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EXTERNAL REFERENCE / VERSION

System Load Specifications

Load Specification for DNB Vessel

This document list exhaustively all the loads which will be apply to the DNB vessel all along its life.
After a general presentation of the document, the vessel is descibed, all signle load applied are listed and explained. Then all load combination to consider in the calculationa of the vessel are listed.

Approval Process			
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Change Log			
Load Specification for DNB Vessel (3R7A9D)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	Signed	14 Jan 2011	
v1.1	Approved	15 Apr 2011	Updated version taking into account comments of version 1.0
v2.0	Revision Required	03 Dec 2012	Full update of the document: - New safety requirements (SMHV) - Comments from the previous version and HNB vessel document
v3.0	In Work	10 Jul 2020	Update according comments of reviewers New reference for seismic load New fire load
v3.1	Revision Required	10 Jul 2020	Minor typo error
v3.2	Signed	23 Oct 2020	Update according comments of reviewers
v3.3	Approved	24 Nov 2020	Update according comments of reviewers

Table of Contents

1 General information

1.1 Purpose

This document will be used as a reference document for the mechanical analysis performed on the DNB vessel. It describes all the loads applied to this component and the combinations to be tested.

1.2 Scope of this document

The aim of this document is to gather all information relative to the loads applied to the DNB vessel.

The DNB vessel must be designed to resist all loads and load combinations that are within the design basis. In order to meet this requirement, both internal and imposed loads must be defined.

This document specifies the DNB vessel individual loads to be applied in the structural analysis of the ITER DNB vessel and lists the load combinations to be considered.

The load conditions defined in this document shall be consistent with Preliminary Safety Report prepared by the IO.

This document is used as a basis to progress the design towards the FDR. Some information is subject to change during the design process.

This document is based on the official Guideline for ITER System Load Specifications (see [14]).

1.3 Scope of Reviewers

Given in the IDM page.

1.4 Definitions

1.4.1 Units

ITER project uses metric system (SI).
All pressures used in this document are absolute pressure.

1.4.2 Coordinate systems

Usually, the Tokamak coordinate system is used to express position of components. For referring to a position in one injector, the following reference system is more comprehensible.

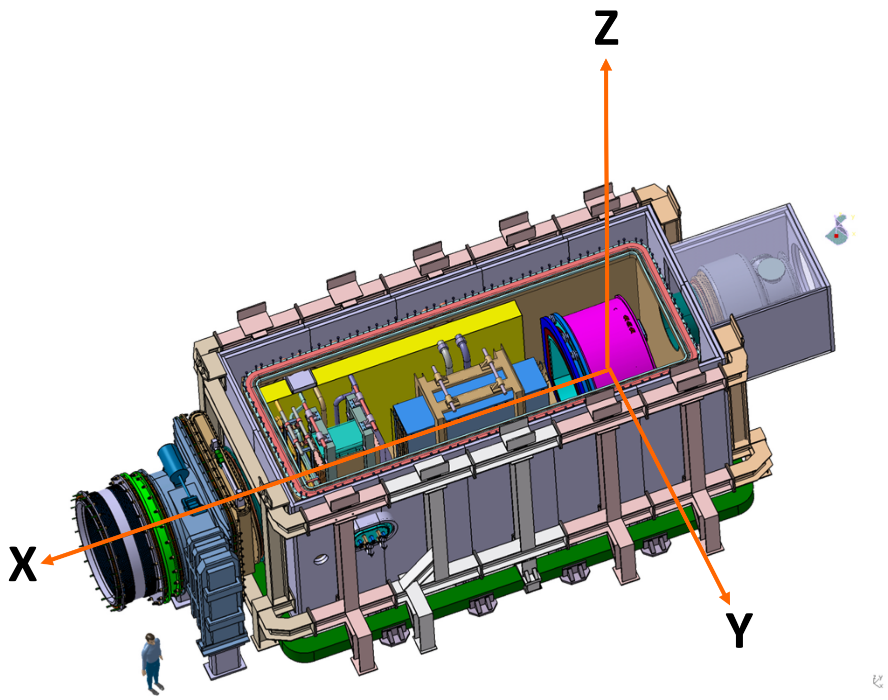

Figure 1 – Diagnostic Neutral Beam injector coordinate system

The origin of the coordinate system is the centre point of the grounded grid. Y is perpendicular to the beam in horizontal plane, X is parallel to the beam in horizontal plane and Z is vertical.

For information, the coordinate in millimetres of this origin in Tokamak complex coordinate system is (11410.436; 26617.882; 920).

1.4.3 Abbreviations

ACCC: Active Correction and Compensation Coils
BLC: Beam Line Components
BLK: Blanket
BS: Beam Source
BST: Beam Source Transporter
CCFE: Culham Centre for Fusion Energy
CDR: Conceptual Design Review

DL: Duct Liner
DNB: Diagnostic Neutral Beam
DT: Drain Tank
EM: Electro Magnetic
FEM: Finite Element Method
FMEA: Failure Modes & Effects Analysis
FRS: Floor Response Spectra
FS: Fast Shutter
FW: First Wall
HNB: Heating Neutral Beam
HV: High Voltage
HVB: High Voltage Bushing
ICE: Ingress of Coolant Event
LCS1: Local Coordinate System 1
LOCA: Loss Of Coolant Accident
LV: Low Voltage
MITICA: Megavolt ITER Injector & Concept Advancement
NB: Neutral Beam
NBI: Neutral Beam Injector
NED: Neutraliser Electron Dump
PHTS: Primary Heat Transfer Systems
PMS: Passive Magnetic Shield
PS: Power Supply
RID: Residual Ion Dump
ST: Suppression tank
SMHV: Séismes Maximaux Historiquement Vraisemblables (Maximum Historically Probable Earthquake).
TL: Transmission Line
VMB: Vacuum Measurement Box
VVPSS: Vacuum Vessel Pressure Suppression System

1.5 System Description

1.5.1 Design Status

This load specification is based on the DNB vessel Catia models available at IO design office in February 2020.

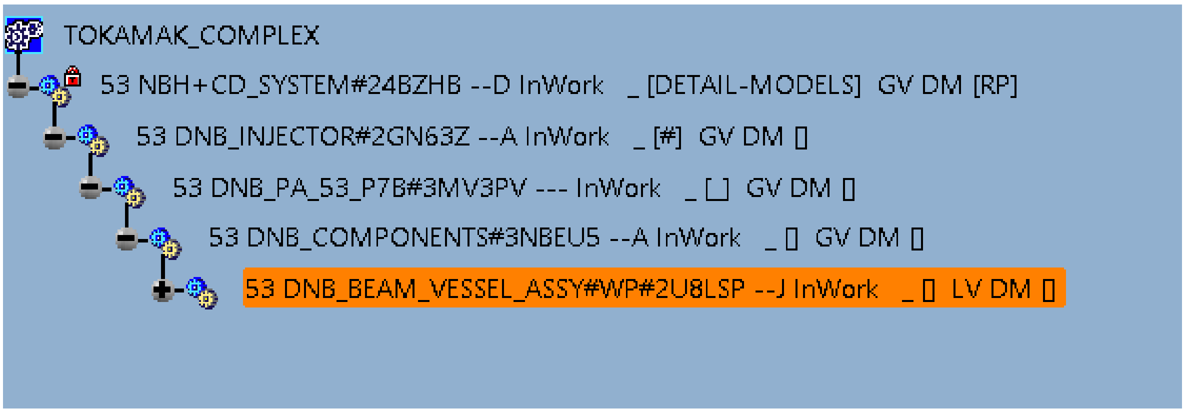

Figure 2 – 3D Models of DNB vessel in ENOVIA

The masses evaluation is based on the CATIA 3D models available in Enovia under the reference: NBH+CD _system#WP#2GN3ZT (see table 1).

The DNB vessel is made of two separate components:

- The vessel
- The top lid

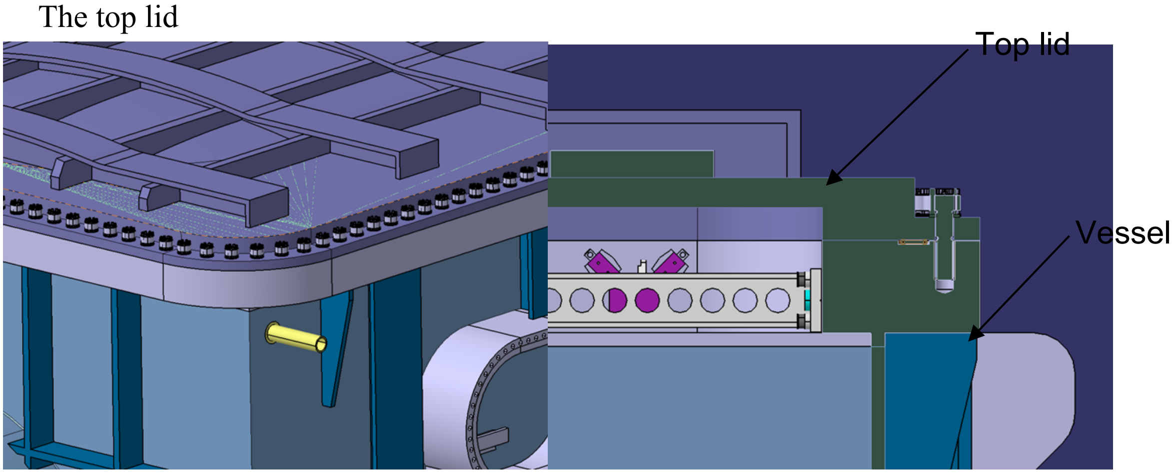

Figure 3 – Description of DNB vessel

1.5.2 System Design Description

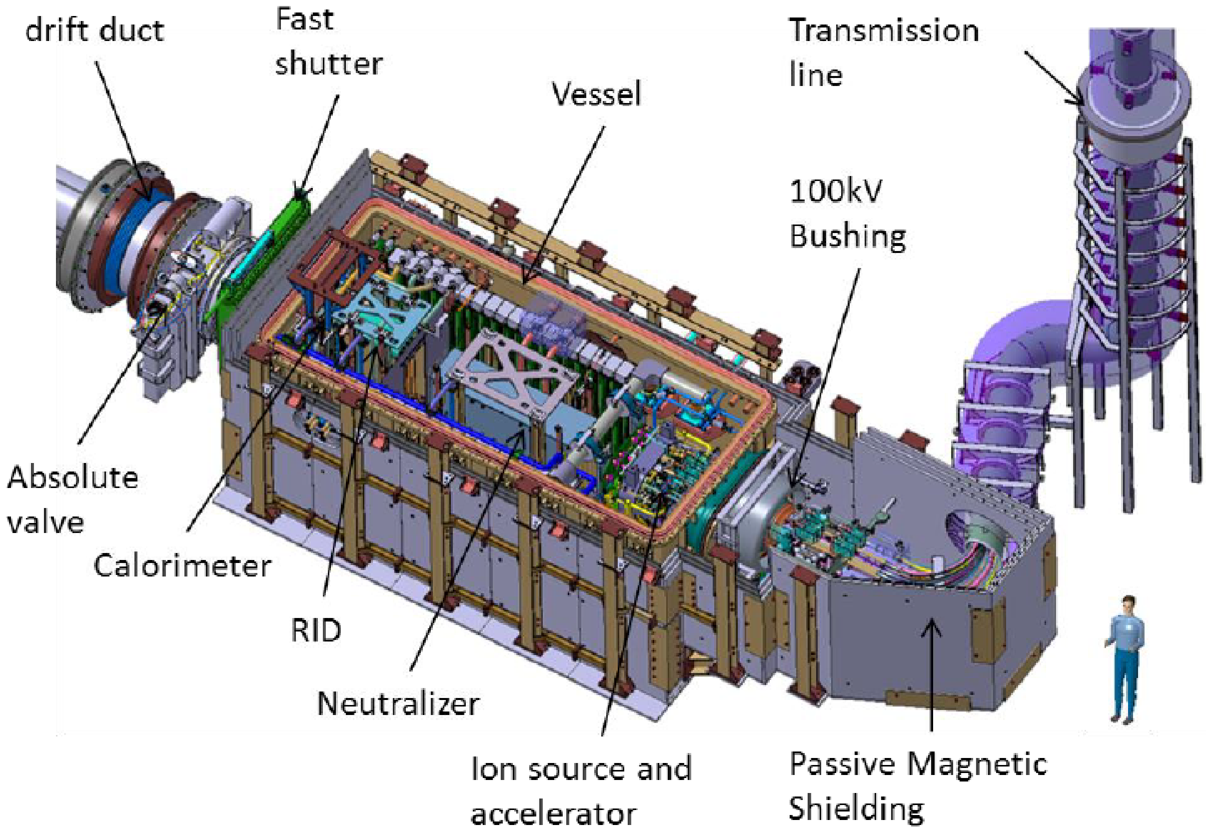

Figure 4 – Description of DNB components

In normal operation these two components are bolted together to form the DNB vessel but during assembly or remote handling the top lid is disconnected.

The top lid is sealed using rubber seals for the tests of high voltage power supply. Rubber seals are also used during vacuum tests during manufacturing. For the DT phase covers lip-welded to the top lid will ensure the leak tightness of the vessel. A provision is made on the vessel for installation of metallic seals.

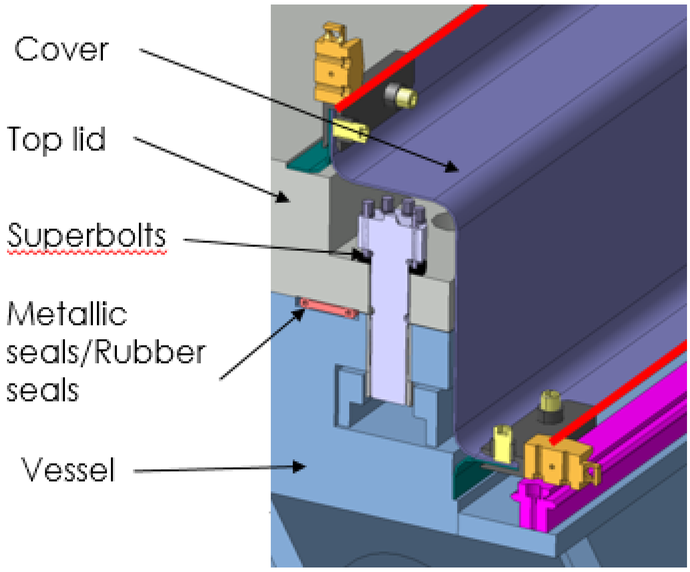

Figure 5 – Cross section of the top lid flange

1.5.3 Classification

DNB vessel comes under the following classifications:

- **SIC1** (see [1])
- **Seismic Class:1 S** (see [2])
- **Seismic level:** SL-1, SMHV and SL-2
- **Quality: class 1** (see [3])
- **Vacuum Quality Classification: 1A** (see [4])
- **Remote handling: class 3** (2 for top lid) (see [5]).
- **TritiumClass 1 A**
- **RCC-MR Class 2**

1.5.4 Fabrication and Assembly

Fabrication is not yet defined. But the vessel should be built using traditional heavy plate works. The fabrication and assembly of the DNB vessel must comply with the ITER Vacuum Handbook. The only exception comes from the standard code to follow (analysis, manufacturing…) which is now the RCC-MR [23].

After fabrication a special treatment must be applied to the vessel to eliminate the residual stress present in the welds.

1.5.5 Functions

The functions of the vessel are:

- To provide boundary between high vacuum of the Tokamak and the NB Cell (the maximum leak rate is set as $1x10^{-10}$ $Pa.m^3.s^{-1}$)
- To be the first confinement boundary of the tritium present in the vessel.
- To act as ground potential electrode of the HV system
- To interface and support the internal components (the displacement transmitted to the component must be limited, see document [19])
- To interface and support the bushing (the displacement transmitted to the bushing must be compliant with its fixation on TL).
- To allow maintenance of internal components and facilitate the RH
- To interface with the fast shutter

1.5.6 Interfaces

The vessel has four main external physical interfaces:

- the front components: contact with fast shutter on the front opening
- the HVB: contact on the bushing flange of the vessel
- the PMS: the vessel is fixed on the floor via the PMS
- the Beam Line Components (the vessel supports them)

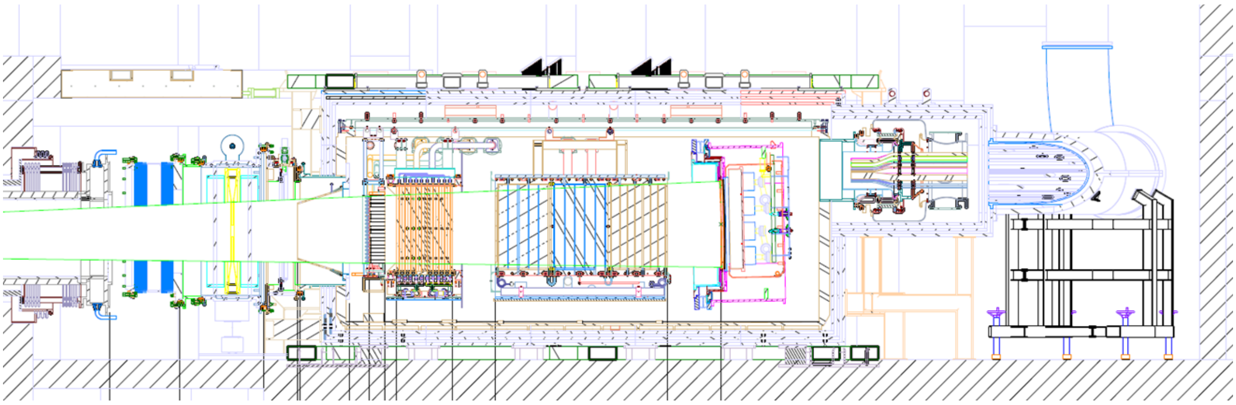

Figure 6 – Main DNB vessel mechanical interfaces

Interfaces with other ITER system are listed in [6].

