Table of Contents

[1 Purpose 3](#_Toc404602831)

[2 Scope 3](#_Toc404602832)

[3 Scope of the reviewers 4](#_Toc404602833)

[4 References 5](#_Toc404602834)

[5 System Classifications 6](#_Toc404602835)

[6 Definitions 6](#_Toc404602836)

[6.1 Units 6](#_Toc404602837)

[6.2 Coordinate systems 7](#_Toc404602838)

[6.3 Abbreviations 8](#_Toc404602839)

[7 Types of Loads 9](#_Toc404602840)

[8 Path of the Main Loads 9](#_Toc404602841)

[9 System Description 9](#_Toc404602842)

[9.1 Design Status 9](#_Toc404602843)

[9.2 System Design Description 10](#_Toc404602844)

[9.2.1 System, Components, Parts 10](#_Toc404602845)

[9.2.2 Fabrication and Assembly 12](#_Toc404602846)

[9.2.3 Functions 12](#_Toc404602847)

[9.2.4 Interfaces 12](#_Toc404602848)

[10 Single Load cases 13](#_Toc404602849)

[10.1 Masses 13](#_Toc404602850)

[10.2 Pressures 14](#_Toc404602851)

[10.3 Thermal loads 16](#_Toc404602852)

[10.4 Seismic loads 19](#_Toc404602853)

[10.5 Assembly and maintenance loads 19](#_Toc404602854)

[10.6 Fire load 19](#_Toc404602855)

[10.7 Interface loads 20](#_Toc404602856)

[10.7.1 PBS 15 - VV (at double bellows) 20](#_Toc404602857)

[10.7.2 • PBS 18 - PIS / GIS and PBS 55 – Diagnostics (at bellows) 20](#_Toc404602858)

[10.7.3 • PBS 22 – Assembly 20](#_Toc404602859)

[10.7.4 RH (at temporary RH flange) 21](#_Toc404602860)

[10.7.5 Vacuum (at TCP flange) 21](#_Toc404602861)

[10.8 Insignificant Loads 21](#_Toc404602862)

[10.8.1 Magnet Fast Discharge 21](#_Toc404602863)

[10.8.2 Major Disruption 21](#_Toc404602864)

[10.8.3 Cryostat ICE (Water) 21](#_Toc404602865)

[10.8.4 VV LOVA III 21](#_Toc404602866)

[10.8.5 IVCLOFA III 21](#_Toc404602867)

[10.8.6 LOCA\_NB III 21](#_Toc404602868)

[10.8.7 LOCA\_Vault IV 21](#_Toc404602869)

[10.8.8 LOCA Galleries III 21](#_Toc404602870)

[10.8.9 LOOP 21](#_Toc404602871)

[10.8.10 Explosions 22](#_Toc404602872)

[10.8.11 Flooding 22](#_Toc404602873)

[10.8.12 Airplane crash 22](#_Toc404602874)

[11 Load combinations 23](#_Toc404602875)

[11.1 Normal operation definition 23](#_Toc404602876)

[11.2 Cat. I and II Load Combinations 24](#_Toc404602877)

[11.3 Cat. I and II fatigue cycles 25](#_Toc404602878)

[11.4 Cat. III Load Combinations 26](#_Toc404602879)

[11.5 Cat. IV Load Combinations 28](#_Toc404602880)

[11.6 Load to be considered for TCPH bellows 29](#_Toc404602881)

# Purpose

The Torus Cryo-Pump Housing (TCPH) is a penetration located on the Cryostat cylinder which main functions are to accommodate and support the Torus Cryo-Pump (TCP), connect it to the Vacuum Vessel and provide tritium confinement and primary vacuum boundary (for full function list see 9.2.3). There are a total of six TCPH located at the lower port level of the Cryostat lower cylinder in Port Cell numbers 4/6/10/12/16/18.

The System Requirement Document for TCPH is reported in the Cryostat global System Requirement Document [1].

This System Load Specification is written following guideline [2].

# Scope

The purpose of this document is to:

* Define all states of the TCPH during its life.
* Define all possible events in each state.
* Describe the loads affecting the TCPH and their load path through the mechanical connections for the verification of the structural integrity of the TCPH.
* Specify the load combinations and their categories for the verification of the structural integrity of the Cryostat and its components.

This System Load Specification only concerns the housing connecting the TCP and its ribs at the Cryostat cylinder (see chapter 10 for a full description of the TCPH components).

All other parts or components are outside the scope of this document.

This specification will be reviewed by IO / DA. No ANB review is needed.

# Scope of the reviewers

The name of the reviewers and their scope of review are given in Table 1.

|  |  |
| --- | --- |
| Reviewer | Scope of review |
| I. Sekachev | Check the contents of this load specification in general |
| C. H. Choi | Check that the interface loads from the Vacuum Vessel System are correct |
| R. Pearce | Check that the interface loads from the Vacuum System are correct |
| R. Reichle | Check that the interface loads from the Diagnostics System are correct |
| A. Tesini | Check that the interface loads from the Remote Handling System are correct |
| R. Shaw | Check that the interface loads from the Assembly System are correct |
| S. Maruyama | Check that the interface loads from the Fuelling & Wall Conditioning System are correct |
| D. Sands | Check that this document is written following quality assurance requirements |
| G. Sannazzaro | Check that this document follow the requirements of Guideline for ITER System Load Specification  Check Standard Choice is acceptable  Check that the document provides sufficient detail to allow analysis of the TCPH  Check that the loads and combinations are appropriate  Check that global loads are correct |
| JJ. Cordier | Check that content of this document is consistent with Design Integration requirements |
| C. Seropian | Check that this document is written following Safety requirements |

Table 1 – List and scope of reviewers

# References

This System Load Specification is written with respect of the requirements and recommendations of the following reference documents:

1. SRD, [ITER\_D\_28B2TP v3.0](https://user.iter.org/?uid=28B2TP)
2. SLS Guideline, [ITER\_D\_33TTPJ v2.5](https://user.iter.org/?uid=33TTPJ)
3. Load Specifications, [ITER\_D\_222QGL v6.0](https://user.iter.org/?uid=222QGL)
4. Heat and Nuclear Load Specifications, [ITER\_D\_2LULDH v2.3](https://user.iter.org/?uid=2LULDH)
5. Accident Analysis Report, [ITER\_D\_2ZTMLF](https://user.iter.org/?uid=2ZTMLF)
6. Safety Important Functions and Components – Classification Criteria and Methodology, [ITER\_D\_347SF3 v1.8](https://user.iter.org/?uid=347SF3)
7. Quality Classification Determination [ITER\_D\_24VQES v4.1](https://user.iter.org/?uid=24VQES)
8. Cryostat Load Specification, [ITER D 34HHUG v2.3](https://user.iter.org/?uid=34HHUG)
9. [PCR-404 - 6 direct divertor pumping ports and removal of branch ducts](https://user.iter.org/?uid=ETMWWS)
10. Draft of specification for TCPH bellows, [ITER D FZU3H8 v2.0](https://user.iter.org/?uid=FZU3H8)
11. Load specification for port duct and port cell bellows, [ITER D 33K3PR v2.0](https://user.iter.org/?uid=33K3PR)
12. Design Description Document for Cryostat, [ITER D 3YHDLL v1.0](https://user.iter.org/?uid=3YHDLL)
13. ITER Vacuum Vessel Load Specification, [ITER D 2F52JY v3.3](https://user.iter.org/?uid=2F52JY)
14. Accident Analysis Report (AAR) Volume II - Figures, [2EBGU5 v4.7](https://user.iter.org/?uid=2EBGU5)
15. Cryostat wall behaviour under water and He ingress, [35CF69 v2.2](https://user.iter.org/?uid=35CF69)
16. Cryostat Global Structural Analysis, [3T4W2X v1.3](https://user.iter.org/?uid=3T4W2X)
17. Global Tokamak Dynamic Analysis Report (VDE III), [35EJZF v1.1](https://user.iter.org/?uid=35EJZF)
18. Global Tokamak Seismic Analysis Report, [33W3P4 v2.1](https://user.iter.org/?uid=33W3P4)
19. Global Tokamak Dynamic Analysis Report (VDE IV), [6A88WM v1.0](https://user.iter.org/?uid=6A88WM)
20. Cryostat wall behaviour under water and He ingress, [35CF69 v2.2](https://user.iter.org/?uid=35CF69)

# System Classifications

The following requirements are defined from reference documents [6] and [7].

TCPH is a continuity of Vacuum Vessel Ports. These ports are defined as SIC-1 components and therefore **TCPH is a SIC-1 component**. It is required to bring to and maintain ITER in a safe state and it is considered as a confinement barrier of the main radioactive inventories.

As a SIC-1 component, **the seismic class of TCPH is SC1 (S and F)**. This means that structural stability and required functional seismic safety performance has to be maintained in the event of an earthquake.

