetic fields, and thermal emissions.

[PR1428-R;Defined Requirement] Releases of radioactive materials shall be kept As Low As Reasonably Achievable (ALARA) and in all cases within design and operational guidelines.

[PR1429-R;Defined Requirement] Radioactive tritiated gaseous effluents shall be released through the Detritiation System to control releases.

[PR2261-R;Defined Requirement] Means shall be provided to detect a leakage of coolant from a primary heat transfer system loop into the TCWS vault, so that the vault can be isolated to minimize releases.

[PR2262-R;Defined Requirement] Fluid effluents shall be monitored, characterized, controlled and discharged per approved procedures.

[PR2069-R;Defined Requirement] Systems that contain water or liquid effluents shall be designed to minimize leakage.

[PR2071-R;Defined Requirement] Systems that contain water or liquid effluents shall be suitably monitored (including periodic inspection) in order to detect, as soon as possible, a leakage, and shall be equipped with an appropriate alarm system.

[PR2070-R;Defined Requirement] In the event of a water or liquid effluent leak, it shall be possible to isolate the leaking system, purge it and/or collect the leakage.

[PR2072-R;Defined Requirement] Potential liquid effluents that are generated by the fire suppression substances, or a leak of an effluent-bearing system, shall be collected, to prevent dispersion of radioactive or toxic substances.

7.11 Radioactive and hazardous waste

[PR1435-R;Defined Requirement] Radioactive and other hazardous liquid and gaseous effluents that arise from operation shall be limited to the maximum extent possible in the design, and their impact shall be maintained As Low As Reasonable Achievable (ALARA) during operation.

[PR1436-R;Defined Requirement] For solid radioactive and other hazardous wastes that arise throughout the plant life (from construction through to decommissioning and dismantlement) the quantity and the level of radioactivity, or toxicity, shall be minimized by design and operation.

7.12 Occupational health and safety

[PR2263-I;Defined Requirement] Occupational Health and Safety (OHS) is related to the prevention or mitigation of all risks of injury or long term illnesses from workplace exposure other than nuclear risks.

[PR2264-I;Defined Requirement] IO staff and contractors might be exposed to a wide range of "non-nuclear" hazards, such as:

- Beryllium;
- Cryogenic hazards, including oxygen deficiency hazards;
- Explosion risk (hydrogen or other);
- Fire risk;
- Electrical hazards;
- Laser risk;
- Circulation of and interaction with heavy plant (truck, cranes).

[PR2265-R;Defined Requirement] Hazard identification and risk assessment (HIRA) process shall be implemented in design phase in order to:

- Identify workplace OHS hazards whose control shall have impact on ITER systems design;
- Assess the level of risk related to them in order to control them.

[PR1444-R;Defined Requirement] Preventive measures shall be considered in the design phase to reduce the frequency or the probability of an event and that should establish the rules to follow for the construction, installation and utilization of equipment in order to protect people and equipment from OHS risks.

[PR1446-R;Defined Requirement] Systems that contribute to mitigation measures - to reduce the severity of an event - shall have a high reliability. This includes using automated systems, reducing the reliance on human intervention.

[PR1448-R;Defined Requirement] Information shall be provided on panels at relevant places to inform people about the risks, the individual protection systems needed, the state of the equipment, alarms and other information relevant to occupational health and safety.

[PR1438-I;Defined Requirement] The ITER facility utilizes large quantities of cryogens in the cryoplant and tokamak areas during operation. Risks include:

- Asphyxiation by displacement of oxygen in the event of large spills;
- Material-behaviour changes by contact with cryogens;
- Burns from contact with cryogens;
- Pressurization from rapid expansion of cryogenic gases.

[PR1447-R;Defined Requirement] Appropriate training shall be mandatory before access to a zone that has cryogenics-related safety risks.

[PR1449-R;Defined Requirement] The wearing of appropriate individual protection equipment shall be mandatory before accessing an area where there may be non-nuclear safety risks to workers.

[PR1450-R;Defined Requirement] The cryogenic installations are exposed to the risk of anoxia and they shall comply to the general requirement on monitoring of oxygen levels in zones accessible to personnel.

[PR5421-I;Defined Requirement] Regarding workers protection during maintenance activities, the requirements PR5417 and PR5419 applies.

7.13 Fire protection

[PR1280-R;Defined Requirement] Fire protection for the ITER site shall be provided to meet the following objectives:

- Prevent fire and fire damage that could lead to the release of radioactive or hazardous material to the environment;
- Limit releases in the case of postulated fires to within acceptable limits;
- Ensure personnel safety;
- Limit damage to the machine and property (investment protection).

[PR1286-R;Defined Requirement] It shall be possible to maintain ITER in a safe condition during and following a fire.

[PR1287-R;Defined Requirement] Fire protection systems in zones containing radioactive material shall help to minimize the potential for fire to challenge confinement systems or to disable safety functions.

[PR1288-R;Defined Requirement] For each radioactive inventory, at least one confinement system shall remain intact during and following a fire.

[PR1291-R;Defined Requirement] To provide an adequate degree of fire protection for ITER, a “defense-in-depth” fire protection program shall be established that includes:

- Fire prevention;
- Fire detection, and suppression where appropriate;
- Fire mitigation, to prevent spread and to limit the consequences of a fire, and to extinguish it as soon as possible;
- Fire incident response.

[PR2267-R;Defined Requirement] Fire loads in rooms containing tritium shall be kept to a minimum and shall include only those materials related to the process.

[PR2268-R;Defined Requirement] Because they may introduce or generate fire loads, maintenance activities in rooms containing tritium shall be limited to periods when the tritium process is shut down and the hydrogen is removed from the process.

[PR2269-R;Defined Requirement] Any fire loads introduced or generated in a room containing tritium during tritium process shutdown shall be removed before tritium processing starts up.

[PR2270-R;Defined Requirement] The quantity of combustible materials and loads in each room or area shall be limited to the minimum process requirements, with appropriate control and monitoring measures.