The DNB vessel is also in interface with the following systems (apart from PBS 53):

- **Vacuum (PBS 31)**: cryopumps and cryo feedthroughs, communication with VV, fore pumping, SVS of all flanges, vacuum measurement boxes.
- **Cooling (PBS 26)**: cooling circuit for BLC and exit scraper.
- **Remote handling (PBS 23)**: various interfaces for NB components maintenance.
- **Building (PBS 62)**: clearance for handling and interface through the PMS
- **CODAC (PBS 45 & 46)**: signals used by CODAC go through the vessel. Interlock system protect the vessel from energy deposition from the beam.
- **Diagnostics (PBS 55)**: clearance above the DNB vessel is used for diagnostic maintenance.

Other systems in interfaces are part of PBS 53.

Document	Link	IUD	Version
ICD	ICD-31-53 Interface Control Document for Vacuum System (PBS 31) and Neutral Beam H&CD System (PBS 53)	2LJ9V5	V2.2
	ICD-26-53 CWS NBI	2NST3N	V2.3
	ICD-23-53 Interface Control Document for Remote Handling System (PBS 23) and Neutral Beam H&CD System	3244GY	V1.5
	Interface Control Document (ICD) between Tokamak Building (PBS 62-11) - Neutral Beam H&CD System (PBS 53)	27SB82	V1.4
IS	ITER_D_UVGSPA - IS-53-31-102-DNB-Interface between the cryopump and the DNB injector vacuum vessel	UVGSPA	V1.4
	ITER_D_UVKNPN - IS-53-31-104-DNB-CVB and cryojumpers for the supply of the DNB cryopump	UVKNPN	V1.1
	ITER_D_UVL2SD - IS-53-31-105-DNB-Fore line routing and fore line isolation valve for the DNB vessel	UVL2SD	V1.0
	ITER_D_UVPJAV - IS-53-31-106-DNB-Purge line of the DNB vessel	UVPJAV	V1.2
	ITER_D_ UVPY8H - IS-53-31-107-DNB-Service Vacuum System for the DNB	UVPY8H	V2.3
	ITER_D_ UVPYKN - IS-53-31-008-DNB-Vacuum instrumentation for the DNB vessel	UVPYKN	V2.1
	ITER_D_47PKF6 - IS-26-53-006 Interface sheet between PBS 53 and PBS 26-PH,-CV,-DR,-DY	47PKF6	V3.2
	ITER_D_2NGAWW - IS-23.05-53.04-015 DNB Vessel and NBRHS	2NGAWW	V4.1
	Interface Sheet (IS) between Tokamak Building (PBS 62.11) and NB H&CD System (PBS 53)	2NNMU	V9.0

Table 1 – List ICD of IS for DNB vessel

1.6 Loads

1.6.1 Types of loads

The following types of loads are applied to the vessel:

- Weights. When the load is directly measured on the 3D model, an additional facto of 10% shall be taken to take into account weight of the welds.
- Pressure: due to difference of pressure between NB Cell, inner vessel pressure and bushing pressure.
- Thermal loads
- Nuclear loads
- Interface loads (loads transmitted by other components at the interfaces of the vessel)
- Seismic loads
- EM loads

1.6.2 Main Loads

The main loads are the pressure difference between the inside and outside the vessel and the effects of an earthquake.

1.6.3 Path of the Main Loads

Pressure acts on the vessel shell and is internally reacted with the exception due to the vessel opening which causes an axial force along the X axis (in LCS1) (see the different combination with VV pressure and valve closed or opened chapter 2.8.2). This force is transferred through vessel support to the PMS and to the floor of the NB Cell.

All the weights are transferred to the floor through the vessel shell to the PMS.

1.7 States of System and Components

This list describes the different states in which the vessel will be during its life. The load combinations are partly based on this list. Incidental and accidental loads are not described here.

1.7.1 State 1: Transport & handling

The different elements of the vessel will have to be transported on ITER site. No additional load apart from those described below should be applied to the vessel components.

During manufacturing, transport and assembly, vessel components are moved using different tools (crane or trolleys). The handling phase is described in chapter 2.8.8. This state ends when the vessel is installed on site.

1.7.2 State 2: Outgassing

During manufacturing, it is foreseen to perform an outgassing of the DNB vessel in order to eliminate all residual product used during the manufacturing and ensure a good cleaning of the surfaces of the vessel exposed to vacuum.

1.7.3 State 3: leak test

After manufacturing, after welding and after each opening of the vessel, a leak test has to be carried out. Dedicated blanking flange will be used to close the openings at manufacturer and

IO site. The loads will be the atmospheric pressure and the bushing (for the test in NB cell) and vessel weight. This test is realized at room temperature.

1.7.4 State 4: Spark gap test

The aim of this test is to test the HV PS and to validate the HV transmission line above 100 kV. The vessel is under atmospheric pressure with air. To avoid cryopumps pollution, this test is carried out before the assembly of the in-vessel components. Electrodes are put in place of the vessel.

The test is carried out at room temperature.

1.7.5 State 5: set up / maintenance

In this state, the vessel is opened (no lid) in order to install or maintain the components present in the injector. The vessel is loaded by the weight of the different in-vessel components (BLC's, cryopumps, beam source and accelerator and bushing).

1.7.6 State 6: during pulse

This state describes normal operation when the beam is launched in the plasma. All in-vessel components are present, the vessel is closed and under vacuum. As the injector works, the cooling system is in operation. BLCs temperatures are within 35 - 100°C and the cryopumps cool down vessel walls. The cryopumps thermal shields are at 90K and the cryopanels at 4K. The thermal shield cools down the vessel walls.

1.7.7 State 7: between pulse

This state describes the period between pulses when the system is waiting for the next pulse. The loads are similar to "during pulse" case. The difference is on the water cooling temperature: inlet and outlet are at similar temperature. The BLCs are at the same temperature. The cryopumps are in the same state as during pulses and cools down vessel walls.

This state alternates with "during pulse". This alternation cause thermal stresses cycles which have to be considered in a fatigue assessment.

During this period the fast shutter is closed.

1.7.8 State 8: cryopumps regeneration

This state describes the period when cryopumps are warmed up for their regeneration. The outgassing of the panels produces a rise of the pressure. There are three types of regenerations: 100K, 300K, 400K. Water cooling is operational to avoid freeze-up of the water cooling pipes and BLCs. The thermal load associated to the regeneration is foreseen to be negligible for the vessel.

1.7.9 State 9: test of cooling circuit

After maintenance involving the cooling system, a pressure test has to be carried out to control the leak tightness of the circuit. Two kinds of tests will be carried out, one using helium, and the other water. The pressures that will be applied are higher than operating pressure. The pressure test should follow either the ASME B31.3 or the Pressure Equipment Directive.

$P_T = 1.5 \cdot P \cdot S_T / S$

Where:

- P_T is the minimum test pressure
- P is the Maximum Allowable Working Pressure
- S_T is the allowable membrane stress evaluated at the test temperature 20°C
- S is the allowable membrane stress evaluated at the design temperature 220°C
- The ratio S_T / S shall not exceed 6.5

2 Single Load Cases

2.1 Masses

2.1.1 Presentation

All listed masses shall be considered in the verification of the system. These masses are the values available during the writing of the document. The final values will be available when the design of all the components will be finished.

For cooled components, the weight is calculated with the coolant.

Components for which the mass is measured based on CAD a margin of 10% shall be considered.

Centre of gravity can be determined using CAD model provided.

DNB Inertial loads	N°	Single load name	Cat.	Value (Kg)	Application point	Comment
Vessel	1	Vessel Weight	I	53770	Stands of vessel (fixation with PMS)	
Top Lid	2	Top lid	I	25500	Vessel Flange	
Temp. lids for testing	3	Temp. lids for testing	I	TBD	Opened end of the vessel	
Feedthrough box	4	Feedthrough box	I	600	PMS	

Table 2 – Dead weight table

As the design is in evolution, the latest weights should be checked before calculation.

2.1.2 Application points

The masses listed above are reacted at different locations:

- The vessel is supported by the PMS (see interface load)
- The feedthrough box is supported by the PMS through a bracket (see interface load)
- The top lid is supported either by the vessel flange or by the “RH top lid opening system” (see interface load)

2.2 Pressure loads

All the pressures mentioned in the document are absolute pressures.

During the different phases of the project, different pressures will be applied inside and outside the vessel. These loads are the same for the vessel and for the lid.

Concerning the cooling system, according to the on-going PCR-409, all the components (LV, HV and Front End Components) will be supplied by the NBI PHTS with the exception of the ACCCs.

The 0.2MPa pressure of the NB cell (PCR-398) is not considered for the vessel.[1]

All pressure loads are listed in the following table and described in the following chapters:

DNB Pressure loads	N°	Single load name	Cat.	Value (MPa)		Nb of Cycles	Application point	Comment
				Inside	Outside			
NBI PHTS Pressure	20	Pulse pressure	I	2.6	0.1	50000	Cooling pipe feedthroughs	
	21	Test pressure (max.)	I	3.9	0.1	50		
	22	Min outlet pressure	I	0.8	0.1	50000		
	23	Draining	I	0.5	0.1	Static		
	24	Drying	I	0.5	0.1	Static		
Pressure combination	25	Vacuum	I	0	0.1	500	Shell of vessel	
	26	Vessel at atmospheric pressure	I	0.1	0.1			
	27	Spark gap test	I	0.1	0.1	10		
	28	VV ICE II	II	0.1	0.1	15		
	29	VV ICE III	III	0.15	0.1	-		
	30	VV ICE IV	IV	0.2	0.1	-		
	31	LOCA NB II	II	0	0.13			
	32	LOCA NB III	III	0	0.16	-		

Table 3 – Pressure Load Table

2.2.1 Operation and maintenance pressure

- **Pulse pressure** (load n°20)

The NBI PHTS cooling loop is pressurised at 2.6 MPa maximum [24]. This pressure is applied all the time except during shutdowns. The outlet pressure can vary depending on the pressure drop of the components (see below).

- **Test pressure** (load n°21)

The NBI PHTS is designed according to ASME B31.3. This code states that hydrostatic test pressure shall not be less than 1.5 times the design pressure. This value is used as it is higher than RCC-MR requirement (1.43 factor).

- **Outgassing**

During the manufacturing**,** an outgassing will be performed on the DNB vessel. During this outgassing the DNB vessel will be put under vacuum and temperature will be applied on the vessel in order to outgas the remaining manufacturing product. In term of pressure this load is similar to normal vacuum (load n°25).

- **Minimum outlet pressure** (load n°22)

The NBI PHTS outlets pressure can be 0.8 MPa minimum. This pressure is cycled with the nominal pressure. This pressure value comes from the pressure drop of the BLCs, when the pumps are at full speed. In a conservative approach it is assumed that pumps are turned in the trickle flow mode between each pulse. Therefore the return pressure is cycled between 2.6 and 0.35MPa for the number of pulses. In a conservative way, the outlet temperature is assumed to be 100°C for any return pressure.

- **BLC draining** (load n°23)

The draining of the BLC components will require pressurized nitrogen at reduced temperature compared to the nominal baking temperature (50ºC) to blow-out the water. The definition of this pressure load is defined in [25]. The pressure to consider is 5bar.

[1] The 0.2 MPa pressure comes from the leakage of the NB enclosure. As the confinement of the NB system is lost there is no point that the vessel supports this pressure. But it has been checked that the collapse of the vessel do not create leaks on the NB cell confinement boundary.

The N2 pressure is defined according to the component design to ensure the PED classification is below or equal to category 1 [25].

- **BLC drying** (load n°24)
  - *Heating-up phase:* Drying gas (N2) at high temperature (≈220ºC → design temperature, [25]). The N2 working gas pressure at the entrance of the components during the heat-up phase requires optimisation to remain in ESP classification to category 0 or 1.
  - *Depressurisation phase:* The cooling circuit system is depressurised to a pressure below the saturated temperature of water. The vapour formed during the depressurisation phase is condensed in the condensers, and the condensed water is sent to the drain tanks.
  - *Dry-out phase:* The dry-out mode is an extension of the depressurization mode in which the system removes the vaporized water from the components, separates the water slugs, removes mists by a drain and mist separator and a pair of cooler and condensers, and withdraws the drained fluid to the drain tank. During the dry-out phase, the maximal pressure will be 5bar to ensure the ESP classification to category 1 or below.
- **Vacuum** (load n°25)

The vessel is under vacuum during and between pulses. Internal pressure is 10^{-7} Pa but can be considered as 0 for the analysis.

- **Vessel at atmospheric pressure** (load n°26)

During maintenance the vessel is filled with air at atmospheric pressure. The number of cycles vacuum to atmospheric pressure is set at 500 by [26] (chapter 4.2.2)

- **Cryopumps regeneration**

During the regeneration of the cryopumps the pressure will rise until 2kPa. This pressure can be considered as vacuum for mechanical calculations.

2.2.2 Pressure test

No pressure test will be carried out on the vessel. It is not required as the vessel is not classified pressure equipment (PED regulation concerns only loads up to cat.III (1.5bars), the 2 bar pressure (cat.IV is out of the scope of PED).

Beside pressure test, all other leak checking method can be used. At minimum, all welds will be verified and a leak test will be carried out.

- **NBI PHTS** (load n°21)

This test aims at validating NBI PHTS circuit leak tightness. The NBI PHTS is a Pressure Equipment and shall be pressure tested. According to PED this value is 1.43 time the nominal pressure value. To be compliant with ASME B31.3 a factor of 1.5 is used.

This pressure value is cycled with the nominal pressure each time a test is required. In a conservative way it is assumed to be less than 50 cycles.

- **Leak test** (similar to Vacuum load n°22)

This test will be carried out after manufacturing and assembling of the vessel. It shall be repeated after each opening to validate the leak tightness of the vessel. It is also done to validate

NBI PHTS piping before pressurisation. In this state the blanking flanges are installed on all openings of the DNB vessel.

The vessel is pumped and the NB Cell is at atmospheric pressure.

- **Spark gap test** (n°27)

This test aims at testing 100 kV insulation of the transmission line and the bushing. The vessel is at atmospheric pressure. This test is carried out once before the assembly of the internal components. The NB cell is at atmospheric pressure.

2.2.3 Accidental pressure

Among these loads, some come from incident or accident events. The Accident Analysis Report (AAR) [7][8][9] extracted from FMEA studies a list of events (incident and accident) which have an impact on the safety of ITER. Among these events three of them have to be considered for the DNB vessel design[2]:

- **VV ICE II: FW pipe leakage (cat.II)** (n°28)

This event corresponds to the ITER Reference Event V1 (II) reported in [8]. This accident describes the consequences of rupture of 1 to 10 pipes (Ø10mm) of one blanket module during baking. During this event the DNB internal pressure rises to 106kPa.

- **VV ICE III: FW/BLK module branch pipe break (cat.III)** (n°29)

This event corresponds to the ITER Reference Event V2 (III) reported in [8]. This accident describes the consequences of rupture of one feeding pipe (Ø50mm) of one blanket module during baking. During this event the DNB internal pressure rises to 150kPa, which is limited by the rupture disks In the VVPSS.

This event defines the design pressure of the vessel as no plastic deformation should appear after this event.

- **VV ICE IV: Multiple FW pipe break (cat.IV)** (n°30)

This event corresponds to the ITER Reference Event V2 (IV) reported in [8]. This accident describes the consequences of a multiple rupture of FW cooling tubes[3] belonging to three FW/BLK cooling loops. These leaks damage the divertor creating a few (1-10) leaks on the divertor cooling lines (Ø10mm). The pressure is released by the rupture disks of the VVPSS (at 150kPa). After several hours[4], the vapour heated by hot surfaces produces a rise of the temperature and of the pressure which can reach 170kPa. Taking into account uncertainties on this calculation (10-15%), 200kPa shall be considered.

- **LOCA NB II: Loss of coolant inside NB Cell (cat. II)** (load n°26a)

The NB Loss Of Coolant Accident can occur either during plasma operation or during baking. Bounding case (in term of safety) for this event is a cooling pipe break in a port cell. It is assumed that the break is coincided with loss of off-site power for 32h, hence active cooling of the in-vessel components is lost. This load shall applied on the external surfaces of the vessel.

The pressure inside the DNB vessel is vacuum during this event (worst case).

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[2] These events are equivalent to events occurring in the VV. During the accidental analysis: VV, all ports, and DNB vessel are considered as a single volume.

[3] Multiple means 130 of FW 10mm cooling pipes which is equivalent to a 0.02m^2 section.

[4] It is assuming that no action is done to limit the phenomena and that electrical power is lost.

According to [12], NB LOCA II is not defined but it has been agreed with ITER safety section to consider it according to pressure and temperature value as defined in Table 3 and Table 5.

- **LOCA NB III: Loss of coolant inside NB Cell (cat.III)** (n°28)

This event is equivalent to the ITER Reference Event X8 reported in [8]. The postulated initiating event is here a double ended pipe rupture of the largest diameter (Ø66mm) cooling pipe of the FW/BLK PHTS. This event will discharge coolant from a pipe that has the highest coolant enthalpy during full power operation (500 MW of fusion power), directly into the port cell (or NB Cell) creating a possible overpressure condition in the port cell volume.