Design, material specification, fabrication, examination, testing and inspection have to follow an appropriate code or standard. Deviations from the code requirements must be justified. The chosen code is **ASME VIII Div.2 Edition 2013**. The choice of this code is given in reference document [9].

The classification of mechanical equipment as SIC does not imply any requirement in respect of pressure equipment classification. Given its volume and maximum allowable pressure, TCPH is not subjected to pressure equipment regulatory rules (French Decree 99-1046 regarding conventional pressure equipment or French Order dated 12th December 2005 related to nuclear pressure equipment).

As being a SIC-1 component, **TPCH is a Quality Class 1 component**.

In summary, the system classifications of the TCPH are as follows:

* Safety Classification (for confinement function): SIC-1
* Vacuum Classification: VQC 1A
* Remote Handling classification: RH Class 3
* Tritium classification: TC 1A
* Quality Classification: QC1
* Seismic Classification SC1(S and F)

# Definitions

The identifying names of components and single parts are given in chapter 9.2.1 of this document.

## Units

The units used in this analysis are the standard SI base and derived units listed in Table 2.

Standard prefixes are also used, e.g. MPa for pressure. Temperature is sometimes given in degrees Centigrade.

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Unit Name** | **Unit Symbol** |
| Length | Meter | m |
| Mass | Kilogram | kg |
| Time | Second | s |
| Temperature | Kelvin / Centigrade | K / °C |
| Acceleration | - | m.s-2 |
| Force | Newton | N |
| Moment | - | N.m |
| Pressure | Pascal | N.m-2 |

Table 2 - Units

## Coordinate systems

Otherwise specified, this document uses the ITER Tokamak Global Coordinate System which is defined on Figure 1. The axes/directions of this coordinate system are named: radial, toroidal, and vertical. The identifier of the toroidal angle is ϕ counter clockwise when viewed from above.

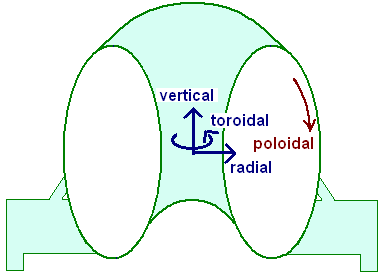
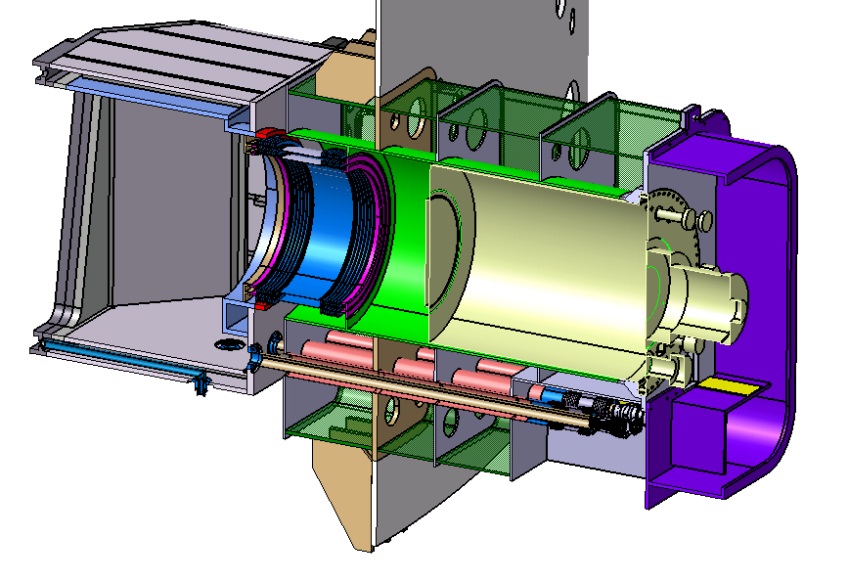


Figure 1 - Definitions of Tokamak directions and global cylindrical coordinate system

A local TCPH coordinate system is defined. It is located at the center of the Cryostat Wall Flange of the TCPH as shown in Figure 2.

The position of this local coordinate system with respect to the TGCS is:

* x (radial) = 14.270 m
* y (toroidal)
  + y = 70⁰ (port 04)
  + y = 110⁰ (port 06)
  + y = 190⁰ (port 10)
  + y = 230⁰ (port 12)
  + y = 310⁰ (port 16)
  + y = 350⁰ (port 18)
* z (vertical) = - 4.393 m



**z**

**y**

**x**

Figure 2 – TCPH local coordinate system

## Abbreviations

The list of abbreviations used through this document is given in Table 3.

|  |  |
| --- | --- |
| **Abbreviation** | **Description** |
| SLS | System Load Specification |
| TCPH | Torus Cryo-Pump Housing |
| TCP | Torus Cryo-Pump |
| ECTS | Equatorial-level Cryostat Thermal Shield |
| PC | Port Cell |
| SIC | Safety Important Component |
| VDE | Vertical Displacement Event |
| AVDE | Asymmetric Vertical Displacement Event |
| MD | Major Disruption |
| VV | Vacuum vessel |
| CR | Cryostat |
| ICE | Ingress of Coolant Event |
| ϕ | Toroidal angle |
| RF | Reaction Force |
| F | Force |
| M | Moment |
| u | Displacement |
| LOFA | Loss of Forced Flow Accident |
| LOCA | Loss of Coolant Accident |
| PA | Procurement Arrangement |
| DA | Domestic Agency |
| SL-1 | Seismic Level 1 – Defined by ITER for investment protection |
| SL-2 | Seismic Level 2 – equivalent to Safe Shutdown Earthquake |
| SMHV | Séismes Maximaux Historiquement Vraisemblables = Maximum Historically Probable Earthquakes |
| CoG | Center Of Gravity |
| CS | Coordinate System |
| DDD | Design Description Document |
| HTC | Heat Transfer Coefficient |
| BK | Baking |
| NO | Normal Operation |

Table 3 - Abbreviations

# Types of Loads

The loads acting on the TCPH are divided into four categories:

* Pressure loads: these include the various pressure states existing in the Vacuum Vessel, TCP / TCPH and Port Cell environments both in normal operation and during accidental events.
* Inertial loads: these are caused by accelerations due to gravity (dead weight of the TCPH, TCP) and seismic events (SL-1, SMHV and SL-2).
* Thermal loads: conductive, convective and radiative heat exchanges have to be considered between the different parts of the TCPH and its surrounding environment.
* Assembly and maintenance loads: mechanical loads from assembly and maintenance of TCP have to be considered.

# Path of the Main Loads

The structural load path of the TCPH with its surrounding environment is show on Figure 3.

CR Upper cylinder

Bellows

Cylindrical shell

Bellows

Flange

**TCPH**

VV

TCP

Bio Shield

RH cask

Temporary RH Flange

Cylindrical shell

Bellows

CR Skirt

Figure 3 – Schematic view of the TCPH load path

# System Description

## Design Status

The design status of the TCPH is at Final Design Review stage.

The current CATIA model version is referenced N5F9K8 as shown in Figure 4.

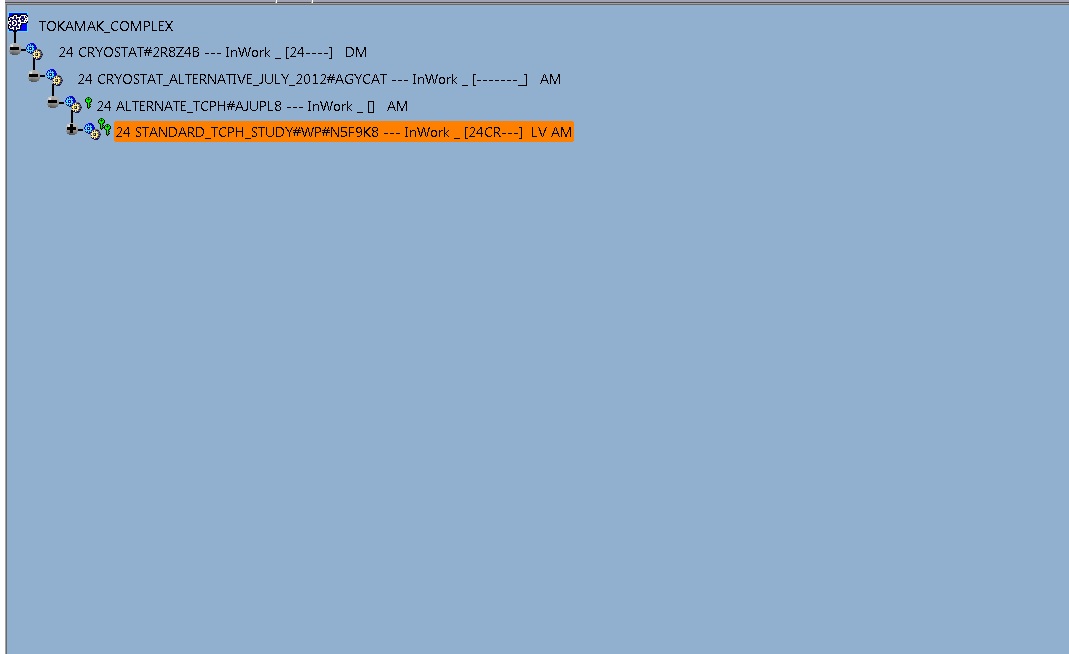


Figure 4 – Catia model version

## System Design Description

The following data is also reported in the TCPH Design description Document, appendix of the Cryostat DDD referenced [12].