[PR2271-R;Defined Requirement] Potential ignition sources shall be prevented or limited, and where an ignition source is present in a room, area or component appropriate protection measures shall be taken.

[PR2272-R;Defined Requirement] Each room of the nuclear buildings and of the building containing Protection Important Components (PIC) shall be equipped with a fire-detection and alarm system appropriate to that risk and to the environmental conditions of the room.

[PR2273-R;Defined Requirement] Each room of the nuclear buildings and of the building containing Protection Important Components (PIC) shall have fire suppression systems (fixed and/or mobile) appropriate to the fire risk, the response time of the fire detection system, the potential presence of contamination sources and the need to protect personnel (including fire fighters) and PIC against the fire and associated secondary hazards (including those resulting from the type of fire suppression system used).

[PR2274-R;Defined Requirement] In the event of a fire in a ventilation zone, the air supply of the ventilation system towards this zone shall be isolated.

[PR2275-R;Defined Requirement] Appropriate auxiliary systems for fire protection shall be provided within buildings such as permanent emergency lighting, communication system.

8 CONSTRUCTION REQUIREMENTS

[PR4967-I] This chapter identifies the overall construction requirements that ITER must achieve in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

8.1 Classification of systems, structures, and components

[PR1456-R;Defined Requirement] ITER Systems, Structures, and Components (SSC) shall be classified for safety class, quality class, seismic class, vacuum class, maintenance class and remote handling class.

[PR1457-I;Defined Requirement] Criteria and guidelines for Safety Important Class (SIC) are provided in Section 7.3.

[PR1458-R] Quality classification shall be determined in accordance with the ITER Quality Classification Determination [R11].

[PR1459-R;Defined Requirement] Seismic classification shall be determined in accordance with the ITER Seismic Nuclear Safety Approach [R12].

[PR1460-R] Vacuum classification shall be determined in accordance with the ITER Vacuum Handbook [A05].

[PR1461-R] Remote handling classification shall be determined in accordance with the ITER Remote Maintenance Management System [A17].

8.2 Materials, processes, and parts

[PR1463-R] The materials for the ITER systems shall be selected in accordance with the properties specified in the Materials Properties Handbook [A21].

8.2.1 Magnetic materials

[PR1465-R] Magnetic materials with a relative permeability that is greater than 1.03 shall not be used within the cryostat boundary without formal project approval.

[PR1466-R] The materials and fabrication processes of the in-vessel components shall be selected considering whenever possible the minimization of the error fields.

[PR1467-I] Outside the cryostat, the use of magnetic materials is allowed for the building structural elements.

[PR1468-I] In the Tokamak Building, magnetic materials with high permeability can be used to provide magnetic shielding to Neutral Beam Injection components, electronic components and cooling water components (for example, pump motors) provided error field requirements are met (see Section 4.3.2.4).

[PR1470-R] The blanket module materials and manufacturing process shall not modify the average local field in a blanket module by more than 0.1%.

8.2.2 Vacuum materials, processes, and parts

[PR1472-R] ITER shall be designed, constructed, and operated in accordance with the requirements specified in the ITER Vacuum Handbook [A05].

8.2.3 Tritium processing and inventory management

[PR1474-R] ITER shall be designed, constructed, and operated in accordance with the requirements in the ITER Tritium Handbook [A16].

8.2.4 Corrosion prevention and control

[PR2180-R;Defined Requirement] Materials and their joints which are in contact with fluid shall be selected taking into account their corrosion resistance during ITER lifetime.

[PR1476-R;Defined Requirement] To prevent corrosion damage of materials in cooling circuits, the appropriate water chemistry shall be established and controlled within specified limits for all modes of operation including commissioning, plasma operation, baking, and hot and cold standby states.

[PR2181-R;Defined Requirement] The methods for controlling the corrosion behaviour during operation shall be established for all systems.

8.2.5 Activation

[PR2182-R;Defined Requirement] Materials which are subject to neutron irradiation shall be selected taking into account their possible activation during ITER operation.

[PR1478-R;Defined Requirement] Depending on operational conditions (such as maximum expected neutron flux and fluence) and allowable dose rate, the requirements for specific impurities in chemical composition of materials which give significant contribution to activation of materials shall be established. These limits on impurities' concentration shall be technically feasible and reasonably achievable. The requirements for limit of impurities are defined in [A25].

[PR2183-R;Defined Requirement] Low activation materials shall be selected when it enables to reduce the contact dose, decay heat and the activation level of radioactive waste, according to reference [A25].

8.3 Codes and standards

[PR1480-I] The Codes and Standards for ITER Mechanical Components [A06] is a comprehensive document that defines the codes and standards to be used in the design of ITER mechanical components. It invokes the Structural Design Criteria for ITER Magnet Components [A09] and Structural Design Criteria of In-vessel Components [A10] so they are not separately invoked in this PR.

[PR1481-R] ITER mechanical components shall be designed in accordance with the codes and standards identified in the Codes and Standards for ITER Mechanical Components [A06].

[PR1482-R] ITER electrical components shall be designed in accordance with the codes and standards identified in the Electrical Design Handbook Part 3: Codes and Standards [A07].

[PR1483-R] ITER buildings shall be designed in accordance with the ITER Structural Design Code for buildings, Part I: Design Criteria [A11] and Part II: Technical Specifications [A12].

[PR1484-R] ITER magnets shall be designed in accordance with ITER Magnet Superconducting and Electrical Design Criteria [A18].

8.4 Mechanical design

[PR1486-R] ITER Load Specifications [A14] shall be used as the basis for the preparation of fully comprehensive detail load specification on single systems or components.

8.5 Electrical design

[PR1489-R] The design of the earthing and lightning protection systems shall provide a safe environment for personnel and avoid electrical hazards.

[PR1490-R] All surfaces, including bus and cooling lines, that are exposed to the cryostat vacuum shall be connected at the earth point of the tokamak.