The pressure rises to 140kPa (even if set point pressure of the relief panels in the cell is 120kPa). But the pressure limit is fixed at 160kPa because of uncertainties of the model. Temperature rises only during a short period. The related thermal load does not need to be considered. The pressure in DNB vessel is vacuum (worst case).

- **ICE events from NB components**

All these events are negligible. Justification is given in [24].

- **Leak from the cryopumps**

In case of big leak in the cryopumps, it is assumed that the valves located in the cryogenic valve boxes in L3 will close instantaneously. The helium inventory of the cryopumps with the inventory in cryolines will be released into the DNB Vessel.

In the worst case scenario both circuits, radiation shield and cryopanels will burst and both cryopumps in the DNB Vessel will burst. In this extremely conservative case the helium inventory released into the DNB Vessel is 23 kg and leads to a pressure of 85 kPa below atmosphere, assuming a volume of 171 m3 for the DNB Vessel. As detailed in [27] the pressure is less severe than the other pressure loads.

2.3 Assembly and Pretension Loads

The assembly loads for the vessel are the inertial loads n°92 and n°93 for the top lid.

Concerning the pretension load, all the flanges will be under the tension on the bolts. The following pretensions are used:

- Pretension for the top lid Superbolts™: see 2.8.1
- Pretension for the Fast Shutter flange: see 2.8.2
- Pretension for HVB flange: see 2.8.3
- Pretension for the HVB flange: see 2.8.3
- Pretension for the support leg with PMS: see 2.8.5.1
- Pretension for the cryopump flange: see 2.8.4.4.4
- Pretension for IO standard flanges: see [10]

2.4 Seismic Loads

2.4.1 General information

- **Classification**

The DNB vessel comes under Seismic Class 1(S). Three level of ground motion are to be considered:

- SL-2 (cat.IV): it corresponds to the seismic level required by French nuclear practise (RFS 2001/01). In this event it shall be demonstrated that all safety functions are maintained. For this event one event must be considered.
- SMHV (cat.III) (Séismes Maximaux Historiquement Vraisemblables = Maximum Historically Probable Earthquakes): it is the most penalising earthquakes liable to occur over a period of about 1000 years.
- SL-1 (II): it corresponds to an event with a probability in 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). The facility has to be designed to restart and operate after an SL-1 event without special maintenance or test. 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 protection, a number of occurrence of 5 is considered.

10 load cycles shall be considered in one seismic event.

- **Damping**

In document [12] are reported some indication about the damping coefficient for typical mechanical structures. With the present design of the PMS a damping of 4% for SMHV and SL-2 shall be used.

The floor response spectra are provided for specific values of damping. If for a specific damping value the spectrum is not provided, values can be derived by interpolation using the formula:

$$(A_{i-1} - A_i)/ (A_{i-1} - A_{i+1}) = \ln(\zeta_{i-1}/\zeta_i)/ \ln(\zeta_{i-1}/\zeta_{i+1})$$

$$A_i = A_{i-1} - (A_{i-1} - A_{i+1})* \ln(\zeta_{i-1}/\zeta_i)/ \ln(\zeta_{i-1}/\zeta_{i+1})$$

A_{i-1} ,A_i, and A_{i-1} are the spectral acceleration for the damping value ζ_{i-1}, ζ_i, and ζ_{i+1}.

2.4.2 Floor response spectra

The FRS is a powerful way to give the seismic acceleration versus frequency for a component connected to the building.

The construction design FRS report [11] provides the FRS values of each node of the tokamak building. Figure 7 describes the nodes available for the NB-Cell.

The following spectra must be used for the DNB vessel (nodes 45391). The nodes locations are shown on the Figure 7.

- **Map of calculated points (L1):**

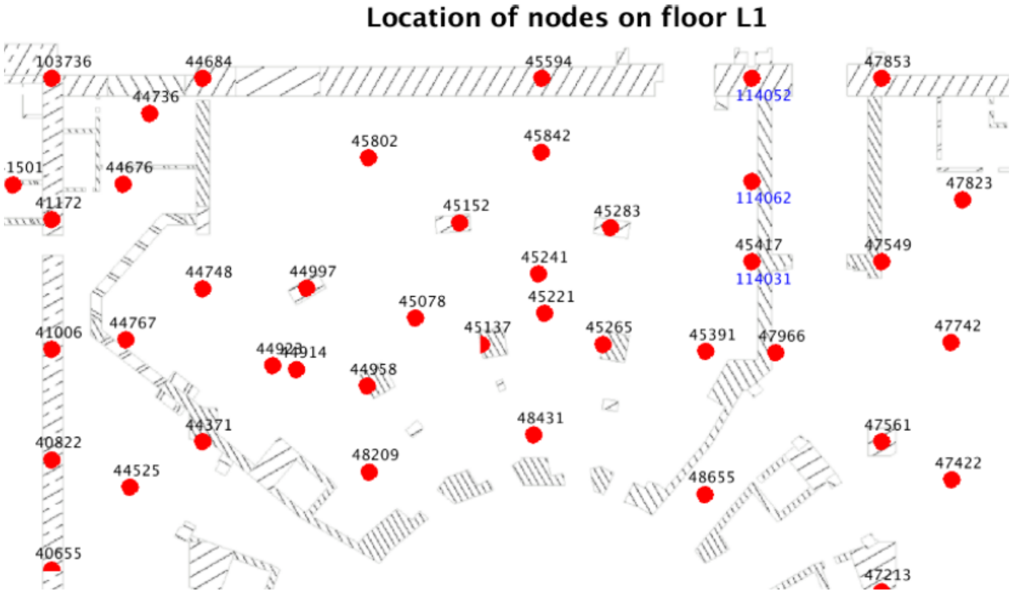


Figure 7 – Seismic floor response calculated points in Level 1

- **Acceleration**

As far as only the FRS of the SL-2 is available, the SL-2 acceleration shall be calculated using the FRS at 4% damping.

For the SL-1 seismic event, the accelerations of the SL-2 (at 4% damping) shall be multiplied by a factor of 0.34 to calculate the SL-1 seismic event.

For the SMHV seismic event, the accelerations of the SL-2 (at 4% damping) shall be multiplied by a factor of 0.73 to calculate the SMHV seismic event.

DNB Seismic loads	N°	Single load name	Cat.	Nb. Of Cycles	Value	Comment
Earthquake with 10^{-2}/year probability	35	SL-1	II	50	See spectrum	
SMHV	36	SMHV	III	10		
Safe shutdown Earthquake	37	SL-2	IV	10		

Table 4 – Seismic loads

2.5 Electromagnetic loads

2.5.1 Stray field and slow transient

The stray field is produced mainly by the poloidal coils. The plots Figure 8 are extracted from the report [17] (fig 3.5). It gives the maximum field and field variation in case of a 15MA plasma for various distance from the Tokamak axis. These results are given excluding the plasma and having conducting walls[5] (worse case).

[5] Take into account the rebar in the concrete.

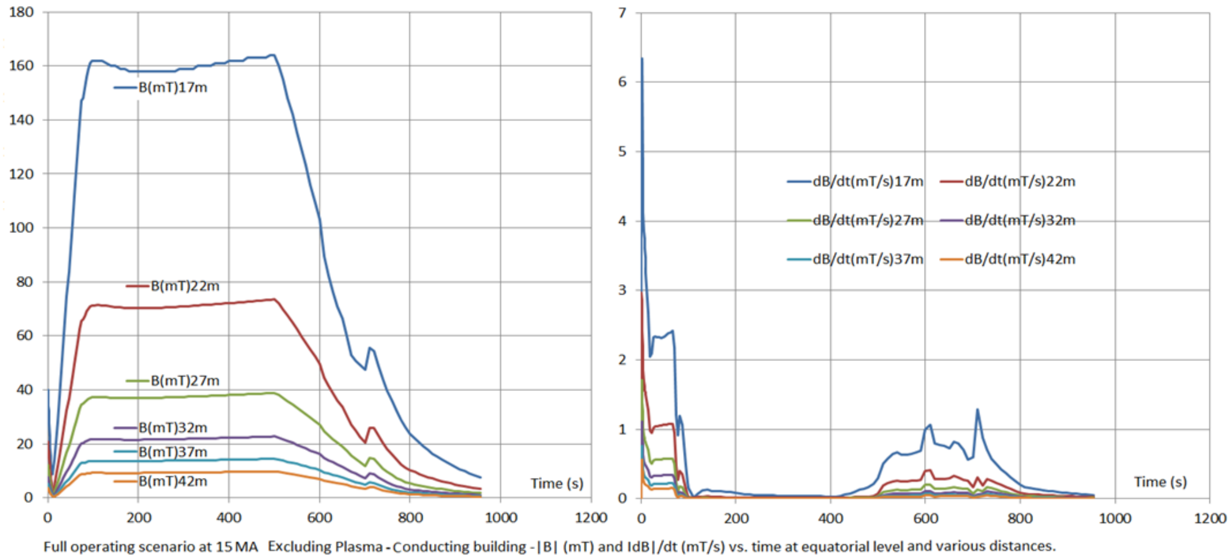


Figure 8 – Magnetic field and field variation during a 15MA scenario for the equatorial level.

The closest feedthrough (HVF) is located 27m away from the Tokamak axis. The maximum field is below 40mT and the field variation below 2mT/s. The closest IF is located 35m from the Tokamak axis.

The amount of magnetic material of the feedthrough being very small, and the feedthrough being shielded by the PMS and the ACCCs, the mechanical loads associated with this field value are considered negligible. The field variation is slow and is also considered as negligible.Fast transients

2.5.2 Fast transients

These EM loads coming from transient events can have various origins: plasma disruption, vertical displacement events (VDEs) and magnet current fast discharge (MFD). Additional information about these transient events can be found in chapter 7.2 and 7.3 of [12]. The main consequence of these transients is the induction of currents in the conducting structures which, in turn, gives rise to significant internal and mutual loads.

The only fast transient event reported in [17] (figure 3.1) for a 15MA plasma is a VDE with a linear current quench of 36ms (see Figure 9). It is a worst case that encompasses all the other fast transient events[6].

[6] All the transient events give a similar stray field and field variation outside the bioshield.

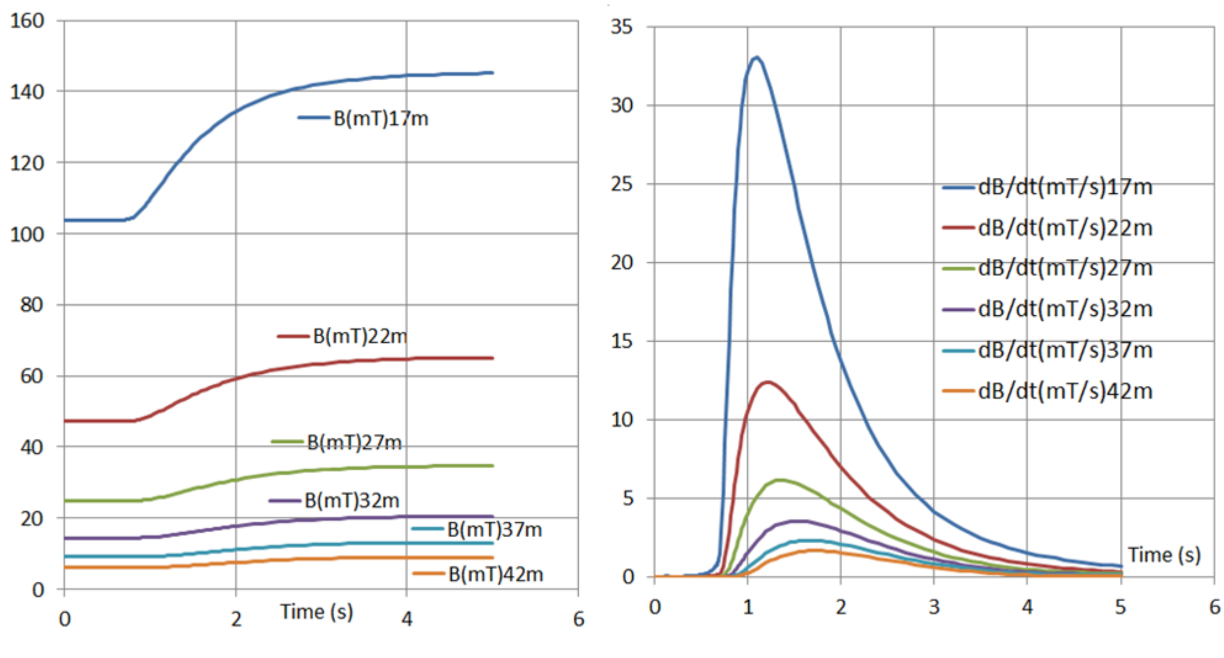


Figure 9 – Magnetic field and field variation during a VDE at 15MA (current quench linear 36ms) for equatorial level.

The DNB vessel is located between 20 and 35m away from the Tokamak axis. The maximum stray field will be below 120mT. Concerning the field variation, the highest dB/dt is below 25mT/s. No analysis was carried out to assess mechanical loads with this value but an assessment using 24mT/s (combined with other field parameters, see [18]) was performed for the HNB vessel. This analysis did not take into account the shielding effect of the PMS and the ACC coils. Therefore, the values calculated are higher than what is expected in reality.

This analysis gives the following values: fast disruption generates torques on the three axes. The higher one is around the radial direction (X axis in GGCS) (21890 N.m to be applied on the BLV and the BSV). To have a conservative assessment of the reaction forces generated on the vessel support, we apply this torque only on the BLV (worst case as height and width are smaller than BSV). This torque generates a force of 8.3kN which is distributed on 4 supports. For comparison, the weight of the BSV with all its equipment generates a load of 165kN on each support.

Therefore we judged EM loads negligible compared to dead weights and other pressure loads.

2.6 Thermal Loads

Thermal loads on the vessel have various origins:

- **Room temperature** (load n°40 and 41): the room temperature is regulated by the local air cooler located in the NB Cell. It is designed to maintain the NB cell temperature between 18 and 35°C. This system will maintain the NB cell air temperature below 35°C during pulses.

- **Escaped particles from the beam**: their effect is negligible as all areas likely to receive these particles are protected.
- **NBI PHTS** (load n°42 to 44): heat is transmitted to the vessel via the coolant circulating in cooling pipe feedthroughs. This load is required to size the thermal sleeves of the vessel. Temperature and pressure values are indicated in Table 3 and Table 5. Depending on the pipes, the situation is different:
  - Inlets: the temperature during pulse is constant.
  - Outlets: the temperature is cycled between inlet and outlet temperature and pressure.
  - Drying: temperature.
- It is assumed that the draining does not generate thermal load.
- **Cryopumps**:
  - Normal operation (load n°45): during cryopumps normal operation the thermal shields are at 90K. They pump heat from the vessel by absorption of the radiation. Consequently, the temperature of the vessel wall decreases (-7ºC starting at 20ºC and after 72h operation). The ribs being in contact with ambient air see a negligible temperature change (-1.5ºC max.). According to [20], the vessel wall facing the cryopumps will reach 12°C after 25h operation (minimum temperature in the middle of the wall).

  Cryogenic pump regeneration can also create thermal loads by combination of radiation and convection (pressure can rise to 2 kPa): there are three type of regenerations with different periodicity: 100K 5000 times in Iter's life, 300K 300times and 400K 50 times. 300K regeneration is not considered as a thermal load.

  For the modelisation of the effect of the cryopumps temperature onto the vessel walls a heat transfer coefficient of 5W.m2.K-1 shall be applied on its the external surfaces as given in [20].

  - 100K regeneration: during this regeneration the energy content of the gas released by the pump is quite small compared to the mass of the vessel. Moreover the duration of high pressure phase lasts only 50 min. The ribs of the vessel are slightly heated up by the ambient air (by 0.5ºC). This load has a negligible effect on the interface displacement.
  - 400K regeneration: during this regeneration, both circuits of the pump are heated up to 400K in order to decontaminate the cryopump (release of all tritiated water isotopes). Conservatively 72h of regeneration are considered. During this event, the pressure can vary between 100 and 200 Pa. For mechanical calculation it is considered as vacuum.
  - Leak of cryogenic fluid: as described in [20], if both cryopumps breaks their two circuits, the amount of cold helium released in the vessel is 20kg. Compared to the hundred tons of the vessel and BLCs, this thermal load is negligible.
- **Bushing and Transmission Line** (load n°47) (conduction): The bushing and the TL will heat during operation. A part of this heat is transferred to the vessel. This load could be considered as negligible if justification provided.
- **PMS** (load n°48): radiation from PMS is already taken into account in the heat transfer coefficient used for the thermal analysis of the vessel [20]. In addition, conduction and

convection will be significant drivers for equalising the temperatures of the PMS and the vessel with ambient NB cell air temperature. The power on all vertical surfaces (vessel & PMS) is around 5W/m^2/K. The PMS act as a cold mass connected to the vessel and increases its thermal inertia. During normal operation the temperature of the PMS is defined as the room temperature.