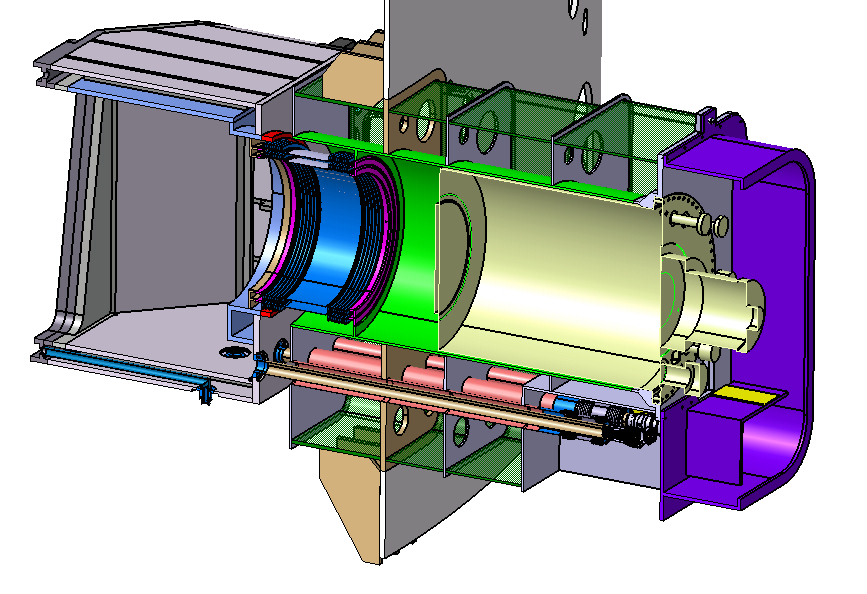
### System, Components, Parts

Figure 5 is showing a section view of the TCPH and is giving the names of the components of its surrounding environment. Only the TCPH is concerned by this System Load Specification (as already mentioned at chapter 2 of this document).

TCPH Ribs at CR wall

Internal volume of TCPH available for regeneration

VV Port Duct



TCP

Temporary RH flange

Pipes for Diagnostics / GIS / PIS penetrations

TCPH

Double bellows

Figure 5 – Section view of the TCPH

The outer shell of the TCPH is rectangular. Its global dimensions are about 3.4 m in length (radial), 2.7 m in width (toroidal) and 3.3 m in height (vertical). The inner shell of the housing corresponds to a circular tube of about 1.6 m in diameter and 3.4 m in length (radial). The inner and outer shells of the TCPH are connected through internal welded ribs. The internal volume between the outer and inner shell of the TCPH is used as a regeneration volume for the TCP component.

At the most outer radial part of the TCPH, a flange is connecting the TCP. On the VV side, the TCPH is connected to the VV Port Duct through a double bellows which end is welded on the TCPH inner tube surface. Ribs reinforce the TCPH / CR wall welded connection.

TCPH is made out of Dual marked 304/304L stainless steel.

There are a total of six TCPH. The port allocation (ports 1-18) as per PCR-404 is given in Table 4 and showed in Figure 6. All six TCPH have the same uniform design for all six ports except for small details at the diagnostics and PIS/GIS interfaces.

|  |  |
| --- | --- |
| **Port #** | **Description** |
| 4 | Divertor pumping port  Housing (PIS type), Torus cryopump PIS |
| 6 | Divertor pumping port  Housing (Diag type), Torus cryopump |
| 10 | Divertor pumping port  Housing (PIS type), Torus cryopump PIS |
| 12 | Divertor pumping port  Housing (Diag type), Torus cryopump |
| 16 | Divertor pumping port  Housing (PIS type), Torus cryopump PIS |
| 18 | Divertor pumping port  Housing (Diag type), Torus cryopump |

Table 4 – Port allocation

|  |
| --- |
| Figure 6 – Lower Port layout |
|  |

### Fabrication and Assembly

The TCPH will be manufactured in a workshop and then welded onto the Cryostat in the Tokamak pit. The double bellows will then be welded onto the TCPH while being retained by a specific holding fixture. The TCP will be assembled to the TCPH by a bolted connection having a double metallic seal.

A Remote Handling cask, used together with a specific transition piece connected onto the TCPH (temporary RH flange), will be used for those various assembly phases.

### Functions

The TCPH has the following functions:

* Support the TCP
* Connect the TCP to the torus vacuum
* Provide volume for TCP regeneration
* Provide tritium confinement and primary vacuum boundary
* Provides RH docking compatibility for removal of the TCP

### Interfaces

Table 5 is giving the reference documents for interface data.

|  |  |  |
| --- | --- | --- |
| **PBS15** | **VV ELM and Manifolds** | [IS-15-24-05-Cryo pumping port and Cryostat bellows (342VZ6 v1.4)](https://user.iter.org/?uid=342VZ6&version=v1.4) |
| **PBS18** | **Fueling & Wall Conditioning System** | [IS 18-24.CR-001 Interface between Cryostat and Gas Injection System (3F9E7Q v2.1)](https://user.iter.org/?uid=3F9E7Q&version=v2.1) |
| [IS 18-24.CR-002 Interface between Cryostat and Pellet Injection System (3G2PEQ v2.2)](https://user.iter.org/?uid=3G2PEQ&version=v2.2) |
| **PBS22** | **Machine Assembly & Tooling** | [IS 22-24.CR-012 TCPH (3XZ4H4 v2.0)](https://user.iter.org/?uid=3XZ4H4&version=v2.0) |
| **PBS23** | **Remote Handling System** | [IS 23-24.CR-001 Cask and plug handling system to torus cyo-pump housing interface at lower level (3LCBZS v2.0)](https://user.iter.org/?uid=3LCBZS&version=v2.0) |
| **PBS31** | **Vacuum** | [IS 24.CR-31-001 Interface between Torus Cryopump (PBS31) and Torus Cryopump Housing (PBS24.CR) (3VVXWS v2.6)](https://user.iter.org/?uid=3VVXWS&version=v2.6) |
| **PBS55** | **Diagnostic** | [IS 24-55](https://user.iter.org/?uid=2MYTQT) |

Table 5 – TCPH interface data

# Single Load cases

## Masses

This section defines the masses and centres of gravity of the components of the TCPH. An uncertainty of 10% should be assumed for the masses.

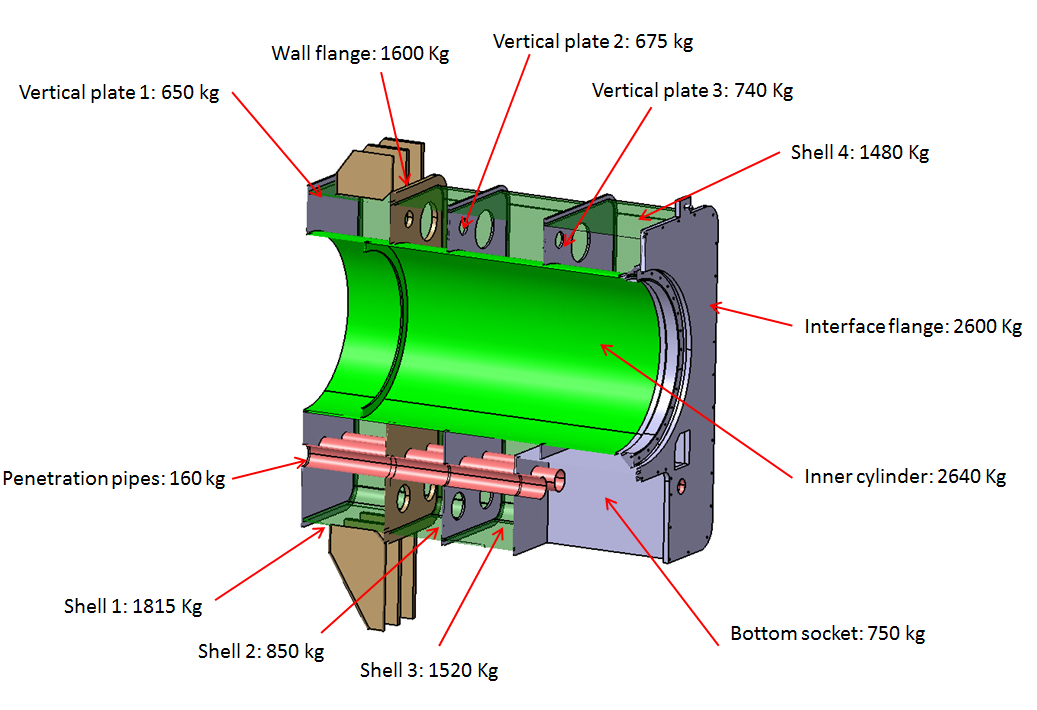
Table 6 provides the breakdown as well as the total masses and CoGs for TCPH.