[PR1491-R] All in-vessel components except for active parts and special sensors shall be electrically connected to the vacuum vessel.

[PR1492-R] The vacuum vessel shall be electrically connected to the cryostat via the connecting ducts and cryostat bellows (along with the tube-type penetrations at the lower level of the machine).

[PR1493-R] Magnet structures shall be connected to or insulated from each other in such a way to avoid flowing of large induced currents during plasma operation.

[PR1494-R] The vacuum vessel shall be electrically insulated from the magnet system.

[PR1495-R] For EMC considerations, electrical conducting objects within the tokamak complex shall be earthed as described in the chapter 8 of the EDH-Part 4 [A07].

[PR1496-R] Coil power supplies shall be capable of being isolated from the earth grid, in order to test for leakage current.

[PR1498-R] To limit the amplitude of the fault current, the earthing system of the coil power supplies (PBS41) shall be based on soft/floating earthing with a system for the real-time detection of the first earth fault.

[PR1499-R] Buildings, outdoor structures and power supply components shall be protected by a lightning protection system to avoid transient overvoltages and ensure the proper plant operation.

8.6 Electromagnetic compatibility

[PR1771-I] IEC standards define the limits of perturbation for electronics devices and the limits of susceptibility. All these standards are included in IEC 61000.

[PR1501-R] As a general requirement for electromagnetic compatibility and shielding, all ITER electrical components shall be designed to comply with IEC 61000.

[PR5304-I] For a few systems, it is not feasible to shield the component and limit its electromagnetic emission within the constraints specified in IEC 61000 therefore deviation from this standard is allowed. Concerned systems are the magnets (with their DC busbars) and RF H&CD systems.

[PR5305-I] For RF H&CD systems, personal safety limits are provided in Section 7.9.6.

[PR1772-R] The components installed near the tokamak shall withstand the magnetic field generated by the magnets and their DC busbars [R20].

[PR5306-R] Radio frequency leakage through vacuum vessel opening and diagnostics windows shall be avoided. In particular any conductive circuit that can pick up RF power from inside the vacuum vessel (VV) shall be properly filtered to avoid RF radiation outside the VV.

[PR5307-I] A typical example is the glow discharge system circuits which feature an electrical circuit in the vicinity of the plasma and have insulated feedthroughs and external power circuits that risk radiating high RF power levels outside the VV and disturb cryogenic measurements and diagnostics.

8.7 Toxic products

[PR1503-R;Defined Requirement] All solid, liquid and gaseous toxic products needed for ITER construction and operation shall be identified and their quantity and characteristics estimated for normal operation, including maintenance operations.

[PR2184-R;Defined Requirement] The inventory for all solid, liquid and gaseous toxic products shall be limited to the maximum extent possible in the design, and their impact maintained As Low As Reasonable Achievable (ALARA) during operation.

[PR1504-R;Defined Requirement] Specific design provisions shall be undertaken to avoid that solid, liquid and gaseous toxic products affect workers during normal operations and to avoid spread of these materials into rooms accessible to workers.

[PR2185-R;Defined Requirement] These provisions shall consider potential corrosive, inflammable and explosible issues associated with these toxic products.

[PR1505-R;Defined Requirement] Provisions shall allow monitoring and characterization of gaseous or liquid releases of the toxic products towards the environment.

8.8 Transportability

8.8.1 Maximum component size and weight

[PR1509-R] The limitations in size and weight of the components (including packages and frames) shall be as follows:

- Maximum length: 19 m with an exception for crane beams: 47 m on a single line;
- Maximum width: 9 m;
- Maximum height: 9.1 m;
- Maximum weight: 600 t.

8.8.2 Tritium shipments

[PR2186-I] 20 to 25 kg of tritium will be required for D-T operation of ITER.

[PR1516-R;Defined Requirement] Tritium Shipments shall be in B(U) containers capable of storing not more than 70 g of tritium. (B(U) is an IAEA classification for containers qualified for transportation of radioactive material.)

8.9 Identification and control of items

[PR1518-R] ITER Organization shall implement a method for identifying items at their receipt and during all stages of manufacturing, delivery and installation.

[PR1519-R] Where traceability is required, as for all SIC systems, structures or components, or for parts whose lifecycle has to be monitored during the life of the project, unique identification of individual items or batches shall be implemented.

[PR1520-R] ITER Organization shall develop and maintain a database that allows to secure and access all records related to any traceable item.

8.10 Standardization

[PR1522-R] A standardization policy shall be implemented as much as reasonably acceptable throughout all ITER plant systems in order to ensure as much interchangeability of similar components as possible, the objective being to reduce the cost of operating and maintaining the ITER machine with a high availability by reducing:

- Complexity of the design;
- Number of required spare parts;
- Number of tools required to repair/adjust/calibrate the components;
- Diversity of skills and training required to operate and maintain the systems;
- Number of procedures required to operate and maintain the systems;
- Complexity of decommissioning, dismantling and recycling operations at the end of the lifecycle of the machine;
- Costs and delays associated with all of the above.

[PR1531-R] Each plant system shall take into account as a crucial design principle the importance of using interchangeable components inside its own boundaries.

[PR1532-R] Major components being used in sufficient numbers in several plant systems and/or procured by several Members shall be considered for standardization:

- At least through the definition of standard specifications that are issued in design handbooks in order to assure interchangeability;
- Or, ONLY in specific cases and AFTER prior agreement of the concerned Members, through the suggestion of specific model(s) and supplier(s) in the Procurements Arrangements.

[PR2187-R] Analysis of the current design documents shall lead to the definition of a list of high-priority components suitable, relative to their number and cost, to be considered for standardization.

[PR1536-R] Dedicated Experts Working Groups shall be designated to assess the requirements and operating conditions of those components in the different systems where they will be used, and to take into account technical and commercial factors to produce a limited number of specifications and standards "packages" that could be used as widely as possible in the systems and required from the suppliers in order to ensure that their products are compatible and can share common spare parts.