- **Front components**[7] (load n°49 & 50): during operation the temperature of the fast shutter in contact with the vessel should contribute a negligible thermal load. During baking, the fast shutter is not baked directly (heat derives from the absolute valve at 200°C). The resulting thermal load is negligible for the vessel.
- **BLCs:** (load n°51) (BLCs + exit scraper): Radiation from these components is negligible as the maximal temperature is 100°C. Conduction has to be calculated. This load is applied during pulses. It is small and localized compared to main loads and can be considered negligible.
- **Exit Scraper** (load n°52): this load describes the contact of the ES with the vessel front panel. It seems small and could be considered as negligible after justification.
- **Radiation from plasma** (load n°53) (nuclear heating): neutrons and γ-rays coming from the plasma create a heat load as described in chapter 2.7.
- **Fire load** (load n°54): A dedicated fire analysis for volume under the balcony has been performed and the results are reported in the reference [28]. This calculation is applicable only for the front part of the vessel's duct which is located in this area. The maximal temperature is this area is 300ºC for 2h.

  As there is no fire analysis available for the NB cell (current load in NB Cell is defined by ISO 834 standard fire curve (EN 1991-1-2 standard temperature time-curve) applied during two hours) at the time of the writing of this document the selected strategy for the protection of the NB components is to wrap them with passive fire protection. Because the vessel is inside the PMS, the passive fire protection will be added on this last component and therefore the temperature of the vessel will be limited in case of fire.

  It is considered that the design of the insulation around the PMS will protect the vessel from flame and the maximum temperature will be 150°C except for the front part under the balcony [29].

  As said before only the front part of the vessel's duct will be affected by temperature under the balcony, see Figure 10. Application point of the temperature onto the duct is limited at the PMS outer face. Rest of the vessel will be at the temperature defined in previous paragraph.

[7] Components cooled by the NBI PHTS (temperature between 40 and 85°C, baking at 100°C): Absolute valve shutter, Drift duct liner.
Components baked electrically at 200°C: absolute valve casing, VVPSS box, Drift duct bellow.

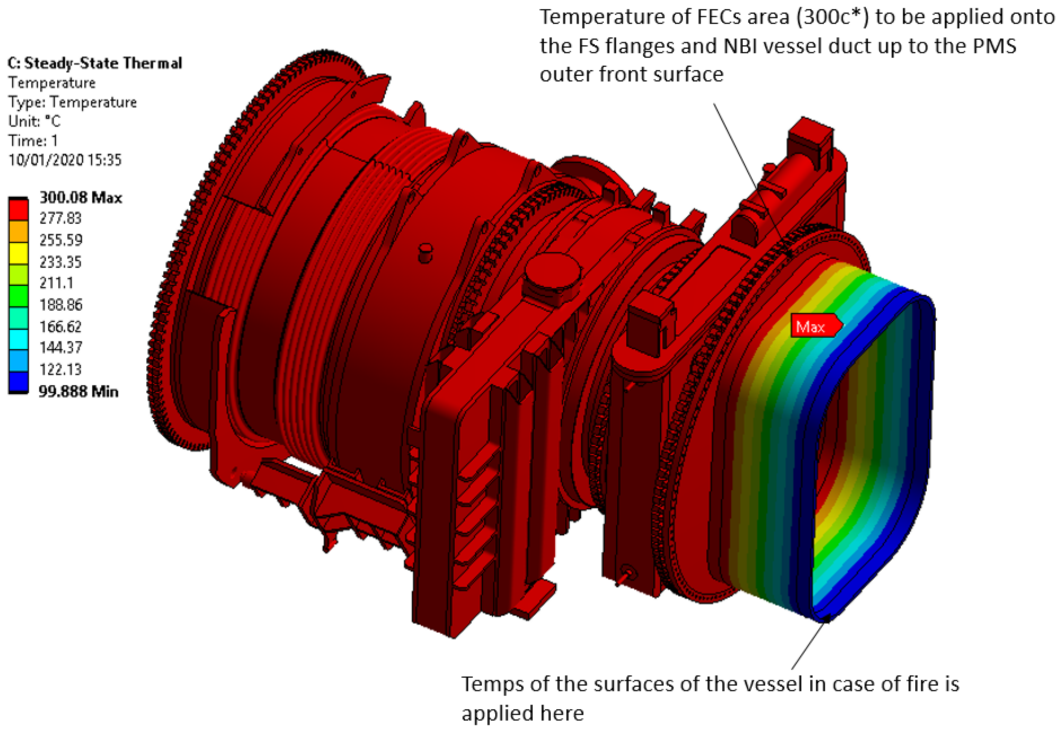


Figure 10 – Temperature on the vessel 's duct in case of fire

- **VV ICE thermal loads (**load n°54**)**

All the ICE events do not generate thermal load as justified in [27]. Temperature is indicated in Table 5.

- **LOCA NB II (**load n°55**)**

  As described in the chapter 2.2.3 the pressure rise is due to the loss of coolant in the NB-Cell, by consequence the temperature will also increase. Temperature is indicated in Table 5.

- **LOCA NB III** (load n°56)

  As described in the chapter 2.2.3 the pressure rise is due to the loss of coolant in the NB-Cell, by consequence the temperature will also increase also. Temperature is indicated in Table 5.

- **Outgassing** (load n°57)

  During the manufacturing**,** an outgassing will be performed on the DNB vessel. During this outgassing the DNB vessel will be put under vacuum and a temperature of 100°C will be applied on the vessel in order to outgas the remaining manufacturing product.

As mentioned above, some thermal analysis has been carried out on the HNB vessel. As the values given by this analysis are the only available information, they are used and applied to the DNB vessel. The following table lists all important thermal loads:

DNB Thermal loads	N°	Single load name	Cat.	Value (°C)	Nb of Cycles	Application point
Room Temperature	40	Room temp. max	I	35	N/A	All NB Cell
	41	Room temp. min	I	18		
NBI PHTS	42	Inlet temperature	I	40	50 000	Cooling inlet pipe feedthroughs
	43	During pulse outlet temp. (Max)	I	100		Cooling outlet pipe feedthroughs
	44	During drying	I	220		
Cryopumps	45	Pumping	I	HTC	50 000	Vessel inner lateral walls
Conduction from Bushing	47	Bushing	I	50	50 000	Bushing Flange
Conduction from PMS	48	PMS	I	Room Temp.	50 000	Link between PMS and vessel
Conduction Front component	49	Front comp. norm op.	I	Same as connected components	30 000	Front flange
	50	Front comp. baking	I		500	
Conduction from BLC	51	BLC	I	N/A	50 000	Link between BLC and vessel
Conduction from Exit scraper	52	Exit scraper	I	N/A	30 000	Link between Exit scraper and vessel
Radiation from plasma	53	Nuclear heating	I	See results chapter 2.7	30 000	Whole Vessel
Fire in NB Cell	54	Fire	IV	150	-	External surfaces of the Vessel (temperature to be calculated based on wrapping design)
LOCA NB II	55	LOCA NB II	II	112	-	All Vessel surfaces
LOCA NB III	56	LOCA NB III	III	118	-	All Vessel surfaces
Outgassing	57	Outgassing	I	100	1	All Vessel surfaces

Table 5 – Thermal loads

2.7 Nuclear Loads

The impact of neutrons and prompt gamma-rays on materials can create various effects in the material of a component. The usually most important consequences are nuclear heating, helium production and damage. Explanation about this phenomenon can be found in chapter 5.3.11 of [13].

The recommended value to be use in engineering analysis is 0.5mW.cm^{-3} [15]. This is a conservative value based on the value at the front where the vessel protrudes through the PMS plates. There is no significant neutron damage to the vessels and no rewilding hence the helium production is not relevant. The contribution of the neutron source in calorimeter and RID to the vessels is negligible compared to the neutrons from the plasma.

2.8 Interface loads

2.8.1 Interface loads from metallic seals (load n°60)

The PCR-001112 has introduced double metallic seals for the sealing of the top lid in addition to the lip welds (see Figure 5). Therefore, the vessels shall accommodate the integration of these components. The require force of 655 N/mm per seal to compress enough these seals is defined by the behaviour of the seals for the "Reference optimized seal as given in Figure 11 below extracted from [31].

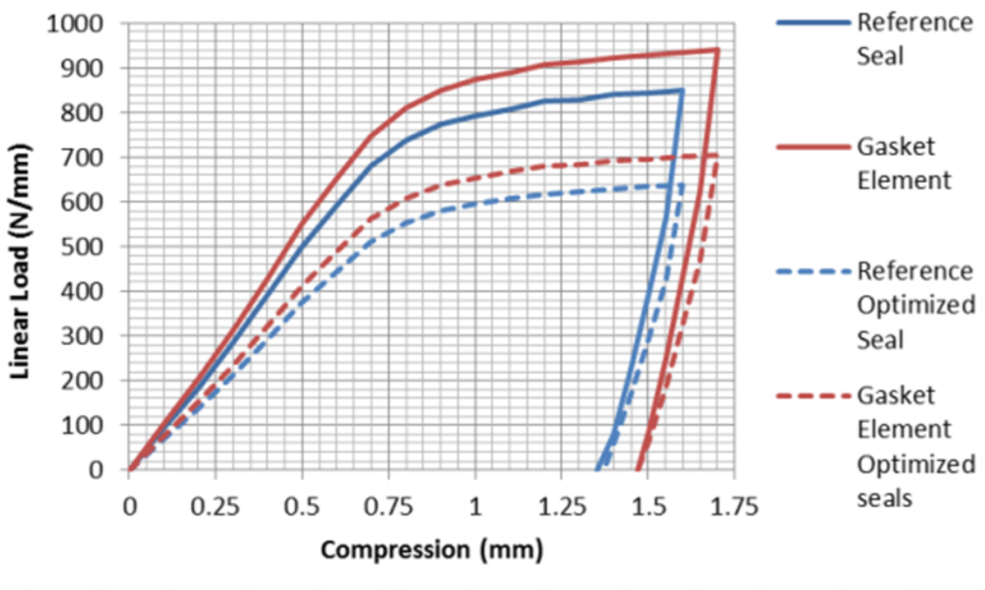


Figure 11 – Characteristic curve considered for metallic seal

This load is identified as load n°6X for the load combination table. It is transferred to the vessel's structure via pre tension forces in superbolts.

This load is applied to the contact surfaces between the vessels' flanges and the lids without considering the limiter holding the seals together and at the interfaces between superbolts and vessels.

This load shall ensure proper compression of the seals during normal operations and limit the opening of the vessel in case of internal overpressure to a value of 0.25 mm (as defined in [31]) as useful spring back of the seal) for the inner seal.

Detailed calculation sheet can be found in Appendix C.

2.8.2 Interface load to Fast Shutter (load n°61)

2.8.2.1 Introduction

The front opening of the vessel is connected to the FEC (Front End Components) via the fast shutter. A load coming from the fast shutter is transmitted to the vessel. This load can have several values depending on pressure in the VV or the DNB vessel or temperature.

This load is identified as load n°6X for the load combination table..

This load applies at the bolted interface between the DNB vessel and the fast shutter (see Figure 12).

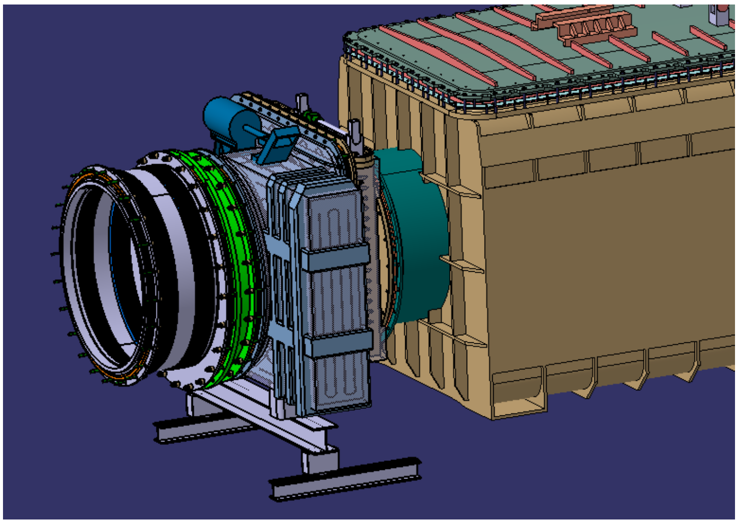


Figure 12 – Detail of connection between DNB vessel and the Front Components

This load is the combination of the different loads coming from the FEC (from DD bellow until FS). It is mainly generated by:

- the spring effect of the DD bellow combined with the VV displacements (thermal expansion)
- the pressure acting on the different surfaces of the components (VV, DNB, NB cell pressures).

In the following data the friction from the FEC trolley is not considered. Vertical (Z) and lateral (Y) forces are reacted by the FEC trolley. They are not passed to the vessel.

This interface is in under the pretension of the bolts of the components flanges.

The displacements of the DD bellow generating loads at the interface with the vessel can be found in [22].

The hydrostatic end thrust effect F_f from the DD bellow due to inner pressure is defined based on the dimensions of the DD bellow:

$$F_f = \frac{\pi.\emptyset_{DDbellow}{}^2}{4}.\,Pressure\ = \frac{\pi.2650^2}{4}.0.1 \approx 560\ kN$$

As the DNB vessel is one of the supports of the FS, half of the fast shutter weight (70kN) must be added to the values above in -Z.

The calculations reported in [22] do not include the seismic loads on the vessel and FEC. But these loads are considered negligible from the results of the integrated seismic analysis [30].

The sealing between the fast shutter and the vessel is realized with a double metallic seals solution. In order to not over compressed the metallic seals a limiter is implemented between fast shutter and vessel flanges see Figure 13. The fast shutter flange will be bolted with 120 M20 bolts with pretension force of 570N/mm for a total tightening load of 10644615N to ensure the efficiency of the metallic seals, see appendix D. This load is to be considered for all load cases except for tests and assembly operations.

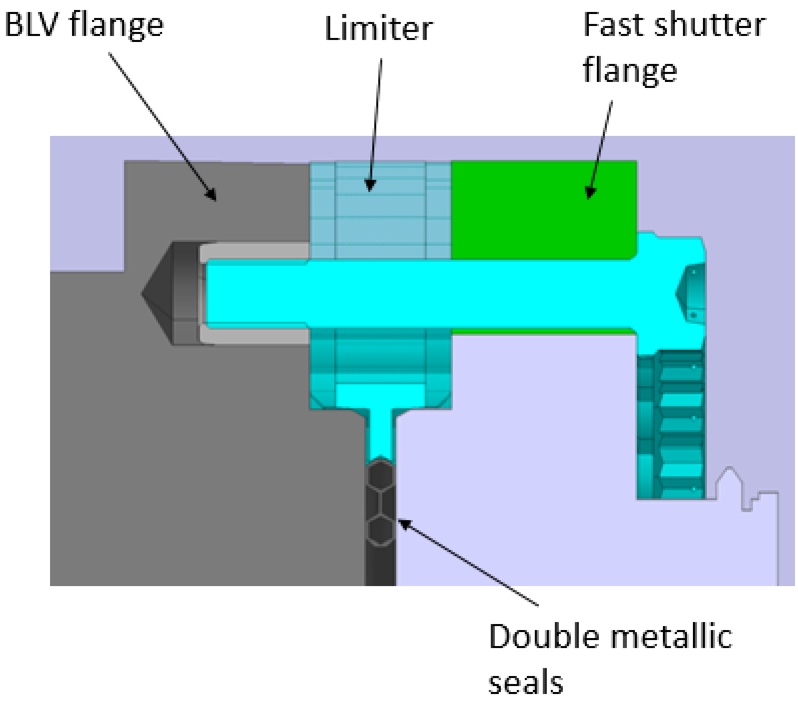


Figure 13 – 2D view of the sealing solution between BLV and fast shutter flange

2.8.3 Interface load to the Bushing (load n°62)

The bushing is connected to the DNB vessel. The load comes from its own weight but also from the HV transmission line. The interface load is finally a composition of the following loads:

- Weight of the bushing
- Stress coming from the transmission line. At present, the link between these two components is designed with flexible elements in order to perform remote handling. Consequently this load can be considered as negligible.

Temperature of the bushing will remain room temperature. If a loss of forced flow occurs, the injector will stop and go in safety state. Consequently, no additional thermal load is expected.

The sealing between the HVB and the DNB vessel is realized with a double metallic seals solution. The HVB flange will be bolted with M20 bolts with pretension force of 570N/mm (same as for Fast Shutter) see appendix D.

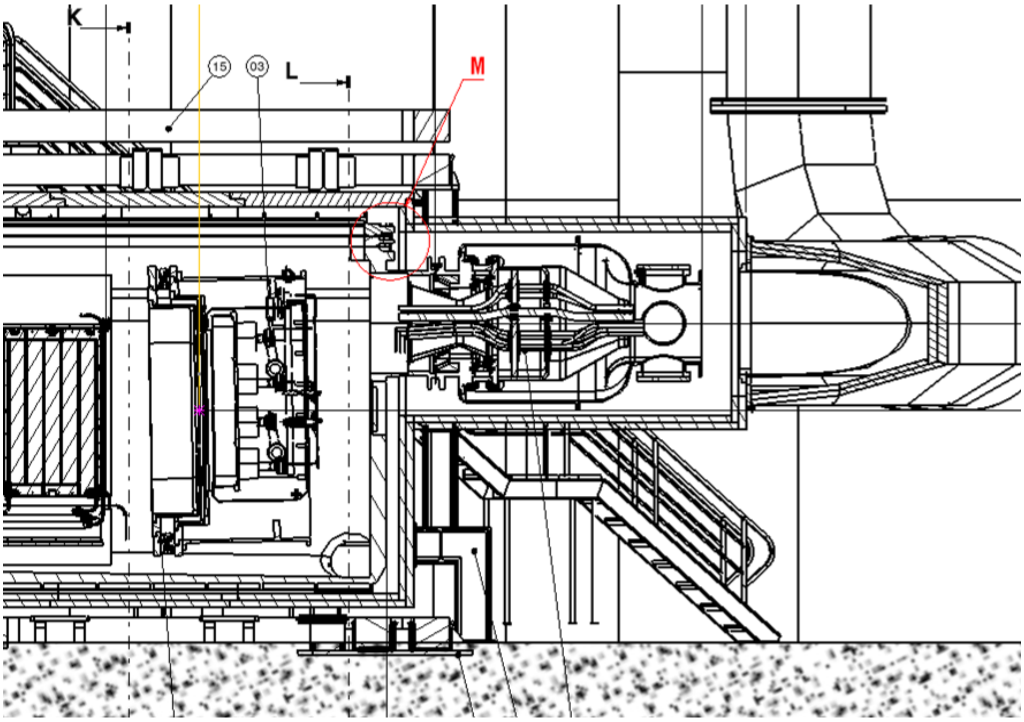


Figure 14 – Detail of connection between TL2 and Bushing

2.8.4 Interface load from Internal Components (load n°70 to 72)

NED, RID Calorimeter and Exit Scraper are grouped under one interface load.