CoG positions are listed with respect to the TCPH local coordinate system (see paragraph 6.2).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sub-part** | **Mass [Kg]** | **CoG x [m]** | **CoG y [m]** | **CoG z [m]** |
| Vertical Plate 1 | 650 | -0.880 | 0.000 | -0.470 |
| Vertical Plate 2 | 675 | 0.540 | 0.000 | -0.450 |
| Vertical Plate 3 | 740 | 1.510 | 0.000 | -0.417 |
| CR wall flange | 1 600 | -0.041 | 0.000 | -0.455 |
| Interface flange | 2 600 | 2.478 | 0.000 | -0.160 |
| Shell 1 | 1 815 | -0.471 | 0.000 | -0.310 |
| Shell 2 | 850 | 0.253 | 0.000 | -0.310 |
| Shell 3 | 1 520 | 1.025 | 0.000 | -0.310 |
| Shell 4 | 1 480 | 2.000 | 0.000 | -0.118 |
| Inner cylinder | 2 640 | 0.660 | 0.000 | 0.000 |
| Bottom socket | 750 | 1.740 | 0.000 | -1.270 |
| Penetration pipes Type B (1) | 160 | 0.515 | 0.000 | -1.220 |
| Penetration pipes (PIS) Type A (2) | 260 | 0.348 | 0.000 | -1.160 |
| Ribs | 1835 | -0.307 | 0.000 | -0.700 |
| **TOTAL Type B** | **17 315** | **0.785** | **0** | **-0.332** |
| **TOTAL Type A** | **17 415** | **0.803** | **0** | **-0.345** |

Table 6 – TCPH masses and CoGs (without 10% uncertainty)

1. Type B: ports 6, 12 and 18
2. Type A: Ports 4, 10 and 16



**Local CS for CoG   
definition**

**z**

**y**

**x**

Figure 7 – TCPH masses (Type A: ports 6, 11 and 18)

Note that, in addition to the masses specified in table 5, the masses of attached components need to be included as well. An overview of the attached masses and CoGs can be found in Table 7.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sub-part** | **Mass [Kg]** | **CoG x [m]** | **CoG y [m]** | **CoG z [m]** |
| TCP | 8 000 | 2.022 (1) / 2.092 (2) | 0.000 | 0.000 |
| Temp. RH flange | 2 800 | 2.832 | 0.000 | -0.462 |

Table 7 – TCPH attached component’s masses and CoGs (without 10% uncertainty)

1. Open valve
2. Close valve

## Pressures

Pressure loads include the various pressure states existing both in normal operation and during accidental events. In order to define pressure loading, four different environments have to be defined:

* Vacuum Vessel (VV)
* TCP & TCPH
* Port Cell (PC)
* Cryostat (CR)

It has to be noted that Vacuum vessel and TCP & TCPH environments can form a unique pressure environments when TCP valve is opened.

Figure 8 is showing these various environments.

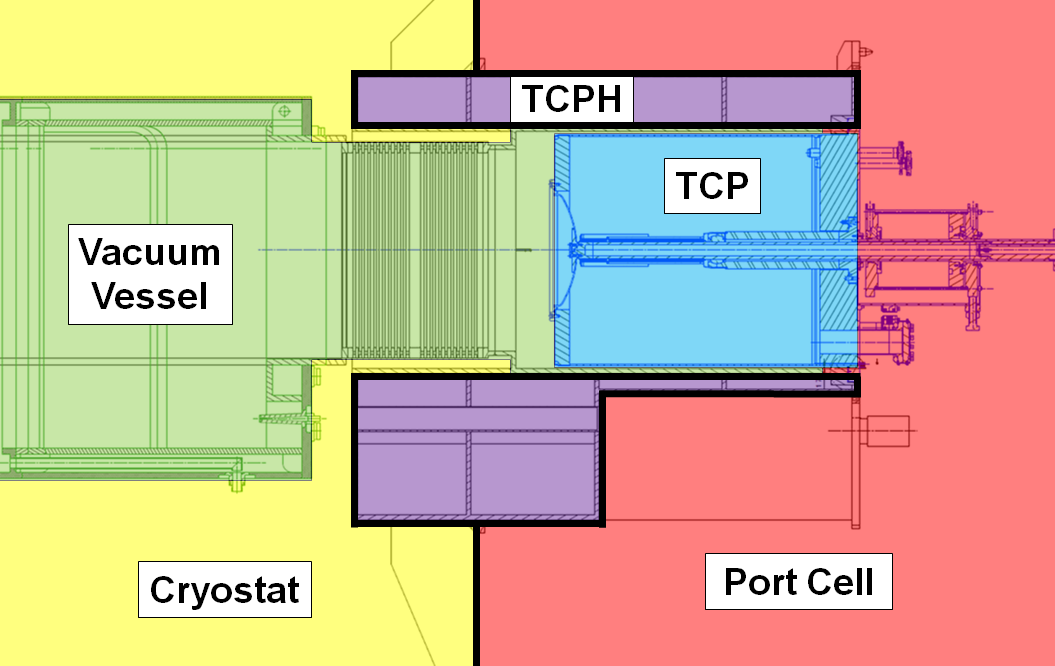


Figure 8 – TCPH’s four different pressure environments

Table 8 is listing the pressure values for the Vacuum Vessel, TCP and TCPH, Port Cell and Cryostat environments for all possible corresponding load cases. The list of load cases have been harmonised with the possible thermal load cases (see paragraph 10.3).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Load Cases** | **Cat.** | **TCP Valve Status** | **Pressure [kPa abs]** | | | |
| **VV from [13] [3]** | **TCP / TCPH** | **PC from [3]** | **CR from [8]** |
| Maintenance | I | NA | 100 | 100 | 100 | 100 |
| NO | I | open | 0 | 0 | 100 | 0 |
| NO (100K REGEN) | I | close | 0 | 0 | 100 | 0 |
| VV BK | I | open | 0 | 0 | 100 | 0 |
| VV BK (100K REGEN) | I | close | 0 | 0 | 100 | 0 |
| NO + VV ICEII | II | open | 106 | 106 | 100 | 0 |
| NO (100K REGEN) +  VV ICEII | II | close | 106 | 0 | 100 | 0 |
| NO (470K REGEN) | II | close | 0 | 0 | 100 | 0 |
| NO + VV ICE III | III | open | 150 | 150 | 100 | 0 |
| NO (100K REGEN) +  VV ICEIII | III | close | 150 | 0 | 100 | 0 |
| NO + VV ICEIV | IV | open | 200 | 200 | 100 | 0 |
| NO (100K REGEN) +  VV ICEIV | IV | close | 200 | 0 | 100 | 0 |
| NO + LOCA PC III | III | open | 150 (1) | 150 (1) | 160 | 0 |
| NO (100K REGEN) +  LOCA PC III | III | close | 150 (1) | 0 | 160 | 0 |
| NO + Cr ICE II | II | open | 0 | 0 | 100 | 31 |
| NO + Cr ICE III | III | open | 0 | 0 | 100 | 156 |
| NO (470K REGEN) | III | close | 98 | 0 | 100 | 0 |
| NO + Cr ICE IV | IV | open | 0 | 0 | 100 | 247 |

Table 8 – Pressure values [kPA abs]

1. This value is conservative with respect to the different values of reference [2] table 7-20

## Thermal loads

Thermal loading of the TCPH is rather complex. The detailed temperature distribution across the TCPH system has to be determined through a proper thermal analysis. Radiative, convective and conductive heat transfers have to be considered for this thermal analysis.

The possible radiative heat transfer between the ECTS and the TCPH can surely be neglected given the small values of the TCPH / ECTS view factors and emissivity of ECTS surface. This assumption would have however to be properly demonstrated.