8.11 Design verification

[PR1538-I] The design verification is the activity confirming the overall design integrity of systems and/or structures through the design reviews / alternative calculations / qualification tests, to ensure that safety-related systems or structures are adequately designed and that design requirements are adequately incorporated in the design.

[PR1539-R;Defined Requirement] The scope of design verification shall be applied to all safety-related systems, structures, and components. However, certain important non-safety-related systems and structures are included in the design verification at the discretion of ITER Organization management.

[PR1540-I] Design verification should be conducted at the earliest possible time after the related design documents have been sufficiently developed to permit a meaningful design verification, prior to release for fabrication, installation, or release to another organization for use in design and/or manufacturing activities.

[PR1541-R;Defined Requirement] Design verification by qualification testing shall be performed as early as possible and prior to the point when related system, structures, and/or components are installed.

[PR1542-R] In all cases, design verification shall be completed prior to the design being relied upon to perform its function.

[PR1545-R;Defined Requirement] If an alternate calculation method or a qualification test method for design verification of a system, structure or component has not been developed or there is difficulty in its application, then the design review shall be used as the design verification method of the system, structure or component. The design review shall be performed either as specific review by one or more independent reviewers competent in a single discipline or by multi-disciplinary review performed by a multi-disciplinary review team.

[PR1547-R;Defined Requirement] If it is possible to verify the design integrity of a system, structure or component by design verification using only design calculation, and an alternate calculation method has been developed, then the alternate calculation shall be used as the design verification method of the system, structure or component.

[PR2188-R;Defined Requirement] If performance of a related component has not been verified due to application of a new design concept, then the qualification test by model test under conditions that simulate the most adverse design conditions shall be used as the design verification method for the component.

[PR1549-I;Defined Requirement] Qualification testing to verify the acceptability of a specific design will be conducted in accordance with approved procedures that address, at a minimum:

- Use of adequate instrumentation;
- Provisions for test monitoring;
- Specification of suitable environmental conditions. For the environmental conditions:
    - Refer to the relevant zonings in chapter 7.9.2 and the Safety Roombook [A27] for workers radioprotection;
    - For radiation conditions for equipment qualification, refer to radiation maps [A26];
- Delineation of test prerequisites, such as calibrated instrumentation, appropriate equipment, trained personnel, and data acquisition equipment;
- Demonstration of acceptable performance under conditions that simulate the appropriate adverse design conditions;
- Delineation of performance specifications, including acceptable deviations from baseline (or mean) benchmarks.

[PR1558-R] The design verification shall be made in accordance with ITER Management and Quality Program [R16] and the Design Review Procedure [R15].

[PR1559-R] For DA/Supplier scope, DA/supplier-level design verification shall be demonstrated and traced, within their scope of work for the ITER Project, in accordance with relevant DA/Supplier procedure (compatible and accepted by IO) at the different Design Reviews in accordance with the expected maturity. In some cases, this activity may continue throughout the Manufacturing and Construction phase.

[PR1561-I] The Performance Requirements in Section 4 are verified by determining the Quality Class in accordance with the "Quality Classification Determination" document [R11]. The appropriate actions are then applied in accordance with the ITER Management and Quality Program (MQP) [R16].

9 ADDITIONAL REQUIREMENTS

[PR4968-I] This chapter identifies other requirements that ITER must achieve at least in its final configuration to undertake the D-T plasma operation during the FPO phase. Additional requirements for three previous configuration are given in Chapter 10.

9.1 Integrated Logistics Support

[PR1564-R] ITER shall define and implement a project-wide strategy for Integrated Logistics Support (ILS). In particular this shall cover:

- Test facilities and testing management
- Spares inventory management
- Technical documentation
- Facilities management
- Packaging, handling, storage, and transportation
- Technical and operational human resources management for sustainable maintenance and operations.

9.2 Security

[PR1573-R;Defined Requirement] ITER Organization shall guarantee the security of its "Installation Nucléaire de Base (INB)" as defined in French laws and regulations, including the equipment and facilities required for the operation of this installation and its related installations and equipment, during their construction, operation, deactivation, and in providing for decommissioning, in accordance with the Headquarters Agreement signed between the French Government and ITER Organization [R25].

[PR1574-R] Security functions shall be provided to ensure the following security objectives for the ITER plant:

- The safety of persons by ensuring that access to hazardous or potentially hazardous areas is possible only if certain protective conditions are satisfied, and limiting such access to suitably qualified persons;
- The security and protection of the plant from sabotage and access by unqualified personnel;
- The confidentiality of data, designs, other information and materials covered by export control and non-proliferation treaties.

[PR1579-R] The ITER security system shall achieve the security objectives by at least:

- Ensuring that access to controlled zones and equipment is only permitted when local environmental conditions are appropriate;
- Only permitting authorized persons to enter controlled zones;
- Determining who is, or has been at a particular moment, present within controlled zones;
- Ensuring that access to information and documents is controlled and authorized.

[PR1584-R] The security functions shall be supported both by technical systems and by management procedures.

[PR1585-R] Safeguards shall be implemented to guard against the theft of tritium.

[PR1586-R] Information pertaining to areas where tritium is stored, such as the Tritium Plant Building, shall be treated as secure information.

9.3 Documentation

[PR1588-R] The ITER documentation such as all specifications, drawings, technical manuals, test plans, procedures, and installation instruction data shall be documented in accordance with the requirements of ITER Management and Quality Program (MQP) [R16] and of ITER Configuration Management Plan [R14].

[PR1589-R] The technical documentation shall include repair manuals, maintenance manuals, user manuals, and other documents that are used to operate or support the system and data to support these, such as:

- Technical manuals;
- Technical and supply bulletins;
- Transportability guidance technical manuals;
- Calibration procedures;
- Repair parts and tools lists;
- Corrective maintenance instructions;
- Preventive maintenance and predictive maintenance instructions;
- Drawings/specifications/bills of materials/ “as built” technical data packages;
- Software documentation;
- Component lists;
- Safety Important Component list;
- Lifting and tie-down instructions;
- Hazardous Material documentation.