2.8.4.1 Beam Source (load n°70)

2.8.4.1.1 Introduction

The interface loads generated by the BS comes from its dead weight and tilting/positioning system. On the side of the vessel, it is planned to have three actuators able to adjust the position and orientation of the BS. Additional information about this system can be found in [16].

A version of this load has to be defined for SL-1, SMHV and SL-2.

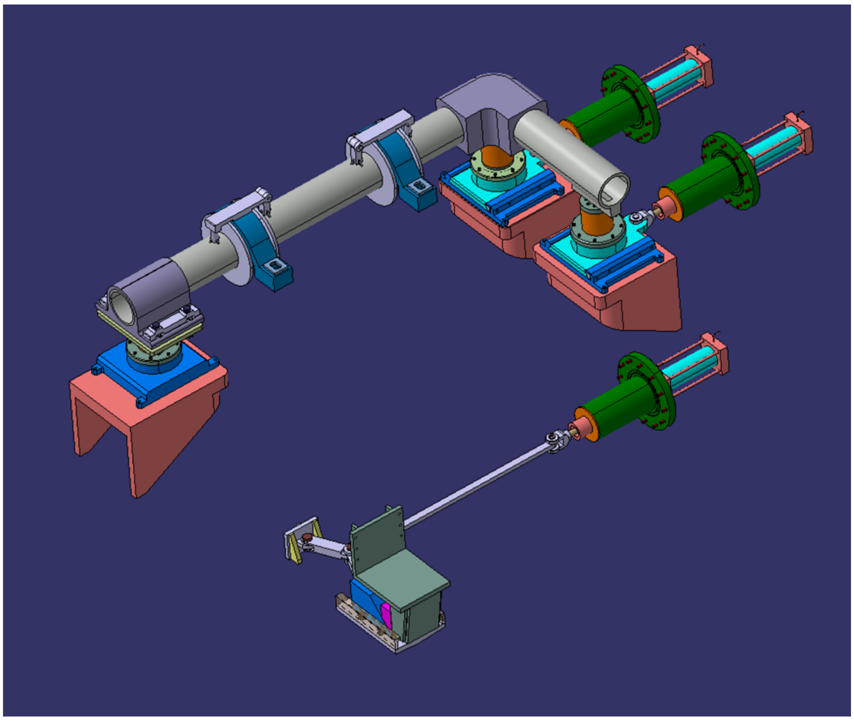


Figure 15 – Positioning and tilting system of the BS

2.8.4.1.2 BS support:

The BS is supported by a beam which is linked to the vessel on each side through brackets:

- Vertically the supports see the BS + Support beam weight: 37.45kN/support.
- Horizontally each support sees:
  - The reaction force from the tilting system: 13.14kN (half on each support) in X (see hereafter).
  - The reaction force from the translation mechanism: 31.47kN in Y to be shared by the two supports (distribution not known, see details below)
  - The reaction force from the rotation mechanism: 32.38kN in Y on the left support (actuator side, see details below)

2.8.4.1.3 BS Tilting system:

The tilting system generates loads in two different locations:

- Interface with tilting mechanism: this interface sees the following loads:
  - The load generated by the BS weight (mass centre not aligned with the revolution joints on the support beam) which is 26.28kN in X.
  - The loads generated by the actuator which is 13.96kN in Y.

  In case of seismic event, this system should absorb the forces in +X and –X directions. This load must be calculated by a seismic analysis.

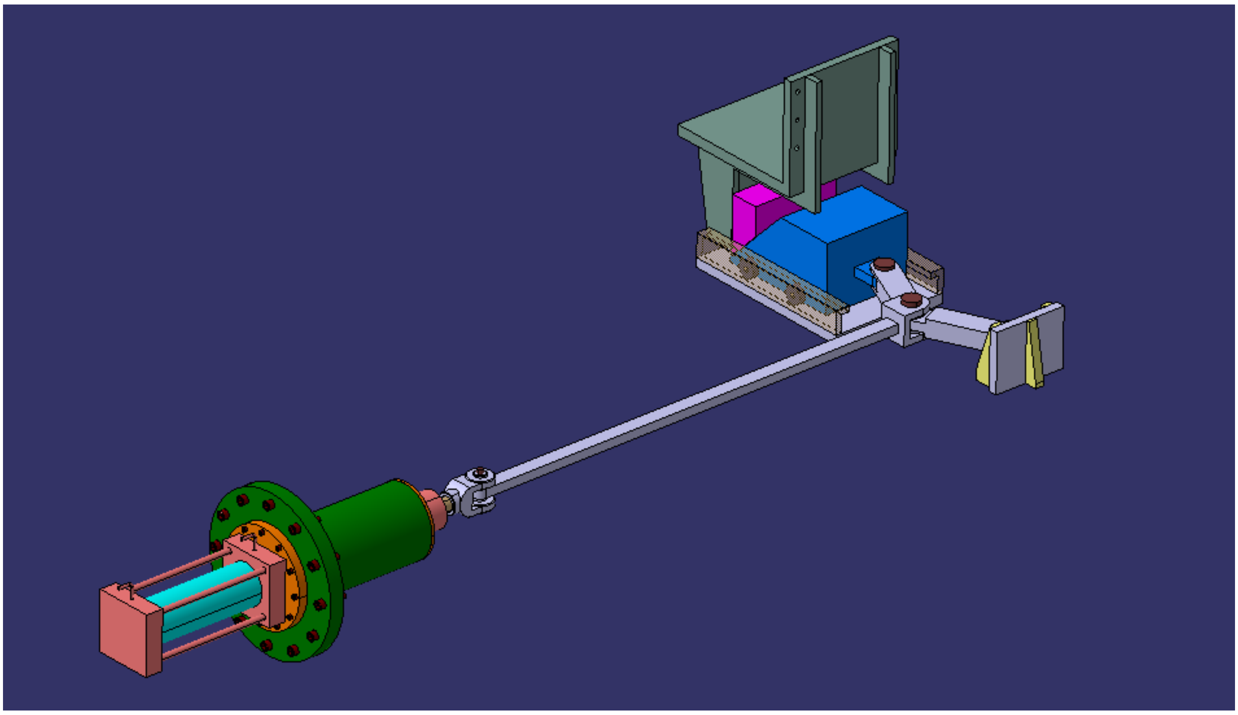


Figure 16 – Tilting mechanism (without electrostatic shield)

- Interface with the tilting actuator: the actuator will generate a load of 50.29kN to maintain the BS tilted with the maximum angle. This load is reacted to the fixation point of the actuator. The load on the vessel is therefore in –Y direction except in case of seismic event.

These loads can be considered as preloads as they will be applied in all load combinations where the BS is assembled with the vessel.

2.8.4.1.4 BS positioning system:

Positioning system uses two actuators: one for y translation, the second for z rotation. The forces generated on the screw are transmitted to the vessel through the screw support. Details on the actuators are shown fig.16.

As this system uses a sliding joint with a non-zero friction coefficient, the load (or preload) intensity will be between 32.38kN for rotation mechanism, and 31.47kN for translation mechanism (based on today's available design). These loads are applied to the vessel through the support of the screws.

As the adherence properties yet have to be established, calculations should be carried out with the maximum value applied all the time (when BS fixed in the vessel). The direction of the load depends on the direction of the last movement. Therefore four combinations of these 2 loads can be obtained. They must be verified for local effects on vessel.

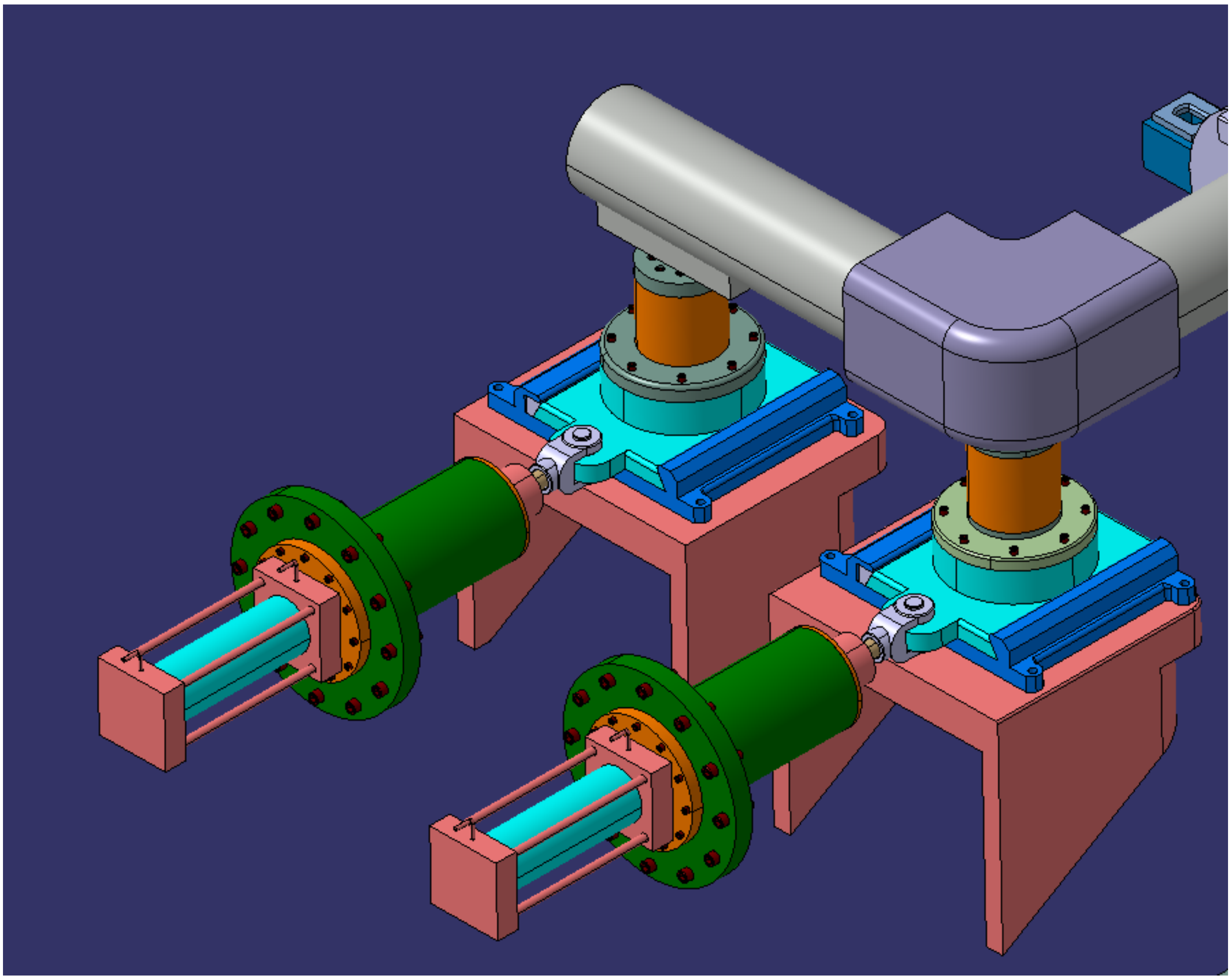


Figure 17 – Positioning mechanism with master/slave support point

2.8.4.1.5 BS cooling:

Two cooling pipes (DN50) dedicated to the Grounded Grid are crossing the side wall of the vessel. Their connection to the BS will be done through flexible connections. Their connection to PBS26 pipes will be done by welding. The interface load is not defined but is considered as negligible for the vessel structure. A local check shall be done.

2.8.4.2 NED, RID and Calorimeter (grouped in load n°71)

2.8.4.2.1 Introduction

These components are fixed to the vessel through one common adjustable bed. They have four contact points with the bed and the bed has 12 pads in contact with the vessel. All interface loads are transferred through these.

A version of this load has to be defined for SL-1, SMHV and SL-2.

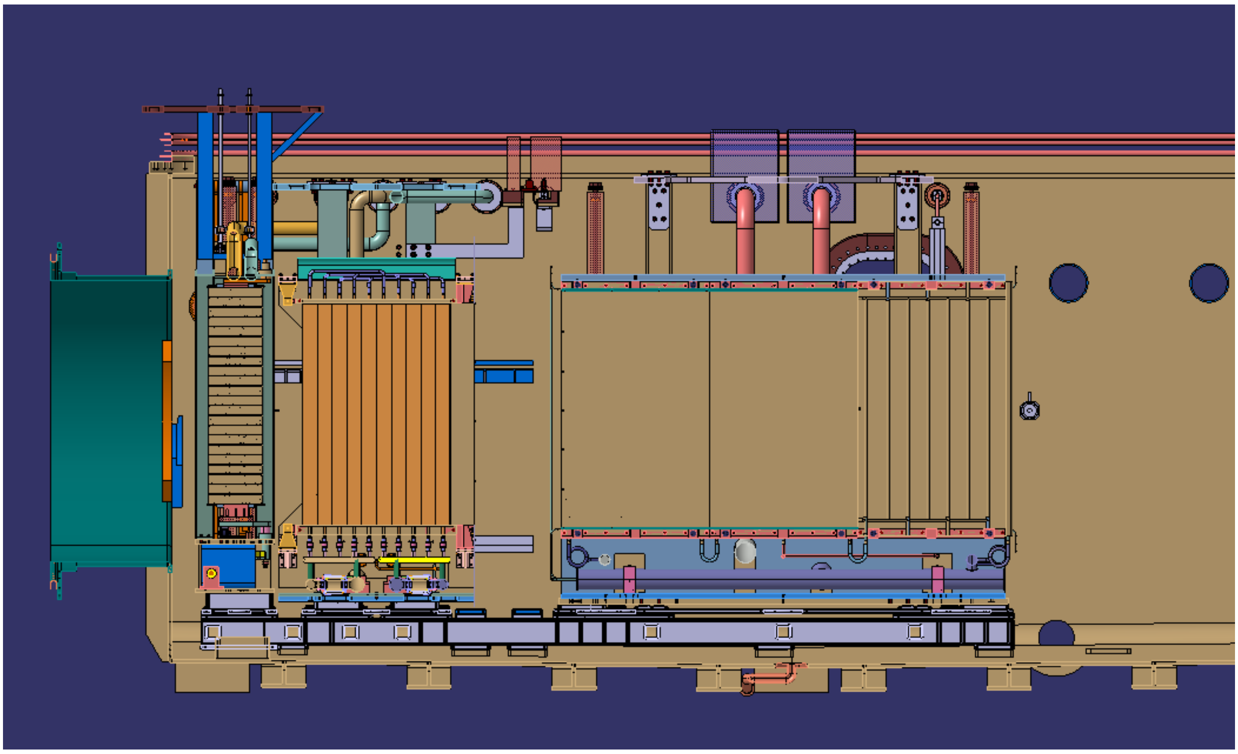


Figure 18 – Section of vessel with the NED, RID and calorimeter

The interface load is composed of:

- The weight of the BLCs
  - NED: 16500kg
  - RID: 4550kg
  - Calorimeter: 2890kg
- The weight of the adjustable beds: 3333kg
- The reaction forces coming from their cooling pipes inside the vessel. These forces were studied for HNB [32] and can be considered as conservative values. They will act on the vessel at the level of the cooling feedthrough and the adjustable supports.
- The reaction force coming from the calorimeter actuator is estimated to be ±10kN in Y and is applied on the flange. In case of control system failure, the jack is able to generate ±20kN force. This later shall be taken into account as a conservative approach.

• **Element**	**FX (N)**	**FY (N)**	**FZ (N)**
Inlet/outlet pipe	<10	40000	<175

Table 6 – Reaction forces at the vessel of Neutralizer cooling lines

The loads coming from the Neutraliser gas line and from the RID busbars are considered as negligible.

The loads from the connection and disconnection of the instrumentation cables are considered as negligible.

2.8.4.3 Exit scraper (grouped in load n°71)

The Exit Scraper (ES) is fixed to the vessel on the vessel front panel. It interfaces the vessel on two different locations: front panel for the mechanical fixation and on the bottom side for the cooling feedthroughs.