As stated in the Cryostat Load Specification [8]:

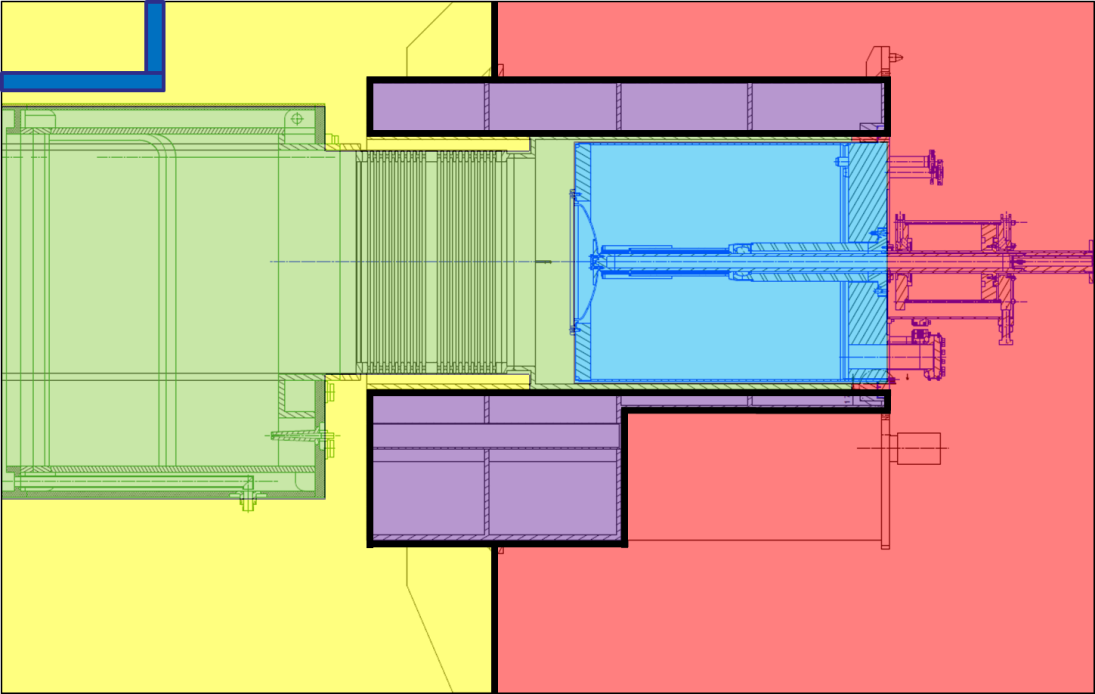
* The emissivity of all Cryostat surfaces can be assumed to be between 0.25 and 0.4. It is intended to confirm this range in the future.
* HTCs during operation are not specified in this document, but have to be calculated based on the relevant geometry. For Cryostat, HTCs values can be extracted from reference document [15].

Three main categories of thermal scenarios have to be considered:

* Normal Operation (including TCP Regenerations)
* Cr ICE events
* VV ICE events

During Normal Operation, VV, TCPH, TCP and CR environments are in a vacuum state and thus only radiative and conductive heat transfers are occurring. Convective heat transfer is occurring only outside the Cryostat in the Port Cell environment which is at ambient temperature (298K).

**Convective HT between TCPH and PC**



**285K**

**250K**

**Convective HT between CR and PC**

**Convective HT between TCP and PC**

**298K**

**Conductive HT between TCP and TCPH**

**Radiative heat transfer between TCP and TCPH**

**Conductive HT between CR and TCPH**

**Conductive HT between VV and TCPH**

**383K**

**Radiative HT between VV and TCPH**

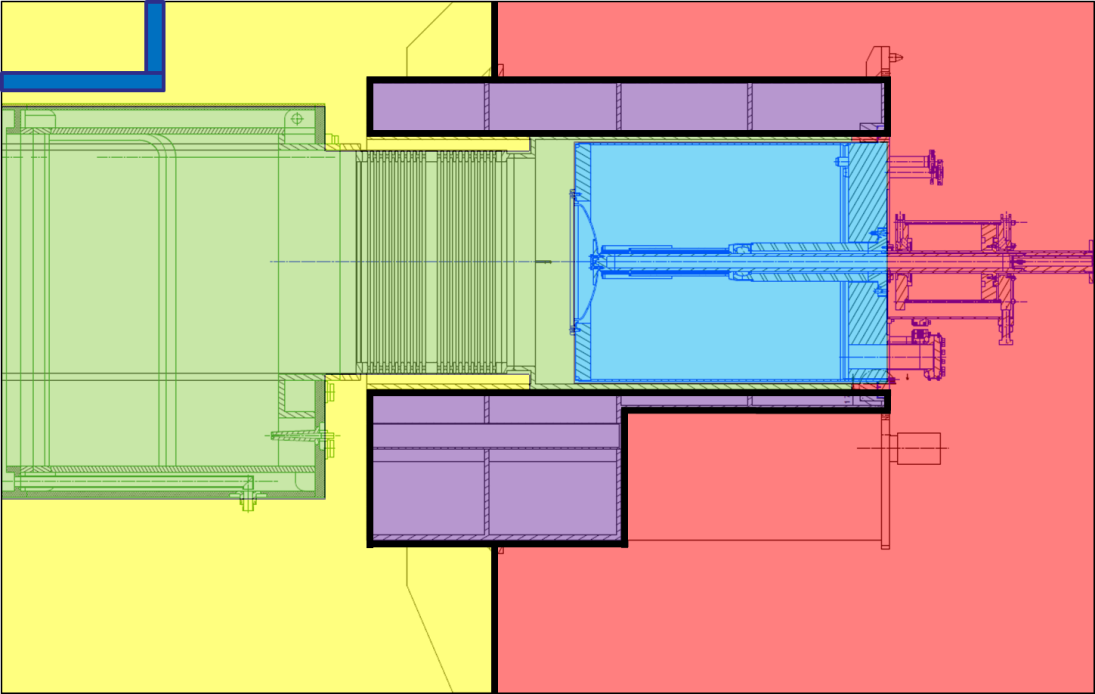
**Radiative HT between VV and TCPH**

Figure 9 – Heat transfer between TCPH and surrounding systems – Normal Operation conditions

During Cr ICE events, convective heat transfer takes place between the inner Cryostat environment and the TCPH. Convection can be considered as a dominant phenomenon compared to radiation and therefore the radiative heat transfer between VV and TCPH can be neglected.

**Convective HT between CR and TCPH**

**Convective HT between TCPH and PC**



**285K**

**Convective HT between CR and VV**

**185K**

**Convective HT between CR and CR Wall**

**298K**

**Convective HT between CR and PC**

**Convective HT between TCP and PC**

**250K**

**Conductive HT between TCP and TCPH**

**Radiative heat transfer between TCP and TCPH**

**Conductive HT between CR and TCPH**

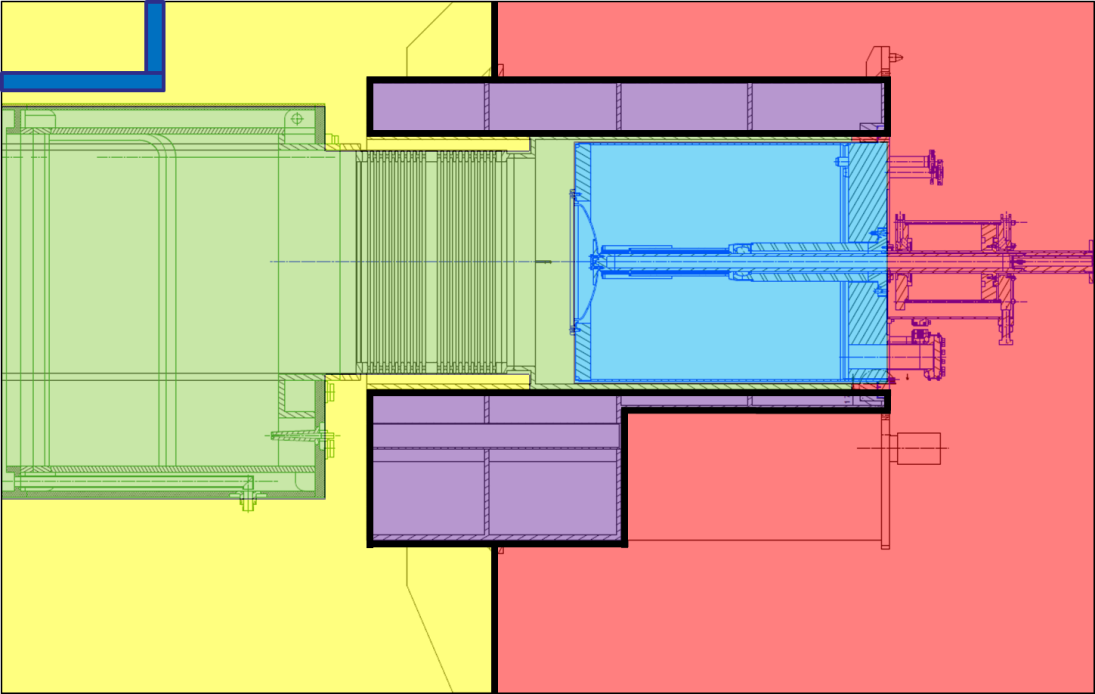
**Conductive HT between VV and TCPH**

**383K**

Figure 10 – Heat transfer between TCPH and surrounding systems – Cr ICEII conditions

During VV ICE events, VV, TCP and TCPH are forming a unique enclosure filled with a convective gas which temperature is governed by VV ICE event. Convection can be considered as a dominant phenomenon compared to radiation and therefore the radiative heat transfer between TCP and TCPH can be neglected.