[PR2257-R] The technical documentation shall be provided to ITER for all plant systems, their components and parts.

[PR1604-R] The technical documentation shall be supplied in a standardized electronic format in the English language.

9.4 Personnel and training

[PR1606-I] In order to ensure the availability of suitably qualified staff to operate and maintain ITER over its lifecycle, it is necessary to ensure the availability in sufficient numbers of personnel having not only the required formal qualifications, but equally training, knowledge and experience of operating and maintaining of the ITER machine.

[PR1607-R] ITER Organization shall implement a training plan and manage human resources to ensure the transmission of knowledge and experience throughout the ITER lifecycle.

[PR2258-R;Defined Requirement] Staff shall be suitably trained and qualified to undertake ITER operations (including maintenance activities).

9.5 PR requirements compliance

[PR1609-R] Compliance of the PR requirements shall be demonstrated throughout the entire ITER Project lifecycle, including their proper propagation throughout the ITER PBS and the supply chain and the justified definition of the propagated requirements. This demonstration shall be performed and traced in accordance with the corresponding procedures with, where deemed necessary, the use of requirement propagation and compliance matrices. Compliance demonstration for requirements critical to the demonstration of the success of the ITER Project shall be assessed as a minimum at the different Design Review Gates, for approval and authorization of use.

10 ADDITIONAL REQUIREMENTS FOR THE STAGED APPROACH PHASES

[PR4947-I;Defined Requirement] The functions and performances for the D-T plasma operation (specified in Chapters 3 and 4) will be developed sequentially following the Staged Approach Strategy. The ITER Research Plan [R07], as amended by [R37] and the ITER Preliminary Functional Description [R34] identify the objectives of the four staged approach phases, including the related specific functions and performances to be achieved by ITER and its systems.

[PR4948-I;Defined Requirement] The ITER systems and sub-systems required to achieve these objectives are listed in the preliminary Staged Approach Configuration - PBS Level 3 [R35]. This includes some captive components that must be installed on-site before planned construction works introduce constraints preventing its later installation. The temporary components are identified in [R36].

10.1 Plasma scenarios for H, D and He operation, commissioning plasma scenarios

[PR533-R] ITER shall allow operation over a range of plasma parameters in hydrogen (H), helium (He) and deuterium (D) to allow the necessary commissioning with plasma and preparatory experiments for deuterium-tritium operation to be completed.

[PR534-R;Defined Requirement] Plasma scenarios for H, He and D operation shall necessarily encompass a wide range of plasma parameters up to the maximum technical capability of the tokamak in order to address:

- Development of the discharge scenario required for full D-T phase reference operation, including features such as plasma current initiation, current ramp-up, formation of a divertor configuration and current ramp-down;
- Commissioning of core tokamak systems, such as Poloidal Field system, Correction Coils system, in-vessel coil systems up to the maximum value of plasma current and toroidal field (15 MA / 5.3 T);
- Progressive commissioning of the Plasma Control System, together with interlock and protection circuits and safety-important systems, as required by the technical performance of the tokamak and the level of plasma performance achieved;
- Development of the "Progressive Start-up" strategy as per the RPrS [R08] for determination of maximum loads on vessel and in-vessel structures due to disruptions and vertical displacement events (Section 4.3.7);
- Provision of experimental data to validate the ITER licensing assumptions;
- Commissioning with plasma of all tokamak auxiliary systems H&CD, diagnostics, fuelling, pumping for which D-T plasmas are not required;
- Characterization of hydrogenic retention and dust production, and demonstration of techniques for their control;
- Commissioning of appropriate mitigation techniques against the consequences of plasma transients and loss of control;
- Demonstration of power handling capabilities of plasma-facing components within the heat load limitations of H, He, and D plasmas including semi-detached divertor operation and low impurity level;
- Achievement of type-I ELMy H-modes for sufficient durations to allow an adequate physics basis for the implementation of full D-T plasma operation including aspects such as H-mode power threshold scaling and energy and particle transport at the ITER scale;
- Finalization of nuclear commissioning with a minimum amount of tritium.

[PR547-R] Plasma scenarios for H, He and D operation will be established within the facility design basis for D-T operation, excepting that the neutral beam injection system shall be capable of high power, long pulse operation in hydrogen at 870 keV.

[PR4969-I] Specific limits on fuelling rates and pressure in divertor that apply for the different plasma operations are given in Section 4.3.11.

10.2 First Plasma phase

10.2.1 Objectives of the FP Phase

[PR4972-R] During the FP phase (at the end of its integrated commissioning campaign), ITER shall produce plasma pulses in non-active hydrogen or helium for at least 100 ms with at least 100 kA of plasma current and half nominal currents in coils.

[PR4973-I] The First Plasma will be low current and circular, and no vertical stability control will be provided.

10.2.2 Required capabilities for the FP phase

[PR4975-R] To achieve FP plasma operations, ITER shall have the following operational capabilities:

- Torus and cryostat vacuum environment with appropriate confinement and shielding for the FP operations;
- Toroidal field at 50 % of nominal value;
- Sufficient electron cyclotron resonance heating to support breakdown and burn-through;
- Fuelling by gas injection;
- Wall conditioning by baking and glow discharge cleaning;
- Diagnostics for First Plasma (e.g. Magnetics, Hα and vis. Bremsstrahlung, Visible TV camera);
- System to manage non-active fuel gas and to process tokamak exhausts;
- Ancillary systems required to support these capabilities (e.g. site infrastructure & buildings, power, cooling, instrumentation & controls, personal and environmental monitoring, assembly tools and remote handling systems).