- ES support interface:

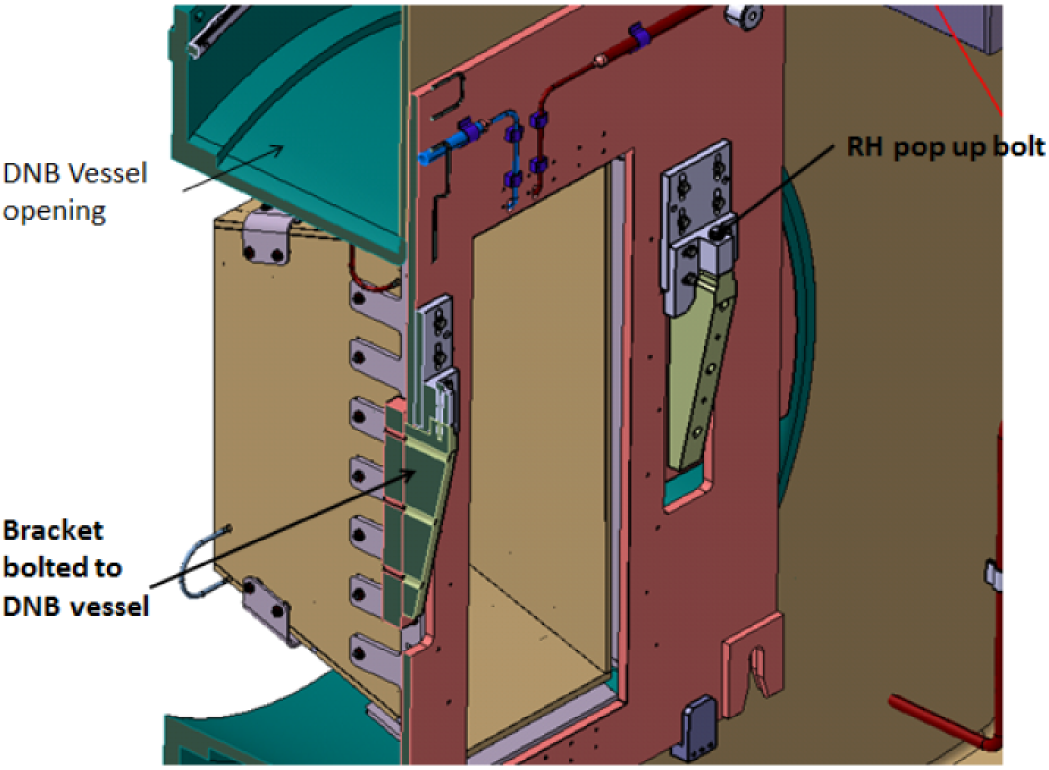


Figure 19 – Exit scraper assembled on the vessel

The ES is laid on two brackets which support the vertical loads and lock Y translation. Four vertical plans contact lock X translation and Y rotation. The Z translation is locked by two bolts (with a preload of 60KN) located on the brackets.

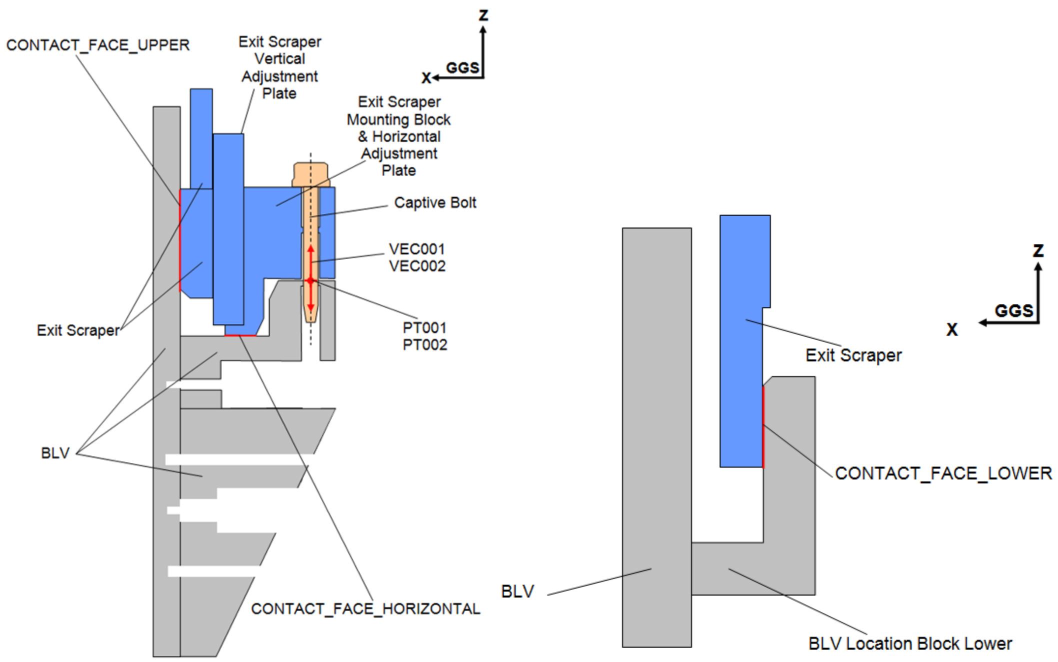


Figure 20 – Schematic cross section of the interface points (top and bottom)

The interface load is coming from the weight of the ES (1500kg) which is cantilevered from vessel contact surface[8]. The resulting maximum load is applied to the different surfaces described above.

The loads during SL-2 are not assessed yet.

- ES cooling pipes interface:

Inlet and outlet pipes from the ES are located on the top part of the vessel front panel. The interface load coming from the DN25 piping was not assessed but could be considered negligible. The maximum outlet temperature will be 50°C.

2.8.4.4 Cryopumps (load n°72)

All values described in this paragraph can be found in [33]. This analysis has been performed for HNB but the values of reaction forces can be considered conservative for the DNB.

2.8.4.4.1 Introduction

The two cryopumps are supported by the vessel side walls. As the pumps are not rigid, they are supported by several points along the vessel. Along the eight meter long cryopump there are three positions were the pump has to be limited in its movements during seismic events. The top lock systems are located at the top of the cryopump and fix the cryopump movement by bolting it to the beam line vessel. The top lock systems are designed to lock the pumps movement in Y-direction but allow a movement of several mm in the X and Z directions. The directions are X: Beam direction towards the VV, Y: Direction of the bolt, Z: Vertical direction.

The cryopump is supported at the back towards the DNB vessel. There are five top supports that are the gravity supports of the cryopump and four sliding supports on the bottom. The sliding guides at the bottom of the cryopump stop the cryopumps displacement during seismic events in y-direction. The top supports block large displacements in y-direction and function as gravity support while the only absolute fix point of the cryopump is the vacuum flange. The forces on the vacuum flange during operation or a seismic event are limited by the cryopump supports to acceptable values for sealing the DNB vessel and keep to the safety requirements.

The function of each support is described in Figure 21.

[8] The mass centers coordinates are given in Appendix A.

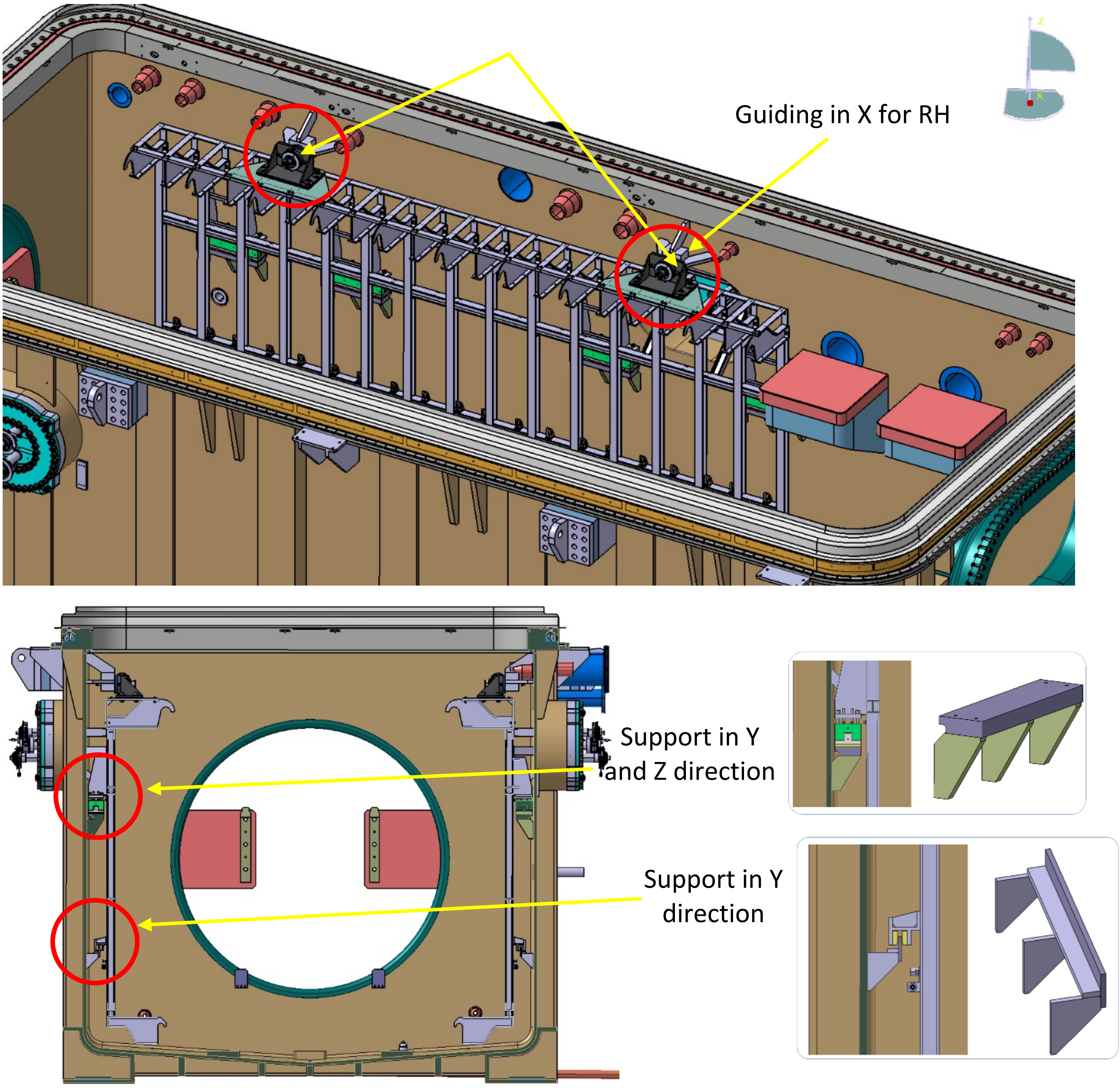


Figure 21 – DNB cryopumps supports and functions

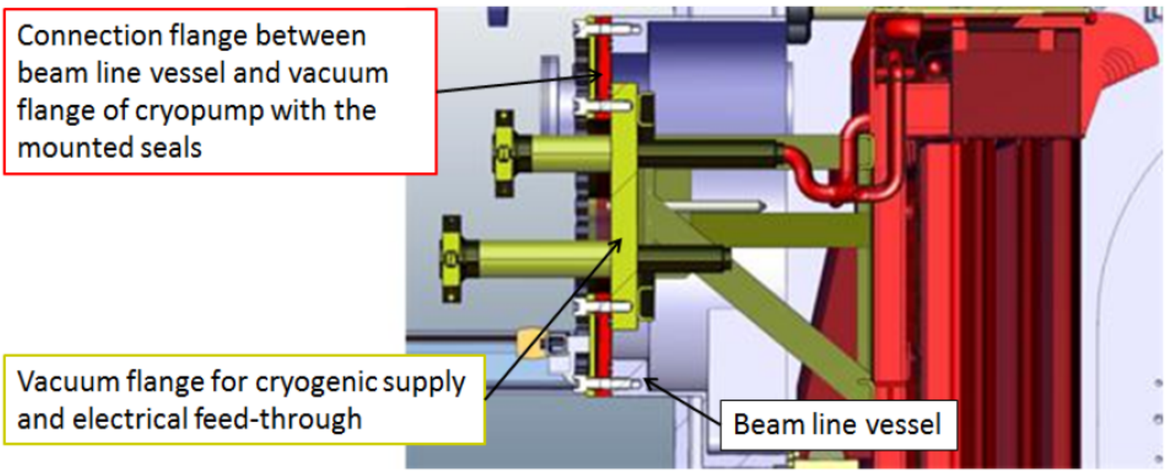


Figure 22 – Detailed view of the cryopump flange interface

2.8.4.4.2 Load on the top row support

The details of the analysis performed on the cryopumps can be found in [33].

The interface load on the top row is composed of:

- Cryopump weight:

  The interface load can be calculated from the cryopump mass (4020kg). In case of water leak inside the vessel, water will be frozen on the cryopump. It was calculated that in worst conditions, 700kg of ice could be attached to each pump [34]. To limit the number of load combinations, the mass of the cryopump is set to 4720kg for all combinations[9].

- Friction on supports:

  During the thermal expansion of the pump, friction will occur on the supports. We assume than adequate materials will be selected to limit it. As no data is available at the moment the value of 0.5 is selected as a maximum and target value to be respected for the design of the pump. This generates a force of 29.5kN in + or – X.

The torque coming from the distance top of the bracket to the cylindrical contact is 55mm and considered too small to generate any relevant torques.

2.8.4.4.3 Load on the bottom row support

- Cryopump mass:

  The bottom row support doesn't have a supporting function in normal operation but during accidental seismic event forces can be generated at this interface. (see values in 2.8.4.4.7).

- Friction on supports:

  Similarly as on the top row (using the same coefficient), the friction forces create a force of ±1.3kN along X axis.

2.8.4.4.4 Load on flange

The interface load on the flange is composed of:

- Pressure difference on the flange surface. This is to be calculated, depending on the scenario calculated, using the values from Chapter 2.2
- Mass of the flange: 220kg
- Mass of the cryogenic lines: definition on-going
- Thermal expansion of the pump between the top row supports and the flange. The pump structure is considered flexible enough to absorb the expansion without generating significant loads on the vessel flange.
- Bolting: 90 × M24 bolts [35]

2.8.4.4.5 Load on the dowel slot

With the present concept of RH tool for the RH pump (see Figure 22) this slot drives the X position of the tool. It means that while the tool moves the flange along Y, the dowel engages the slot and drives the position.

The load on the dowel comes from the rolling resistance of the tool along X and the friction of the dowel. The resulting interface load is considered low enough to be negligible for the vessel slot.

---

[9] The mass centers coordinates are given in Appendix A.

The resistance forces of the 4 rollers of the RH tool (see Figure 22) along X axis is judged negligible for the slot on the vessel as the RH tool

2.8.4.4.6 Load on the top fixture points

In normal operation the support sees only the pretension of the bolts. During the accidental event (seismic events), the reaction forces are given in 2.8.4.4.7.

In addition to the weight the interface loads generated at the level of the cryopump flange are not defined. The main contributor will be the 4 cryo-lines connected to the flange which are heavy and stiff. The cryo-lines will be supported externally and will not give a significant additional load to the flange.

The interface load in case of seismic event is given for the interface points in [33].

2.8.4.4.7 Reaction forces in operation and accidental cases

The table 14 in [33] gives the maximum reaction forces at each interface with the HNB vessel for the worst case scenario. These values have to be considered for the design of the DNB vessel.