**Convective HT between TCPH and PC**



**285K**

**Convective HT between VV and TCPH**

**400K**

**298K**

**Convective HT between CR and PC**

**Convective HT between TCP and PC**

**Conductive HT between TCP and TCPH**

**Conductive HT between CR and TCPH**

**Conductive HT between VV and TCPH**

**383K**

Figure 11 – Heat transfer between TCPH and surrounding systems – VV ICEII conditions

The TCPH thermal analysis is to be based on the thermal boundary conditions listed in Table 9.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Load Cases** | **Cat.** | **Port Duct Wall  Temp.[K]** | **TCP Casing  Temp.[K]** | **TCP Flange Temp.[K]** | **Environment Temp. [K]** | | |
| **VV** | **CR** | **PC** |
| Maintenance | I | 298 | 298 | 285 (4) | 298 | 298 | 298 |
| NO | I | 383 (3) | 250 (4) | NA | NA |
| NO (100K REGEN) | I | 383 (3) | 250 (4) | NA |
| VV BK | I | 473 | 250 (4) | NA |
| VV BK (100K REGEN) | I | 473 | 250 (4) | NA |
| NO + VV ICEII | II | 383 (3) | 250 (4) | 400 (1) |
| NO (100K REGEN) +  VV ICEII | II | 383 (3) | 250 (4) | 400 (1) |
| NO (470K REGEN) | II | 383 (3) | 400 (4) | NA |
| NO + VV ICE III | III | 473 (3)(6) | 250 (4) | 300 (2) |
| NO (100K REGEN) +  VV ICEIII | III | 473 (3)(6) | 250 (4) | 300 (2) |
| NO + VV ICEIV | IV | 473 (3)(6) | 250 (4) | 300 (2) |
| NO (100K REGEN) +  VV ICEIV | IV | 473 (3)(6) | 250 (4) | 300 (2) |
| NO + LOCA PC III | III | 473 (3)(6) | 250 (4) | NA | 393(7) |
| NO (100K REGEN) +  LOCA PC III | III | 473 (3)(6) | 250 (4) | NA |
| NO + Cr ICE II | II | 383 (3) | 250 (4) | NA | 185(5) | 298 |
| NO + Cr ICE III | III | 383 (3) | 250 (4) | NA | 178(5) |
| NO + Cr ICE IV | IV | 383 (3) | 250 (4) | NA | 178(5) |

Table 9 – Temperature values [K]

1. From figure 2.1-3 of AAR Vol. II [14]
2. From figure 3.2.1-1 of AAR Vol. II [14]
3. From table 8-5 of VV Load Specification [13]
4. From paragraph 2.3.2 of IS 24.CR-31-001 (3VVXWS v2.6)
5. From paragraph 3.6 of Cryostat Load Specification [8]
6. Conservative values of VV baking has been considered
7. From ITER LS [3]

## Seismic loads

Seismic loading corresponds to an inertial load applied through acceleration of the TCPH and supported system masses (see paragraph 10.1).

The static equivalent accelerations of Table 10 may be used if the TCPH have a first natural frequency greater than 30 Hz.

If the natural frequency is lower than 30 Hz, there are two possible analysis options. The first is to perform a spectrum analysis using a suitable Frequency Response Spectra. The second is to pick a set of suitable static equivalent accelerations based on the natural frequencies of the TCPH and the FRS at that location.

The following three combinations of accelerations should be considered:

* +100% vertical accelerations + 57% horizontal accelerations (Case 1)
* -100% vertical accelerations + 57% horizontal accelerations (Case 2)
* +40% vertical accelerations + 108% horizontal accelerations (Case 3)

In each case, the horizontal accelerations can act in any horizontal direction. For SL-1, accelerations and interface loads are to be multiplied by 0.34. For SMHV, accelerations and interface loads are to be multiplied by 0.73.

|  |  |  |
| --- | --- | --- |
|  | Estimated Horizontal Acceleration  (Triaxial earthquake) [m.s-2] | Estimated Vertical Acceleration  (Triaxial earthquake) [m.s-2] |
| Cryostat Cylinder  (z < 3.34 m) | 6.7 | 4.5 |

Table 10 - Average accelerations of Cryostat in Cartesian coordinates during SL-2 from [8]

During lifting phases, the seismic load (at SL-1 level) is still to be defined. This load is depending on the lifting configuration (type of sling, location of crane …).

For remote handling operations, the mass of the temporary flange (see table 7) shall be taken into account in the analysis.

## Assembly and maintenance loads

A load has to be considered at the temporary RH flange interface during TCP assembly and maintenance. Values from IS 23-24.CR-001 (3LCBZS v2.0) are considered.

## Fire load

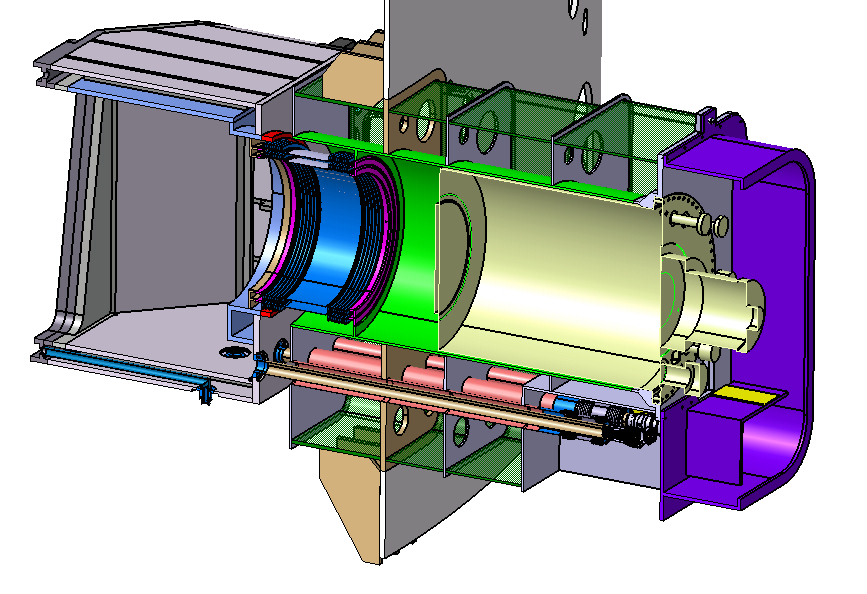
The temperature impact on the TCPH of a possible fire in the Port Cell is not yet fully defined. The current maximum fire gas temperature value in the Port Cell is 627⁰C.

## Interface loads

The following interfaces (see also paragraph 9.2.4) are considered for interface load definition:

* PBS 15 - VV (at double bellows)
* PBS 18 - PIS / GIS (at bellows)
* PBS 22 – Assembly
* PBS 23 – RH (at temporary RH flange)
* PBS 31 – Vacuum (at TCP flange)
* PBS 55 - Diagnostics (at bellows)

Double bellows



TCP flange

Temporary RH flange

PIS / GIS / Diagnostics bellows

Figure 12 – Interfaces to be considered for TCPH interface loads

### PBS 15 - VV (at double bellows)

Interface loads are defined through imposed displacements. The displacements values are available in the Double bellows Technical Specification document [10].

### • PBS 18 - PIS / GIS and PBS 55 – Diagnostics (at bellows)

Interface loads are defined through imposed displacements. The displacements values have not yet been defined but corresponding loads should be negligible.

### • PBS 22 – Assembly

Not defined yet.

### RH (at temporary RH flange)

See paragraph 10.5.

### Vacuum (at TCP flange)

Interface loads are considered through the deadweight of the TCP (see paragraph 10.1). Two positions of the CoG of the TCP need to be considered: open and closed valve configurations.

## Insignificant Loads

### Magnet Fast Discharge

As described in paragraph 3.10.1 of the Cryostat SLS [8], Magnet Fast Discharge loads can be neglected for Cryostat and thus also for TCPH.

### Major Disruption

As described in paragraph 3.10.2 of the Cryostat SLS [8], Major Disruption loads can be neglected for Cryostat and thus also for TCPH.

### Cryostat ICE (Water)

As described in paragraph 3.10.3 of the Cryostat SLS [8], Cryostat ICE (Water) loads can be neglected for Cryostat and thus also for TCPH.

### VV LOVA III

As described in paragraph 3.10.5 of the Cryostat SLS [8], VV LOVA III loads can be neglected for Cryostat and thus also for TCPH.

### IVCLOFA III

As described in paragraph 3.10.6 of the Cryostat SLS [8], IVCLOFA III loads can be neglected for Cryostat and thus also for TCPH.

### LOCA\_NB III

As described in paragraph 3.10.8 of the Cryostat SLS [8], IVCLOFA III loads can be neglected for Cryostat and thus also for TCPH.

### LOCA\_Vault IV

As described in paragraph 3.10.9 of the Cryostat SLS [8], LOCA\_Vault IV loads can be neglected for Cryostat and thus also for TCPH.