[PR4976-R;Defined Requirement] Following FP milestone, the subsequent Engineering Operation campaign shall enable to commission the Magnet systems to full current. The Vertical Stabilisation coils shall also be tested to demonstrate their qualification regarding insulation, pressure and temperature.

10.2.3 System-specific requirements for FP Phase

[PR4978-R] All in-cryostat components shall be installed before cryostat closure including permanent maintenance fixtures - there will be no planned Cryostat re-opening after closure at the end of Assembly I.

[PR2391-R] During First Plasma phase, temporary First Plasma Protection Components shall protect the VV and other already installed in-vessel components to withstand possible plasma disruptions of 1 MA plasma at 2.65 T at 6.2 m, for a discharge duration of up to 3 s. They are foreseen to be replaced by the final components during Assembly II.

[PR2392-R] Blank flanges shall be provided for all penetrations of the Torus vacuum boundary that require a temporary blank according to the assembly and maintenance plan.

[PR2176-I] Temporary GDC electrodes will be installed at the vicinity of port plugs for the first plasma (PBS18).

[PR2393-R;Defined Requirement] Temporary isolation procedures (for example, lock off of temporary openings, waveguides, unused bus-bars) shall be planned, agreed and safety assessed.

[PR2394-R] During the testing and commissioning of the magnets to be performed prior to starting First Plasma operations, the in-cryostat and in-vessel pipework that is not required to be functional shall be dry and isolated before introduction of Magnet cryogenics. This measure is aimed at preventing a potential Helium leak that could affect in-cryostat and/or in-vessel components, and preventing any subsequent Helium release to the environment.

[PR2396-I] Neutral Beam, IC H&CD, and equatorial EC H&CD will not be required for first plasma.

[PR4983-R] For First Plasma, the EC H&CD system shall be able to provide 6.7 MW to assist plasma initiation.

10.3 Pre-Fusion Plasma Operation-1 phase

10.3.1 Objectives of PFPO-1 Phase

[PR4986-R] During the PFPO-1 phase, ITER shall operate a diverted plasma in non-active Hydrogen and Helium for several tens of seconds flattop in L-mode, with a plasma current of at least 7.5 MA.

10.3.2 Required capabilities before the PFPO-1 phase

[PR4988-R] Prior to starting the PFPO-1 Plasma Operation, ITER shall have the following operational capabilities, in addition to those for the FP phase:

- In-vessel components installed with their Plasma Facing Components;
- Magnets operational at full current;
- Fusion Power Shutdown System operational;
- Plasma control associated with vertical stabilization, error field correction, and disruption mitigation;
- Full electron cyclotron resonance heating;
- Additional fuelling with 2 pellet injectors;
- Appropriate Beryllium management capability;
- Additional diagnostics and ancillary systems required to support these capabilities.

[PR4989-R] The PFPO-1 phase shall enable to commission the installed EC H&CD system and to test the plasma vertical stabilization and the disruption management.

[PR5357-I] Operation at a toroidal field of 1.8 T may be undertaken to allow early access to H-mode operation during the PFPO-1 phase.

10.3.3 System-specific requirements for the PFPO-1 phase

[PR2395-R;Defined Requirement] The VV depressurization function shall be available for PFPO-1 operations considering the inventory of water due to the presence of the IBED-PHTS (as if installed completely).

[PR4993-R] For PFPO-1 operation, the EC H&CD system shall provide the full power of 20 MW to maintain plasma temperature and current.

[PR4995-R] Appropriate provisions shall be made to enable the implementation of the HNB system upgrade. This includes the installation of the captive components for HNB03.

10.4 Pre-Fusion Plasma Operation-2 phase

10.4.1 Objectives of PFPO-2 Phase

[PR4998-R] The PFPO-2 phase shall enable to develop further the diverted plasma operation with the following two steps:

- Plasma in Hydrogen or Helium for several tens of seconds flat top in L-mode, with a plasma current of 15 MA and nominal TF current;
- Plasma in Helium or Hydrogen in H-mode, with a plasma current of 7.5 MA and half nominal TF current, including test of the Edge Localized Modes (ELM) control.

10.4.2 Required capabilities before the PFPO-2 phase

[PR5000-R] Prior to starting the PFPO-2 Plasma Operation, ITER shall have the following operational capabilities, in addition to those for the preceding phases:

- Additional fuelling with 2 more pellet injectors;

- Edge Localized Modes control;
- Full heat & current drive capability (ECH, ICH, HNB1, HNB2, provisions for HNB3);
- Additional diagnostics and ancillary systems required to support these capabilities.

[PR5001-I] The first set of TBM modules (EM-TBM) and the associated systems will be installed for the initial phase of TBM test programme.

10.4.3 System-specific requirements for the PFPO-2 phase

[PR5005-R] For the PFPO-2 phase, the HNB01 and HNB02, installed in their final configuration, shall provide NB heating and current drive of up to 33 MW.

10.5 Fusion Power Operation phase

10.5.1 Objectives of FPO phase

[PR5008-I] During the FPO phase, ITER produces plasmas with Q≥10 for period of 300 to 500 seconds with 500 MW fusion power.

[PR5009-I] The beginning of FPO phase is a gradual transition from Deuterium to full D-T plasma operation.

[PR5010-R] The FPO Deuterium Operation shall aim at achieving 15 MA plasmas in Deuterium with a robust plasma control, and commissioning ITER systems prior to operations with Tritium.

[PR5011-R] The FPO Initial D-T Operation shall aim at achieving 15 MA H-mode plasma in Deuterium-Tritium, and producing plasmas with several hundreds MW of fusion power.

[PR5012-I] The full D-T Operation aims at developing long pulse/steady state operation in inductive, hybrid and non-inductive D-T plasma scenarios, with the objective of meeting the Project’s mission goals:

- Inductive reference scenario: Pfus ≥ 500 MW, Q ≥ 10, burn time ≥ 450 s;
- Hybrid reference scenario: Pfus ≥ 400 MW, Q ≥ 5.4, burn time ≥ 1000 s;
- Non-inductive reference scenario: Pfus ≥ 356 MW, Q ≥ 6, burn time ≥ 3000 s;
- Assess to the possibility of achieving the flexibility scenarios (see Section 4.3.1.2).