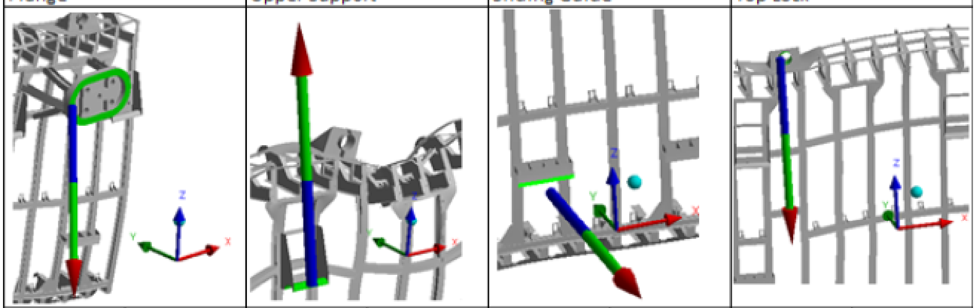
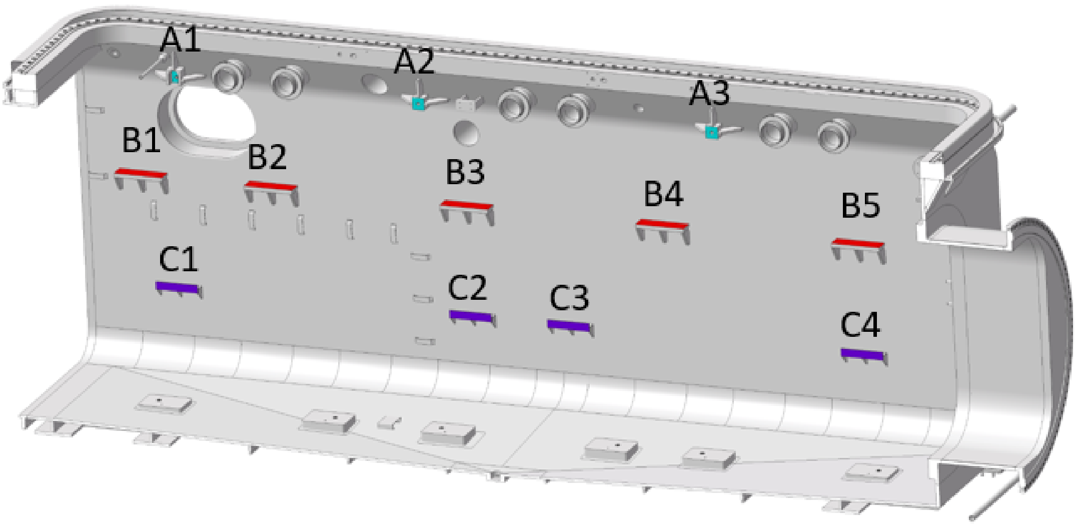
	Flange		Upper Support		Sliding Guide		Top Lock	
								
	Max Value	LC	Max Value	LC	Max Value	LC	Max Value	LC
Fx (N)	-7788	NO SL-2↑	0	Upper Holder 3 NO SL-2↓	0	Sliding Guide 2 NO SL-2↑	0	
Fy (N)	-10223		11503		-4744		-19009	Top Lock 1 NO SL-2↓
Fz (N)	-15644		53862		0		-69668	Top Lock 1 NO SL-2↑
Ftot (N)	20246		55077		4744		72215	
Mfx ($N.m^{-1}$)	-3264	NO SL-2↑	0	Upper Holder 1 NO SL-2↓	0		-448	Top Lock 1 NO SL-2↓
Mfy ($N.m^{-1}$)	-1476		-2551		0		0	
Mfz ($N.m^{-1}$)	5553		1331		0		1275	
Mtot ($N.m^{-1}$)	6608		2877		0		1351	

Figure 23 – Reaction forces of the HNB cryopumps

The boundary conditions to be applied at the interfaces are described in Figure 24



Interface	T_x	T_y	T_z	R_x	R_y	R_z
A1, A2, A3	Blocked	Blocked	Free	Blocked	Blocked	Blocked
B1, B2, B3, B4, B5	Free	Blocked	Blocked	Blocked	Blocked	Blocked
C1, C2, C3	Free	Blocked	Free	Blocked	Free	Blocked

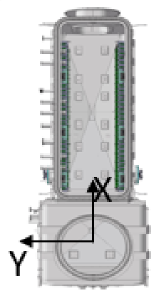


Figure 24 – HNB Boundary conditions at the interfaces of the CP with the vessel

2.8.4.5 Load drop

2.8.4.5.1 Drop of a BLC

This load describes the drop of a BLC on its adjustable bed (itself fixed to the vessel floor). This is an accidental case which could occur when a BLC is held by the RH crane. The RH crane is designed to withstand the BLC payload during the seismic events (SL-1 and SL-2). However, as a defence-in-depth approach, the consequence of the drop of the BLC on the adjustable bed from its maximum lifted height needs to be assessed in safety and investment protection point of view. It cannot be guaranteed that the component will remain parallel to the adjustable bed when dropping. Therefore the impact must be considered on one pad. The component cannot be dropped at another location on the vessel (than on the bed) because before moving the crane, the component will be lifted more than 180mm above the vessel.

2.8.4.5.2 Drop of the top lid

The drop of the top lid is not considered in the vessel load specification. However, its safety consequence needs to be assessed. Specific systems will be designed to avoid any contact between the vessel and the top lid during SL-2.

2.8.4.6 NBI PHTS (load n°73)

This interface load describes the reaction forces transmitted to the vessel due to the NBI PHTS pipes. The vessel is used as a fixed point and will see forces coming from the thermal expansions of the pipes.

These loads are not defined for normal operation at the moment. A first calculation was carried for an SL-2 event; the results are listed in [21].

2.8.5 Interface load to PMS

2.8.5.1 Vessel fixation (load n°80)

The vessel is linked to the bottom PMS plates. The current concept is to lock the rear part of the DNB vessel near the DNB BS and let the other free to slide to allow thermal expansion of the vessels.

The bolting system is designed to avoid any movement of the vessel during seismic events.

This interface load reacts all the other loads applied to the vessel (fixed point). These loads are[10]:

- Vertically (Z) a force composed of:
  - The dead weights of the vessel, BLCs, cryopumps, ES, feedthrough box.
  - The HVB weight
- Horizontally (X) a force composed of:
  - The front component interface load
  - The pressure load associated to the front opening to FEC.

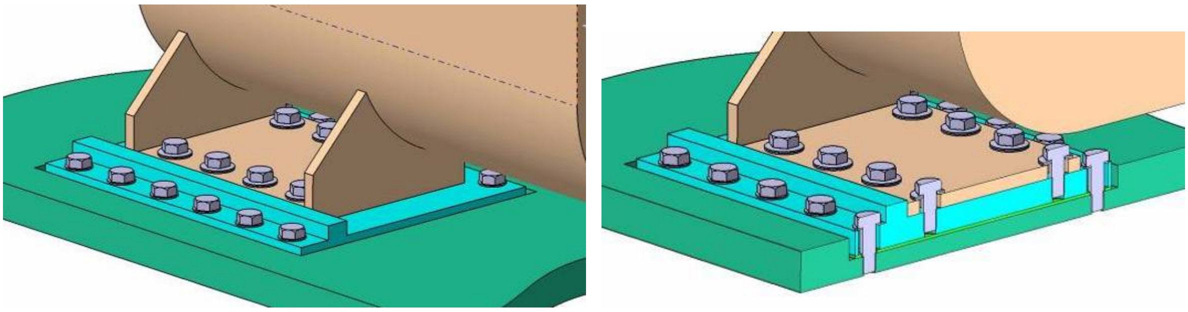


Figure 25 – Thermal expansion management system for the vessel (normal and section view)

The bolting system is designed to avoid any movement of the vessel during seismic events. For information it was assessed to require eight M30 bolts per foot, tightened at 629 N.m (~140kN of pretension).

Another load transmitted to the PMS is related to ICE events. As mentioned in chapter 2.6, ICE events generate a thermal load which will heat up the vessel. For these cases, the fixation of the vessel must comply with the expansion. It is assume that the force coming from the expansion will be larger than the one from seismic events. The bolt holes in the feet will be designed large enough to let the vessel slide. The reaction forces during the events are then linked to the pretension of the bolts and the friction coefficient, both outputs of the design.

2.8.5.2 Feedthroughs box support (load n°81)

The feedthrough box is supported by the PMS. The interface load comes from:

- Its own weight (box + flanges) will be below 1ton according to the first estimation.
- Thermal expansion of the duct connecting the box.

These loads are fully defined today. The loads coming from the RH maintenance of the feedthrough are considered as negligible.

[10] Values given for information, official data to be extracted from the dedicated chapters of the document

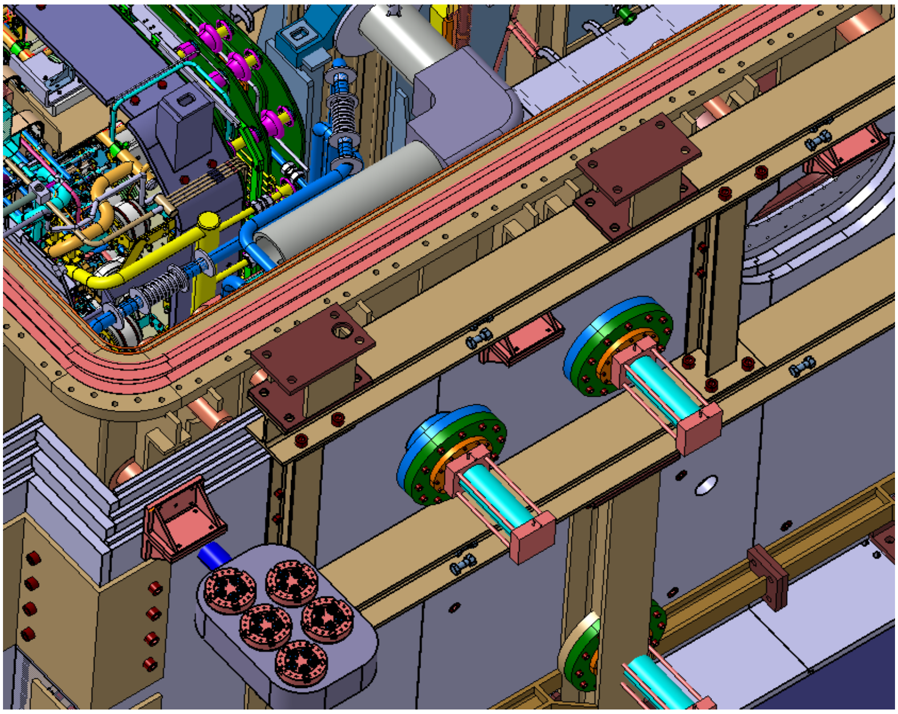


Figure 26 – Feedthrough box supported by the PMS

2.8.6 Interface with annex systems (load n°82)

The vessel is connected to other systems which generate interface loads. The following loads can be simplified by constant loads which are applied to all load combinations. They are grouped under load n°82.

2.8.6.1 Vacuum pipes

Two pipes, one for the venting one for the fore vacuum, are connected to the side of the DNB vessel. Detailed analyses of these pipes are available in documents [36] and [37]. Analyses carried out for these pipes generated many reaction forces values due to the different loads combinations considered. Considering all these values would generate too much analyses case for the vessel. Therefore, it is preferable to use most stringent values only. This is a conservative approach and minimize number of load combinations for the vessel.

For the fore vacuum pumping pipe all reaction forces values can be found in Annex A. Only values highlighted in red shall be considered.

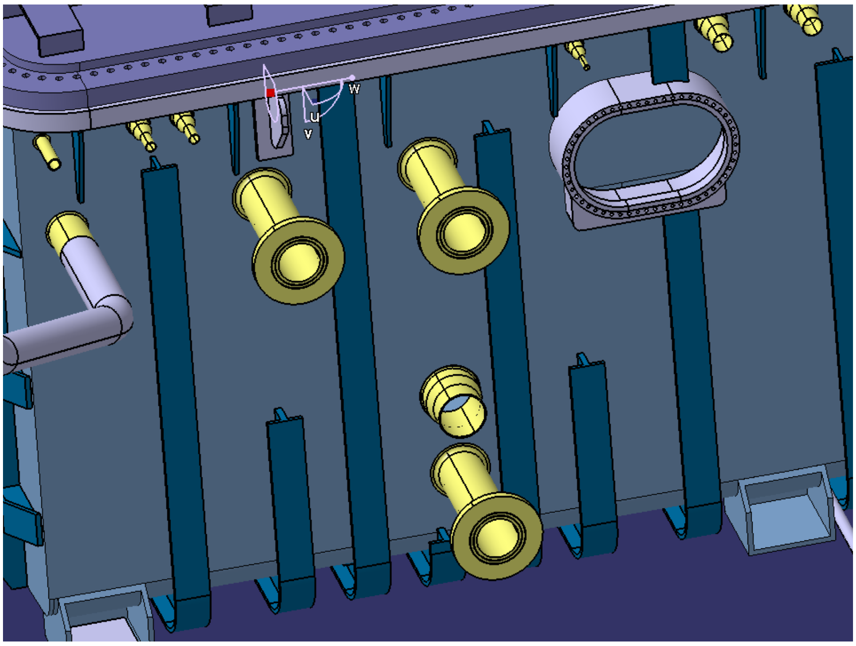


Figure 27 – Connection to fore vacuum pumping

For the vent lines, all reaction forces values can be found in Annex B. To have conservative values for these pipes it is necessary to consider maximal loads on each axis from all reaction forces.

2.8.6.2 Draining

The DNB vessel has a dedicated pipe in order to drain it in case of leaks of components. The PBS 23 will be in charge of opening the flange and insert a pumping system in the large pipe in order to pump out the water. This interface requires only a local check for the dimensioning of the piping and its supports.

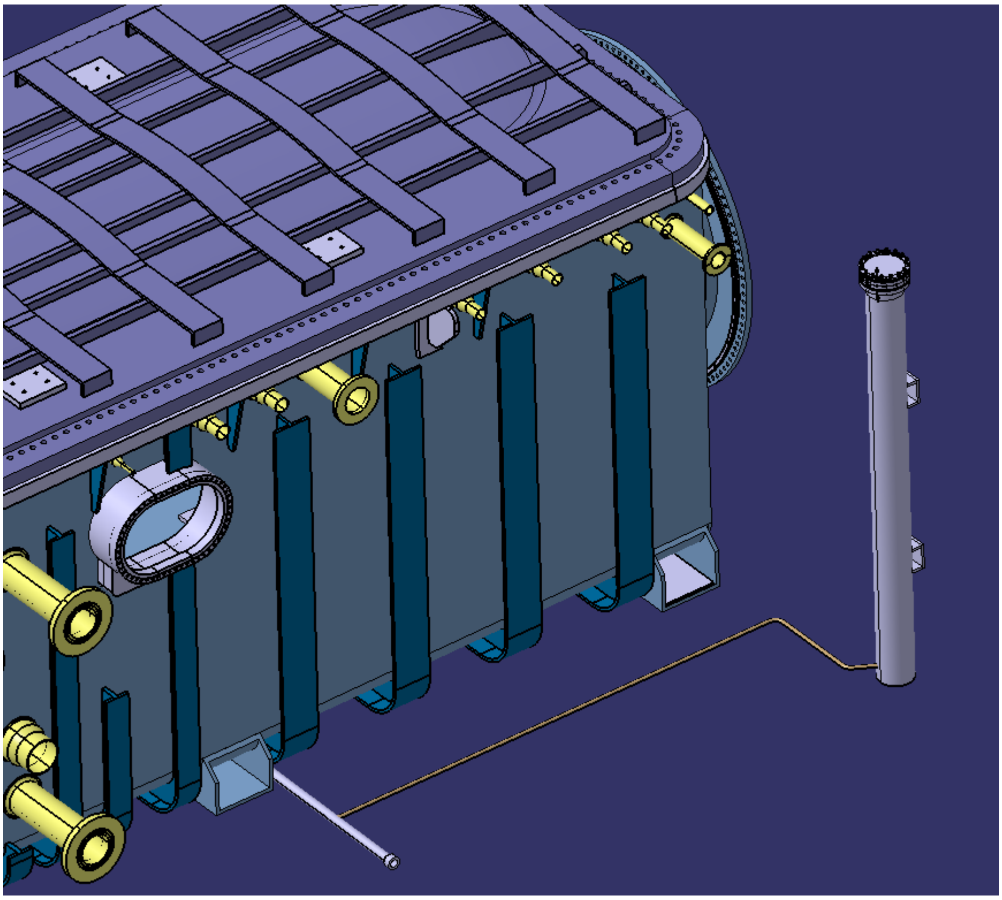


Figure 28 – Vessel draining pipe

2.8.6.3 Vacuum measurement boxes (VMB)

The vessel is equipped with four boxes containing the vacuum instrumentation. They are located at the four corners of the DNB vessel. The front right box piping includes a connection to the venting line.

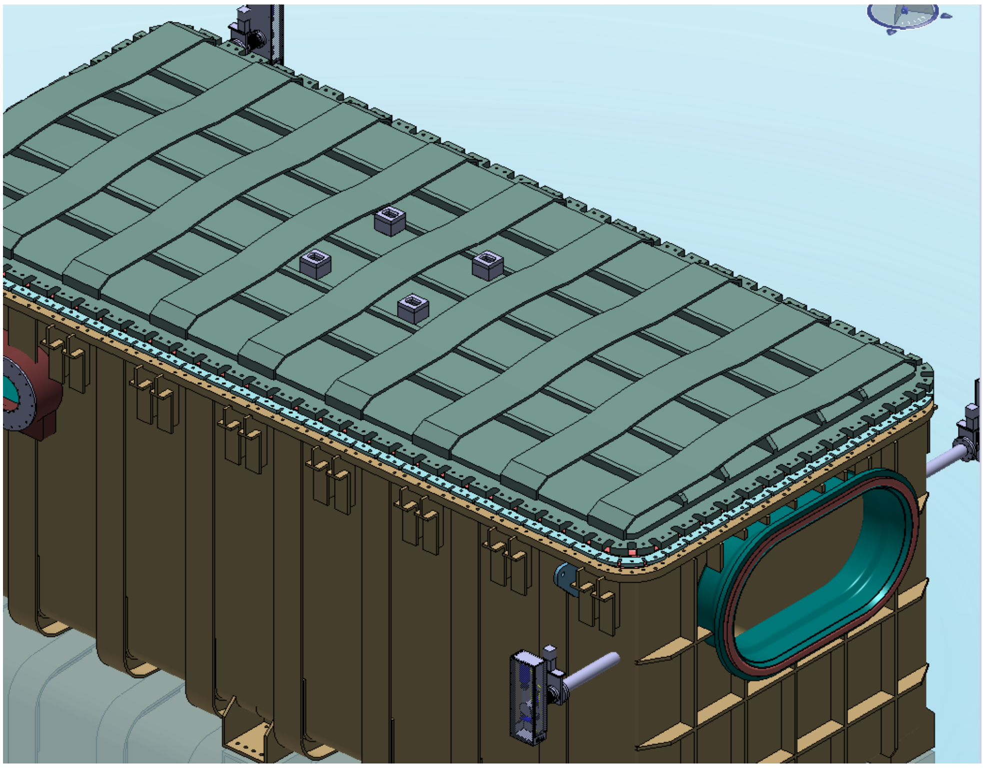


Figure 29 – Vacuum measurement boxes

The VMB will be supported by the PMS as well as their shielding (new concept not shown in the illustrations). The equipment cantilevered on the vessel will be the valve (25kg) and an elbow. The VMB will be mechanically decoupled from the vessel by a bellow.

Waiting for the supporting design, it is assumed that a mass of 30kg is cantilevered 100mm away (on its axis) from the end of the DN65 pipe.