### LOCA Galleries III

As described in paragraph 3.10.10 of the Cryostat SLS [8], LOCA Galleries III loads can be neglected for Cryostat and thus also for TCPH.

### LOOP

As described in paragraph 3.10.11 of the Cryostat SLS [8], LOOP loads can be neglected for Cryostat and thus also for TCPH.

### Explosions

As described in paragraph 3.10.12 of the Cryostat SLS [8], Explosions loads can be neglected for Cryostat and thus also for TCPH.

### Flooding

As described in paragraph 3.10.14 of the Cryostat SLS [8], Flooding loads can be neglected for Cryostat and thus also for TCPH.

### Airplane crash

As described in paragraph 3.10.15 of the Cryostat SLS [8], Airplane crash loads can be neglected for Cryostat and thus also for TCPH.

# Load combinations

## Normal operation definition

Most of the load combinations refer to Normal Operation (NO) plus some other load. The definition of the NO state of the TCPH system is given in Table 11.

|  |  |
| --- | --- |
| Load case | Characteristic loads |
| Masses | * TCPH dead weight * TCP dead weight is 8 tons with CoG located at  428 mm from TCP flange seating (valve opened) |
| Pressures | * Cryostat : vacuum * Port cell: Atmospheric pressure (100 kPa) * Vacuum vessel: vacuum * TCPH and TCP: vacuum |
| Thermal loads | * Cryostat: -- * Port cell: 298 K * Vacuum vessel: port duct wall temperature = 383K * TCPH: -- * TCP casing temperature = 250K * TCP flange temperature = 285K |

Table 11 - Normal Operation (NO) state of the TCPH system

## Cat. I and II Load Combinations

Category I and II Load Combinations from the ITER Load Specification document (222QGL v6.0) are listed in Table 12. Initiating events are in bold. Combinations that are not relevant for TCPH system are in grey.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| # | **Operating conditions** | **Pressure** | **Seismic** | **Plasma** | **Magnet** | **Category** | **# of events** |
| I-1 | Lifting/Assembly/RH |  |  |  |  | I | 1 |
| I-2 | NO |  |  |  |  | I | 300 |
| I-3 | VV BK |  |  |  |  | I | 500 |
| I-4 | NO (100K REGEN) |  |  |  |  | I | 50 000 |
| I-5 | VV BK (100K REGEN) |  |  |  |  | I | 500 |
| I-6 | NO |  |  | **MD I** |  | I | 2600 |
| I-7 | NO |  |  |  | **MFD I** | I | 500 |
| I-8 | NO |  |  | MD I | **MFD I** | I | 500 |
| II-1 | Any of I-2 to I-5 conditions |  |  | **MD II** |  | II | 400 |
| II-2 | Any of I-2 to I-5 conditions |  |  | **VDE II** |  | II | 300 |
| II-3 | Any of I-2 to I-5 conditions |  |  |  | **MFD II** | II | 50 |
| II-4 | Any of I-2 to I-5 conditions |  |  | MD I | **MFD II** | II | 50 |
| II-5 | Any of I-2 to I-5 conditions |  |  | MD II | **MFD I** | II | 50 |
| II-6 | Any of I-2 to I-5 conditions |  |  | VDE II | **MFD I** | II |  |
| II-7 | Any of I-2 to I-5 conditions | VV ICE II |  | **MD II** |  | II | 15 |
| II-8 | Any of I-2 to I-5 conditions | **VV ICE II** |  | VDE II |  | II | 15 |
| II-9 | Any of I-2 to I-5 conditions | **VV ICE II** |  |  |  | II | 15 |
| II-10 | Any of I-2 to I-5 conditions | **VV ICE II** |  | MD I |  | II | 15 |
| II-11 | Any of I-2 to I-5 conditions | **VV ICE II** |  | MD II |  | II | 15 |
| II-12 | Any of I-2 to I-5 conditions | **Cr ICE II** |  |  |  | II | 15 |
| II-13 | Any of I-2 to I-5 conditions | **Cr ICE II** |  |  | MFD I or II | II | 15 |
| II-14 | Any of I-2 to I-5 conditions |  | **SL-1** |  |  | II | 1(1) |
| II-15 | Any of I-2 to I-5 conditions |  | **SL-1** | MD I |  | II | 1 |
| II-16 | Any of I-2 to I-5 conditions |  | **SL-1** |  | MFD I or II | II | 1 |
| II-17 | Any of I-2 to I-5 conditions |  | **SL-1** | MD I | MFD I or II | II | 1 |

Table 12 – Cat.I and II Load Combinations from ITER Load Specification (222QGL v6.0)

1. As this event has a return period of more than 100 years it is expected to occur only once in the machine life. For investment protections it is assumed to occur 5 times. Assume 10 cycles per event for fatigue calculations.

Using data from Table 12 (events listed in bold) and adding system specific combinations (events shown in normal type), the resulting load combinations to be considered for the TCPH load combinations are given in Table 13. This table is to be used for plastic collapse, local failure, ratcheting and buckling assessments.

|  |  |
| --- | --- |
| **Event** | **Cat.** |
| Lifting/Assembly/RH + SL-1 | II |
| **NO (100K REGEN) + VDE II (1)** | II |
| **NO (100K REGEN) + VV ICE II + VDE II (1)** | II |
| **NO (100K REGEN) +VV ICE II (1)** | II |
| VV BK (100K REGEN) + VV ICE II (1) (2) | II |
| **NO (100K REGEN) + Cr ICE II (1)** | II |
| VV BK (100K REGEN) + Cr ICE II (1) | II |
| **NO (100K REGEN) + SL-1 (1)** | II |
| VV BK (100K REGEN) + SL-1 (1) | II |
| NO (300K REGEN) | II |
| NO (470K REGEN) | II |

1. These cases are enveloping the corresponding cases without Regeneration which are thus not listed here.
2. VV BK cannot be combined with VDE events.

Table 13 – TCPH system Load Combinations for Cat.I and Cat.II (for assessments other than fatigue)

## Cat. I and II fatigue cycles

Table 14 is summarizing the cycles to be considered for fatigue assessments.

|  |  |  |
| --- | --- | --- |
|  | **Event** | **Number of cycles** |
| **Individual load case cycles** | Lifting/Assembly/RH | 1 |
| NO | 300 |
| NO (100K REGEN) | 50 000 |
| VV BK | 500 |
| VV BK (100K REGEN) | 500 |
| VDE II | 1 500 (1) |
| VV ICE II | 15 |
| Cr ICE II | 15 |
| SL-1 | 5x10 |
| NO (300K REGEN) | 2 500 |
| NO (470K REGEN) | 1 000 |
| **Load combination cycles** | Lifting/Assembly/RH + SL-1 | 5x10 |
| NO (100K REGEN) + VDE II | 1 500 (1) |
| NO (100K REGEN) + VV ICE II + VDE II | 15 |
| NO (100K REGEN) +VV ICE II | 15 |
| VV BK (100K REGEN) + VV ICE II | 15 |
| NO (100K REGEN) + Cr ICE II (1) | 15 |
| VV BK (100K REGEN) + Cr ICE II | 15 |
| NO (470K REGEN) + SL-1 | 5x10 |
| VV BK (100K REGEN) + SL-1 | 5x10 |

1. 300 VDE events multiplied by 5 cycles of full intensity VDE

Table 14 – TCPH system Load Combinations for Cat.I and Cat.II (for fatigue assessments)

## Cat. III Load Combinations

Category III Load Combinations from the ITER Load Specification document (222QGL v6.0) are listed in Table 15. Initiating events are in bold. Combinations that are not relevant for the TCPH system are in grey.

|  |  |  |  |
| --- | --- | --- | --- |
| **Pressure** | **Seismic** | **Plasma** | **Magnet** |
| VV ICEIII |  | **MD II** |  |
| VV ICEIII |  | **VDE II (1)** |  |
|  |  | **MD III** |  |
|  |  | **VDE III (1)** |  |
|  |  | **VDE III** | **MFD I** |
| VV ICE II or III |  | **VDE III (1)** |  |
| VV ICE II or III |  | **MD III** |  |
|  |  | MD II | **MFD II** |
|  |  | VDE II | **MFD II** |
| Cr LOVA III |  |  | **MFD II** |
| **VV ICE III** |  |  |  |
| **VV ICE II** |  | MD III |  |
| **VV ICE III** |  | MD I |  |
| **VV ICE III** |  | MD II |  |
| **VV ICE III** |  | MD III |  |
| **Cr ICEIII** |  |  |  |
| **Cr ICEIII** |  |  | MFD I or II |
| **Cr LOVAIII** |  |  |  |
| **Cr LOVAIII** |  |  | MFD I or II |
| **VV LOVA III** |  |  |  |
| **VV LOVA III** |  | MD III |  |
| **VV LOCA III** |  |  |  |
|  | **SL-1** | MD II |  |
|  | **SL-1** | VDE II **(1)** |  |
|  | **SL-1** | MD II | MFD-II |
|  | **SL-1** | VDE II | MFD-II |
|  | **SMHV** |  |  |
| Cr ICE III | **SMHV** |  |  |
| Cr ICE III |  |  |  |
| Helium leak in (2) galleries | **SMHV** |  |  |
| LOCA Gallery III |  |  |  |
| **LOCA\_PC III** |  |  |  |
| **LOCA\_NB III** |  |  |  |
| **Helium leak in** (2) **galleries** |  |  |  |
| **IVCLOFAIII** |  |  |  |

Table 15 – Cat.III Load Combinations from ITER Load Specification (222QGL v6.0)

1. VDE events are not considered as they correspond to secondary loads (imposed displacements) which do not need to be taken into account in Cat.III failure modes. Elastic follow-up due to double bellows is not possible because influence of the double bellows loading is away from any potential inelastic areas of the TCPH.
2. HiG event is not considered as it corresponds to secondary loads (imposed displacements) which do not need to be taken into account in Cat.III failure modes.