10.5.2 Required capabilities before each FPO campaign

[PR5014-R] Prior to starting the FPO Deuterium Operation, ITER shall have the following operational capabilities, in addition to those for the preceding phases:

- Plasma control associated with equilibrium control, heat load control, machine protection;
- Reliable disruption mitigation and ELM control;
- Plasma heating and current drive to full power and pulse durations of at least several tens of seconds, including plasma initiation, fuelling and control, plasma parameters measurements, and wall cleaning;
- All fuelling systems operational;
- Extensive diagnostic capability including that required for "advanced control" (for example, current profile) and for burning plasma physics studies (14 MeV neutron diagnostics calibrated at end of Assembly Phase IV);
- The Tritium Plant commissioning should have progressed sufficiently to support the evolving requirements of the experimental programme.

[PR5015-R] Prior to starting the FPO D-T Plasma Operation (that is, prior to introduction of tritium at concentration much greater than 1%), ITER shall have the following operational capabilities, in addition to those for the preceding phases:

- Tritium Plant operational at the level which allows a sufficient D-T throughput to maintain the scenario development programme in short-pulse operation (few tens of seconds of flat-top) with adequate control over the fuel mixture;
- Tritium accounting techniques established;
- Tritium removal techniques demonstrated;
- Isotope mix measurement and control techniques should preferably have been established: at least in HD, and possibly with trace T in D;
- Successful demonstrations of simulated α-particle confinement and stability could be an advantage; e.g. using ICRF system in the FPO phase;
- Successful demonstration of burn control using auxiliary heating as a proxy for fusion power would also be advantageous (can only be conducted in the low-current D Phase of the Research Plan when H-mode threshold is low enough to allow simulated α-heating).

10.6 Additional safety provisions

[PR5020-R;Defined Requirement] The previous Chapters, especially Chapter 7, specify the definitive provisions that ITER shall possess in its final configuration (that is, for FPO onwards) in order to achieve its safety functions.

[PR5021-R;Defined Requirement] For the following safety functions, these definitive provisions shall be implemented before the start of PFPO-1 (at the end of Assembly and Integrated Commissioning phase II):

- The confinement of toxic materials;
- Support systems required to enable the confinement of both radioactive and toxic materials and radiation protection function (for example, site infrastructure and buildings, power, fluid systems, instrumentation and controls, personal and environmental monitoring, assembly tools and remote handling systems);
- Prevention of hazards challenging safety functions;
- Environmental surveillance;
- Crisis management.

[PR5022-R;Defined Requirement] For the radiation protection from mobile sources, definitive provisions shall be available at the start of PFPO-2 (at the end of Assembly and Integrated Commissioning phase III).

[PR5023-R;Defined Requirement] For the confinement of radioactive or toxic materials, definitive provisions shall be available for the start of Assembly and Integrated Commissioning phase IV (prior to FPO).

[PR5024-R;Defined Requirement] Prior to the definitive provisions being available, the safety functions to be achieved by the intermediate ITER configurations shall be guaranteed using temporary provisions with requirements similar to the definitive provisions (for example, redundancy, back-up power supply) or with reduced requirements scope (including case by case: no redundancy, limited use of back-up power supply, and limited resistance to external events), in particular for covering:

- The confinement of toxic materials as soon as they arrive on-site;
- Workers, public and environment protection against exposure to toxic and radioactive materials.

[PR5025-R;Defined Requirement] The appropriateness of any temporary provisions shall be demonstrated by systematic safety analysis based on the quantities, location, and operation related to radioactive and toxic inventories.

[PR5026-R;Defined Requirement] Activities prior to the start of FPO shall not degrade definitive provisions installed for the previous phases (see also PR1311-R).

11 APPENDICES

11.1 Abbreviations

AC	Alternating Current
ACSS	Access Control and Security System
AD	Applicable Document
ADc	Complementary Applicable Document
ADi	Input Applicable Document
ALARA	As Low As Reasonably Achievable
ASN	Autorité de Sûreté Nucléaire (French nuclear safety authority)
ATEX	ATmospheres EXplosibles (Explosive Atmosphere)
BCR	Backup Control Room
Be	Beryllium
BES	Beam Emission Spectroscopy
BLK	Blanket
BM	Blanket Module
BSM	Blanket Shield Module
C	Celsius
C	Carbon
CAD	Computer Aided Design
CC	Correction Coil
CCWS	Component Cooling Water System
CD	Current Drive
CEA	Commissariat à l’Energie Atomique
CFC	Carbon-Fibre Composite
CHWS	Chilled Water System
CIS	Central Interlock System
CMM	Cassette Multifunctional Mover
CMM	Configuration Management Model
CODAC	Control, Data Access and Communication
CS	Central Solenoid
CSS	Central Safety System
Cu	Copper
CVCS	Chemical & Volume Control Systems
CW	Continuous Wave
CWS	Cooling Water System
CXRS	Charge Exchange Recombination Spectroscopy
D	Deuterium
DA	Domestic Agencies
DAC	Derived Air Concentration
DC	Direct Current
DC	Divertor Cassette
DDG	Deputy Director-General
DG	Director-General
DIV	Divertor
DMS	Disruption Mitigation System
DNB	Diagnostic Neutral Beam
DOORS	Dynamic Object Orientated Requirements System
DS	Detritiation System
EC	Electron Cyclotron
ECH	Electron Cyclotron Heating
EC H&CD	Electron Cyclotron Heating & Current Drives
EDH	Electrical Design Handbook
ELM	Edge Localized Mode
EMS	Environment Monitoring System
EP	Equatorial Port
EPMS	Explosive-actuated Protective Make Switch
ESPN	Nuclear Pressure Equipment