Using data from Table 15 (events listed in bold) and adding system specific combinations (events shown in normal type), the resulting load combinations to be considered for the TCPH load combinations are given in Table 21.

Regeneration events are not considered as they correspond to secondary loads (thermal) which do not need to be taken into account in Cat.III failure modes. Regeneration is considered from the point of view of pressure loading only (primary loading).

|  |  |
| --- | --- |
| **Event (2)** | **Cat.** |
| **NO (100K REGEN) + VV ICE III (1)** | III |
| **NO (100K REGEN) + Cr ICE III (1)** | III |
| **NO (100K REGEN) + SMHV (1)** | III |
| **NO (100K REGEN) + Cr ICE III + SMHV (1)** | III |
| **NO (100K REGEN) + LOCA\_PC III (1)** | III |
| RH + SMHV | III |

1. These cases are enveloping the corresponding cases without Regeneration which are thus not listed here.
2. VV BK events are not considered as they correspond to secondary loads (imposed displacements) which do not need to be taken into account in Cat.III failure modes.

Table 16 – TCPH system Load Combinations for Cat.III

The maximum TCPH temperature during each event should be used when defining the stress allowables. In particular, REGEN and VV BK temperatures should be considered.

## Cat. IV Load Combinations

Category IV Load Combinations from the ITER Load Specification document (222QGL v6.0) are listed in Table 17. Initiating events are in bold. Combinations that are not relevant for the TCPH system are in grey.

|  |  |  |  |
| --- | --- | --- | --- |
| **Pressure** | **Seismic** | **Plasma** | **Magnet** |
|  |  | **VDE IV (1)** |  |
|  |  | **MD IV** |  |
| VV ICE III or IV |  | **VDE IV (1)** |  |
| VV ICE III or IV |  | **MD IV** |  |
| VV ICE IV |  | **MD III** |  |
| VV ICE IV |  | **VDE III (1)** |  |
| **VV ICE IV** |  |  |  |
| **VV ICE IV** |  | MD I |  |
| **VV ICE IV** |  | MD II |  |
| **VV ICE IV** |  | MD III |  |
|  |  |  | MFD I |
| **Cr ICE IV** |  |  |  |
| **Cr ICE IV** |  |  | MFD I or II |
| Int. fire | **SMHV** |  |  |
|  | **SL-1** | MD III |  |
| Cr ICE III | **SL-2** |  |  |
| He in Gallery (2) | **SL-2** |  |  |
| Int. fire | **SL-2** |  |  |
| LOOP | **SL-2** |  |  |
| **Int. fire** |  |  |  |
| **LOCA in Vault** |  |  |  |
| **LOCA PC III** + VV ICE II |  |  |  |

Table 17 – Cat.IV Load Combinations from ITER Load Specification (222QGL v6.0)

1. VDE events are not considered as they correspond to secondary loads (imposed displacements) which do not need to be taken into account in Cat.IV failure modes. Elastic follow-up due to double bellows is not possible because influence of the double bellows loading is away from any potential inelastic areas of the TCPH.
2. HiG event is not considered as it corresponds to secondary loads (imposed displacements) which do not need to be taken into account in Cat.IV failure modes.

Using data from Table 17 (events listed in bold) and adding system specific combinations (events shown in normal type), the resulting load combinations to be considered for the TCPH load combinations are given in Table 18.

Regeneration events are not considered as they correspond to secondary loads (thermal) which do not need to be taken into account in Cat.IV failure modes. Regeneration is considered from the point of view of pressure loading only (primary loading).

|  |  |
| --- | --- |
| **Event (2)** | **Cat.** |
| **NO (100K REGEN) + VV ICE IV (1)** | IV |
| **NO (100K REGEN) + Cr ICE IV (1)** | IV |
| **NO (100K REGEN) + Cr ICE III + SL-2 (1)** | IV |
| **NO (100K REGEN) + LOCA PC III + VV ICE II (1)** | IV |
| RH + SL-2 | IV |
| Fire + SL-2 | IV |

1. These cases are enveloping the corresponding cases without Regeneration which are thus not listed here.
2. VV BK events are not considered as they correspond to secondary loads (imposed displacements) which do not need to be taken into account in Cat.IV failure modes.

Table 18 – TCPH system Load Combinations for Cat.IV

The maximum TCPH temperature during each event should be used when defining the stress allowables. In particular, REGEN and VV BK temperatures should be considered.

## Loads to be considered for TCPH bellows

Table 19 lists design conditions for TCPH Bellows.

The displacement values correspond to relative movements between the Cryostat and the Vacuum Vessel and are provided in the TCPH local coordinate system (see paragraph 6.2). X corresponds to Radial (‘’-‘’ meaning compression), Y corresponds to Toroidal and Z lateral corresponds to Vertical.

A maximum temperature of 200⁰C should be considered for bellows assessment.

For category III and IV loads, as fatigue and ratcheting failure modes are not to be assessed, only the load combinations giving the highest displacements values have been retained. This has been done considering each pressure cases.

Reference documents for the displacement values are the following:

VV displacements:

* table 11-36 of [13]
* table 23 of [19]

CR displacements:

* table 3-10 of [16]
* tables 22 and 24 of [17]
* table 9-2 of [18]
* table 23 of [19]

CR ICE displacements are calculated ‘by hand’ through simple equations related to a cylinder thermally contracted. The Cryostat cylinder temperatures considered are from [20], considering a 15% uncertainty:

* CrICE II: minimum temperature of cylinder (HS992) = 225K x 0.85 = 191K
* CrICE III: minimum temperature of cylinder (HS992) = 210K x 0.85 = 179K
* CrICE IV: minimum temperature of cylinder (HS992) = 207K x 0.85 = 176K

Reference temperature is 298K and the thermal expansion coefficient is 15.3x10-6 K-1. Vertical position of lower port from VSS is 3 127 mm. Cryostat radius at equatorial bellows is 14 245 mm.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Event** | **Cat.** | **Pressure [kPa]** | | **Displacement [mm]** | | | **Number of cycles** |
| **Internal (VV)**  **(CR)** | **External (CR)**  **(NB Cell)** | **X** | **Y** | **Z** |
| **NO** | I | 0 | 0 | -22 | 1 | 8 | 300 |
| **BK** | I | 0 | 0 | -45 | 1 | 18 | 500 |
| **NO + VDE II** | II | 0 | 0 | -31 | 6 | 10 | 300x5 |
| **VV ICE II (NO) + VDE II** | II | 106 | 0 | -31 | 6 | 10 | 15 |
| **VV ICE II (NO)** | II | 106 | 0 | -22 | 1 | 8 | 15 |
| **VV ICE II (BK)** | II | 106 | 0 | -45 | 1 | 18 | 15 |
| **CR ICE II (NO)** | II | 0 | 31 | -40 | 0 | 12 | 15 |
| **NO + SL-1** | II | 0 | 0 | -25 | 3 | 8 | 5x10 |
| **BK + SL-1** | II | 0 | 0 | -48 | 3 | 19 | 5x10 |
| **HIG III (BK) + SMHV** | III | 0 | 0 | -52 | 5 | 20 | N/A |
| **VV ICE III (BK)** | III | 150 | 0 | -45 | 1 | 18 | N/A |
| **CR ICE III (NO) + SMHV** | III | 0 | 156 | -49 | 4 | 14 | N/A |
| **HIG III (BK) + SL-2** | IV | 0 | 0 | -54 | 7 | 20 | N/A |
| **VV ICE IV (BK)** | IV | 200 | 0 | -45 | 1 | 18 | N/A |
| **CR ICE IV (NO)** | IV | 0 | 247 | -43 | 0 | 13 | N/A |
| **CR ICE III (NO) + SL-2** | IV | 0 | 156 | -51 | 6 | 15 | N/A |
| **LOCA PC III (BK) + VV ICE II** | IV | 150 | 0 | -45 | 1 | 18 | N/A |

Table 19 - Design conditions for TCPH Duct Bellows (displacement values in TGCS)