FAVC	Faiblement Activé à Vie Courte
FDR	Final Design Review
FP	First Plasma (phase)
FPO	Fusion Power Operation phase
FPSS	Fusion Power Shutdown System
FW	First Wall
GDC	Glow Discharge Cleaning
GIS	Gas Injection System
H	Hydrogen
H&CD	Heating & Current Drives
HAE	Human Assisted Equipment
He	Helium
HEPA	High Efficiency Particulate Air filters
HF	High Frequency
HF	Human Factor
HFIP	Human Factors Integration Plan
HFS	High Field Side
H-mode	High Confinement mode
HIRA	Hazard Identification and Risk Assessment
HNB	Heating Neutral Beam
HRS	Heat Rejection System
HTL	Hands-on Tools
HTW	Highly Tritiated Water Treatment
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
I	Information
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IBED-PHTS	Integrated loop of Blanket, ELM-VS, and Divertor PHTS
IC	Ion cyclotron
ICD	Interface Control Document
ICH	Ion Cyclotron Heating
IC H&CD	Ion Cyclotron Heat and Current Drive
ICRF	Ion Cyclotron Resonant Frequency
IEC	International Electrotechnical Commission
ILS	Integrated Logistics Support
INB	Installation Nucléaire de Base (for the PR: the ITER Installation)
INIRC	International Non-Ionizing Radiation Committee
IO	ITER Organization
IR	Infra-red
ISO	International Organization for Standardization
ISS	Isotope Separation System
IVVS	In-Vessel Viewing System
LFS	Low Field Side
Li	Lithium
LIM	Limiter
L-mode	Low confinement Mode
LP	Lower Port
LS	Load Specifications
LTM	Long Term Maintenance
MARFE	Multifaceted Asymmetric Radiation from the Edge
MAVL	Moyenne Activité et durée de Vie Longue
MC	Maintenance Class
MCR	Main Control Room
MDTns	Mean Down Time not-scheduled
MDTs	Mean Down Time scheduled
MHD	MagnetoHydroDynamic
MQP	Management Quality Program
MSE	Motional Stark Effect
MUT	Mean Up Time

N2	Nitrogen
NB	Neutral Beam
NBI	Neutral Beam Injection
NBPS	Neutral Beam Power Supply
Nb3Sn	Niobium-Tin
NbTi	Niobium-Titanium
NPA	Neutral Particle Analyzer
NTM	Neo-classical Tearing Mode
OHS	Occupational Health and Safety
OLC	Operating Limits and Conditions
PBS	Plant Breakdown Structure
PbLi	Lead-lithium
PCR	Project Change Request
PCS	Plant Control System
PD	Plant Description document
PED	European Pressure Directive
PF	Poloidal Field
PFC	Plasma-Facing Component
PFPO-1	Pre-Fusion Power Operation 1 phase
PFPO-2	Pre-Fusion Power Operation 2 phase
PHTS	Primary Heat Transfer Systems
PIA	Protection Important Activity
PIC	Protection Important Component
PLM	Product Lifecycle Management system
POS	Plasma Operation State
POZ	Plant Operation Zone
PPA	Plasma Performance Assessment
PPEN	Pulsed Power Electrical Network
PR	Project Requirements document
PR-ADMx	Project Requirements Applicable Documents Matrix
PS	Power Supply
PS	Project Specification document
Q	Ratio of fusion power to auxiliary heating power
QA	Quality Assurance
R	Requirement
R&D	Research & Development
RAMI	Reliability, Availability, Maintainability, Inspectability
RCC-MR	Design and Construction Rules for Mechanical Components of FBR Nuclear Islands (AFCEN)
REMS	Radiological and Environmental Monitoring System
RF	Radio Frequency
RGA	Residual Gas Analyzer
RH	Remote Handling
RHE	Remote Handling Equipment
RHM	Remote Handling Manual
RMP	Resonant Magnetic Perturbations
RMS	Root Mean Square
RPP	Radiation Protection Program
RPrS	Report Préliminaire de Sûreté
RQM-RO	Requirement Management Responsible Officer
RTE	Réseau de transport d'Electricité (Operator of the French electric power transmission grid)
RWM	Resistive Wall Mode
SDC	Structural Design Criteria
SDS	Storage and Delivery System
SF6	Sulphur hexa-fluoride
SIC	Safety-Important Component
SL	Seismic Level
SOF	Start of Flat top
SRD	System Requirement Document
SRO	Safety Responsible Office

SS	Stainless Steel
SS	Steady State
SSC	Structure, System and Component
SSEN	Steady State Electrical Network
STM	Short Term Maintenance
ST-VS	Suppression Tank Vent System
T	Tritium, Tesla
TAE	Toroidal Alfven Eigenmode
TBC	To Be Confirmed
TBM	Test Blanket Module
TBS	Test Blanket System
TC (T-C)	Tokamak Complex
TCS	Test & Conditioning State
TCWS	Tokomak Cooling Water System
TEPS	Tokamak Exhaust Processing System
TF	Toroidal Field
TFA	Très Faible Activité
TFC	Toroidal Field Coil
TGCS	Tokamak Global Coordinate System
Th	Thermal
TP	Tritium Plant
TS	Thermal Shield
TS	Thomson scattering
UP	Upper Port
UPS	Uninterruptible Power Supply
UV	Ultra Violet
VDE	Vertical Displacement Event
VDS	Vent Detritiation System
Vis/IR	Visible / Infra-red
VS	Vertical Stabilisation coil
VUV	Vacuum Ultra Violet
VV	Vacuum Vessel
VVPSS	Vacuum Vessel Pressure Suppression System
W	Tungsten
WBS	Work Breakdown Structure
WDS	Water Detritiation System
ZDC	Zone de Déchets Nucléaires (Radioactive waste zones)
ZDN	Zone de Déchets Contrôlés (Non-radioactive waste zones)

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