2.8.6.4 Instrumentation cables

All BLCs instrumentation cables are fixed to the vessel wall from the connecting flange on vessel left side to the feedthrough box. Dedicated interfaces will be designed to support them. The weight (to be defined) of these cables is judged negligible for the vessel structure.

The 126 pins RH connectors fixed to the DNB vessel are supported by the DNB vessel. A local calculation must be done to check the supports. Each support shall withstand around 20kg mass (including the 2 RH socks + 2 RH BLCs plugs).

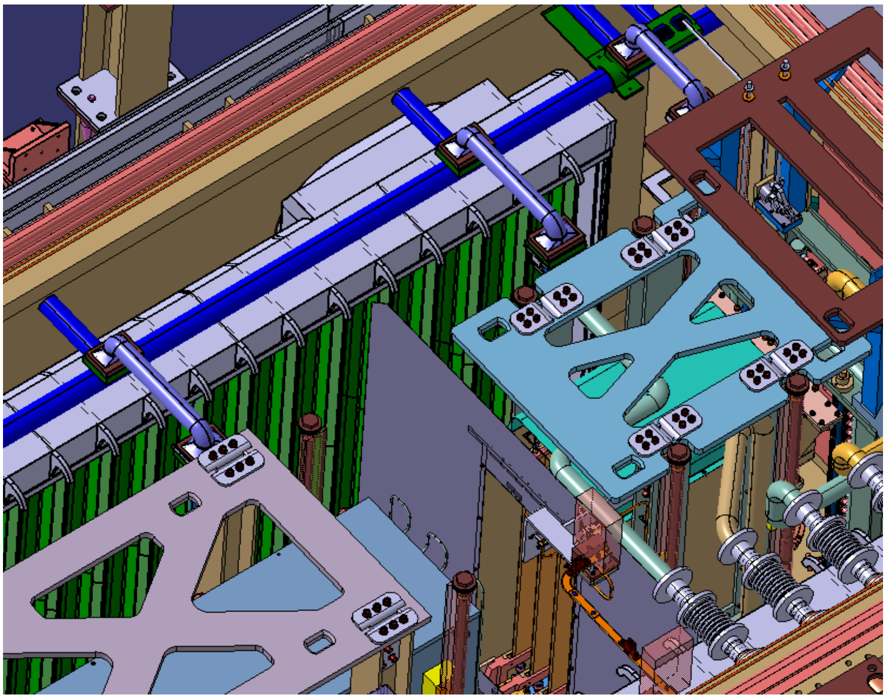


Figure 30 – Instrumentation cables routing

2.8.6.5 Feedthrough flanges

The feedthrough box (part of the DNB vessel) receives flanges which hold the instrumentation feedthroughs. The interface is a flange. The interface load is the weight of the flanges and the pretension of the bolts (to be defined), as well as the difference of pressure. The worst case is applied in all combinations.

The RH operation performed on these flanges are involving only negligible loads for the box.

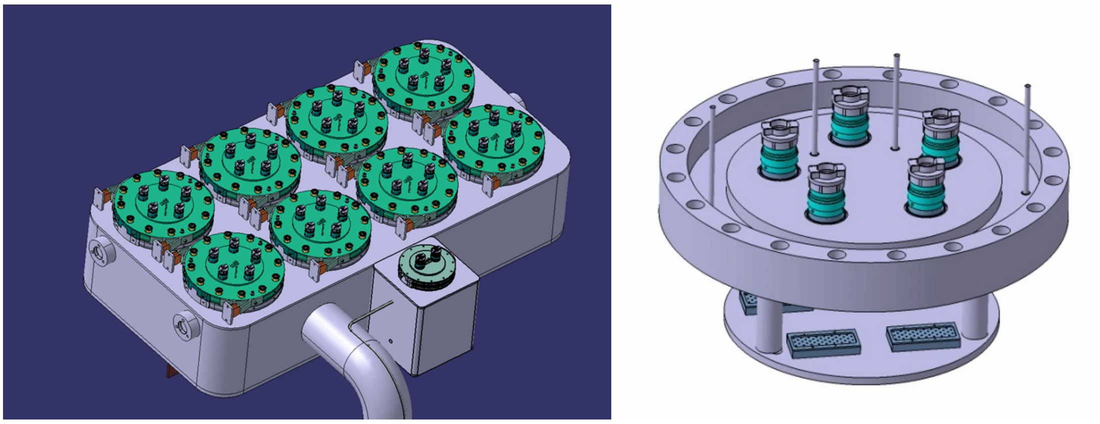


Figure 31 – Feedthrough box and the flange holding the feedthroughs

2.8.6.6 RID HV Feedthrough

The RID HV feedthrough is mounted on a dedicated flange on the DNB vessel side. Its weight is around 40kg (estimation based on available design). The corresponding flange is under the pretension of the bolts. This load is judged negligible for the vessel.

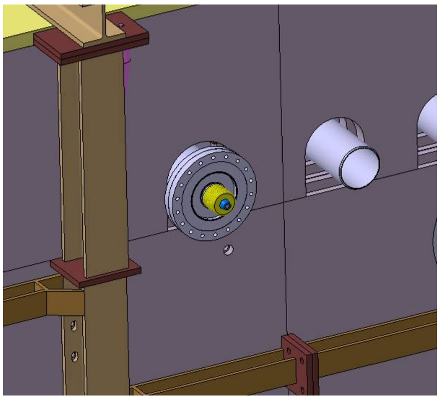


Figure 32 – Feedthrough box and the flange holding the feedthroughs

2.8.7 Interface with Remote Handling

A part of DNB maintenance is remote handled. Remote handling tools are used for the following maintenance (involving vessel):

- Opening of the top lid
- PMS assembly/disassembly
- BLCs assembly/disassembly
- Feedthroughs assembly/disassembly
- BS assembly/disassembly
- Fast Shutter assembly/disassembly
- HV Bushing assembly/disassembly

During these operations no significant load is generated on the vessel.

2.8.7.1 Interface load on the top lid by the RHE during opening the top lid (load n°90)

In order to open the top lid, a lifting adaptor, generic lifting adaptor, and crane lifting frame will sit on top of the top lid. The top lid and the vessel should withstand the load from these RHE. Refer IP3.2 of [38].

- Mass of the Top Lid lifting adaptor: 5tons (assumption)
- Mass of the Generic Lifting Adaptor: 2.3tons
- Mass of the Crane Lifting Frame: 5tons
- Total load on the top lid= 12.3tons

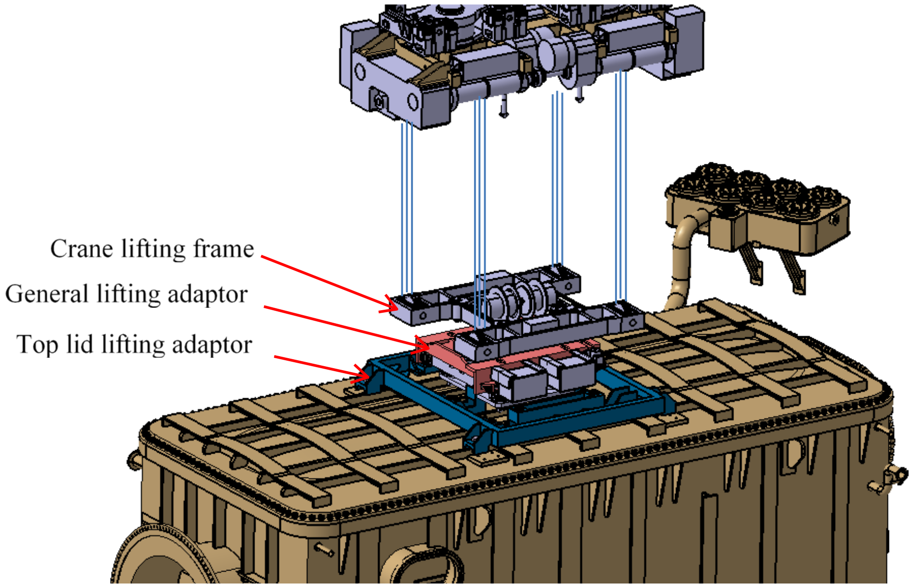


Figure 33 – Lifting RH tools sit on the top lid.

2.8.7.2 Interface load on the DNB vessel top lid during lifting by the crane (load n°91)

During lifting and transportation by the crane, the top lid is hanged under the crane rope together with the crane lifting frame, general lifting adaptor, and the top lid lifting adaptor. During the seismic event the top lid could be up, down, and swing which could result in a shock load on the lifting lugs. The top lid and its lifting lugs should withstand 6.75 times of its own mass until breaking. Refer IP3.2 of [38].

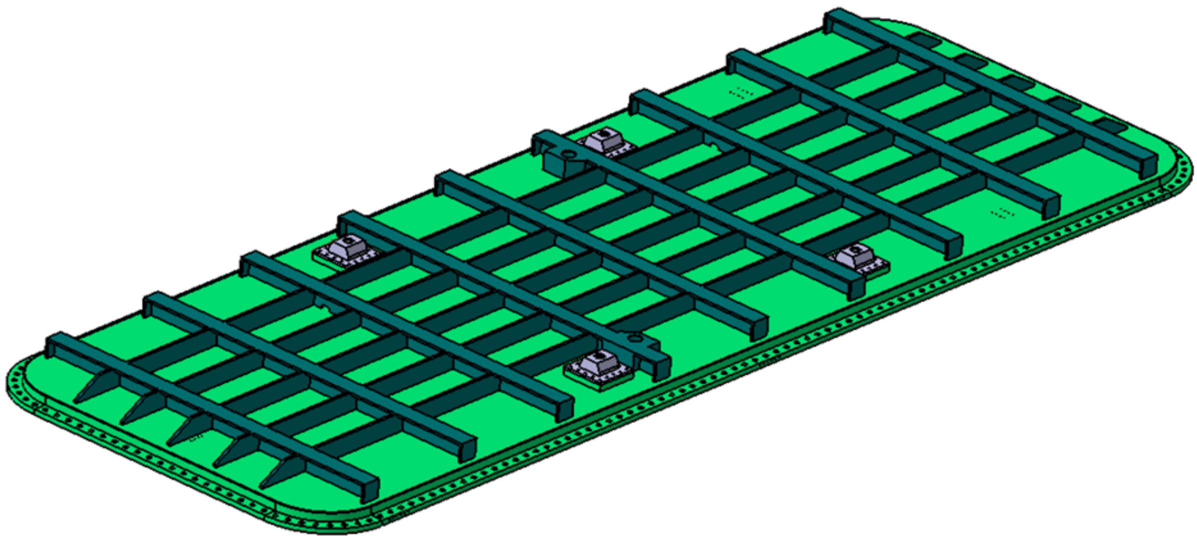


Figure 34 – Lifting and transportation operation on the top lid (HNB vessel as an example in the picture).

2.8.7.3 Interface load on the DNB vessel jacking pads during opening the top lid (load n°92)

During opening the top lid, six RH jacking tools will be deployed on the jacking pads of around the DNB vessel as shown in Figure 35. The jacking tool will be engaged to the jacking lugs on the top lid, and lift it by 100mm. The jacking pads on the DNB vessel should withstand the lifted configuration during all design basis events such as the seismic events. Refer IP2.2 of [38].

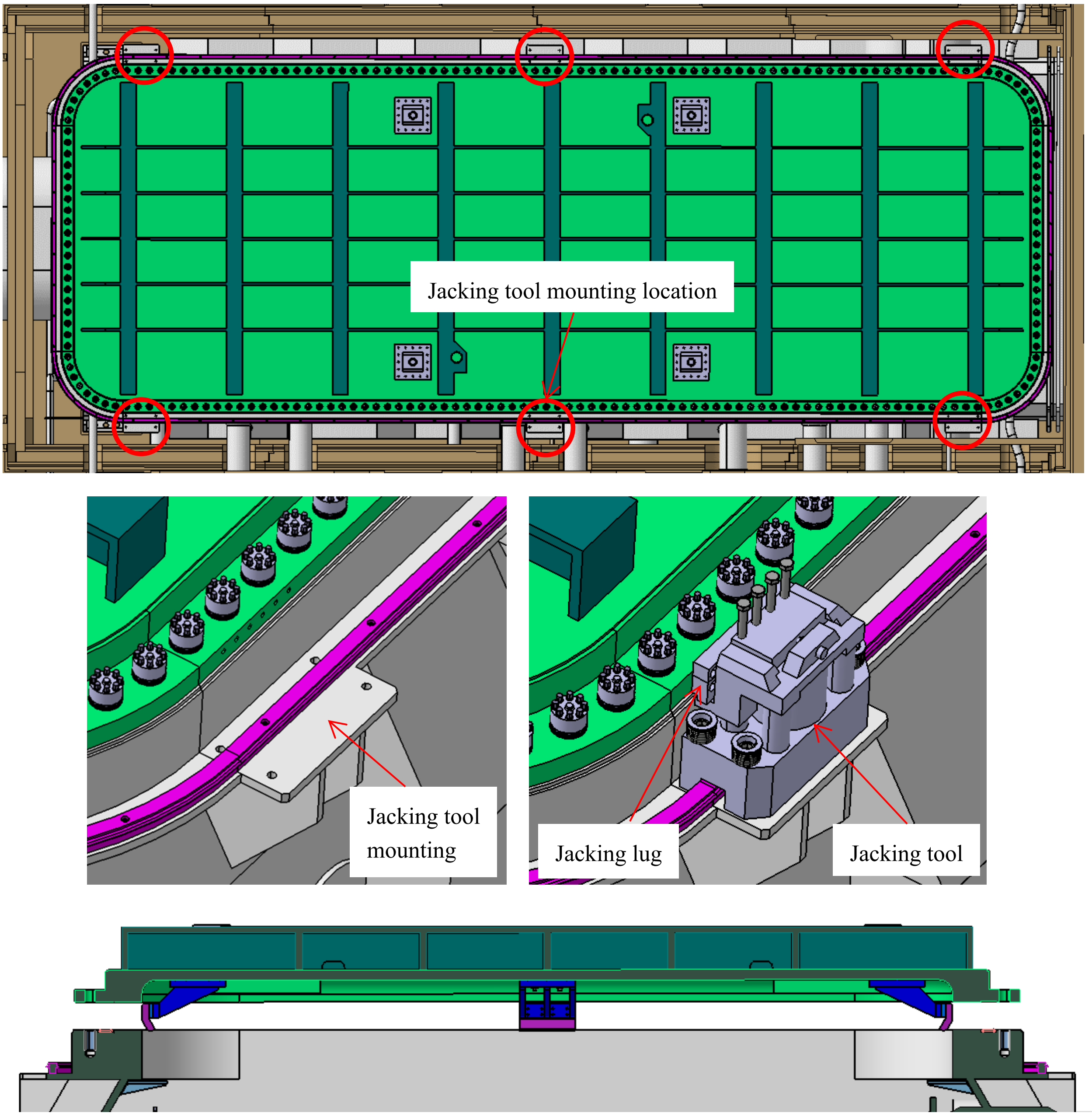


Figure 35 – Jacking operation to lift the top lid (HNB vessel as an example in the picture).

2.8.7.4 Cryopumps assembly/maintenance (load n°93)

During the assembly or the maintenance of the cryopumps, a specific tool will be used to remove and to put in place the pump on its support. This tool is supported by four supports welded on the vessel.

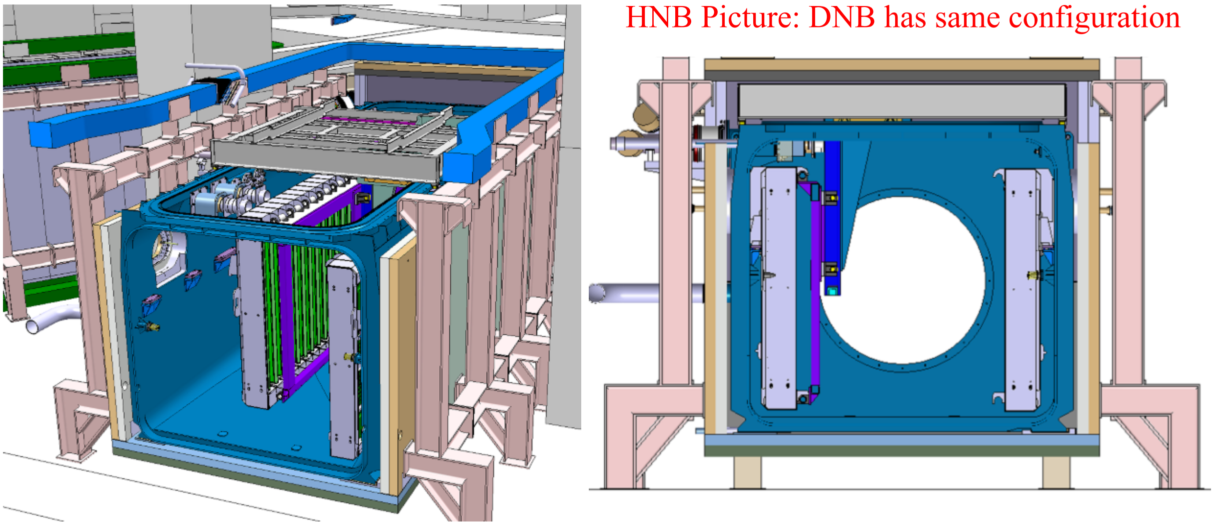


Figure 36 – Cryopumps maintenance (pump in middle and final position)

The tool used to hold and move the cryopumps lies near the vessel flange on four points.

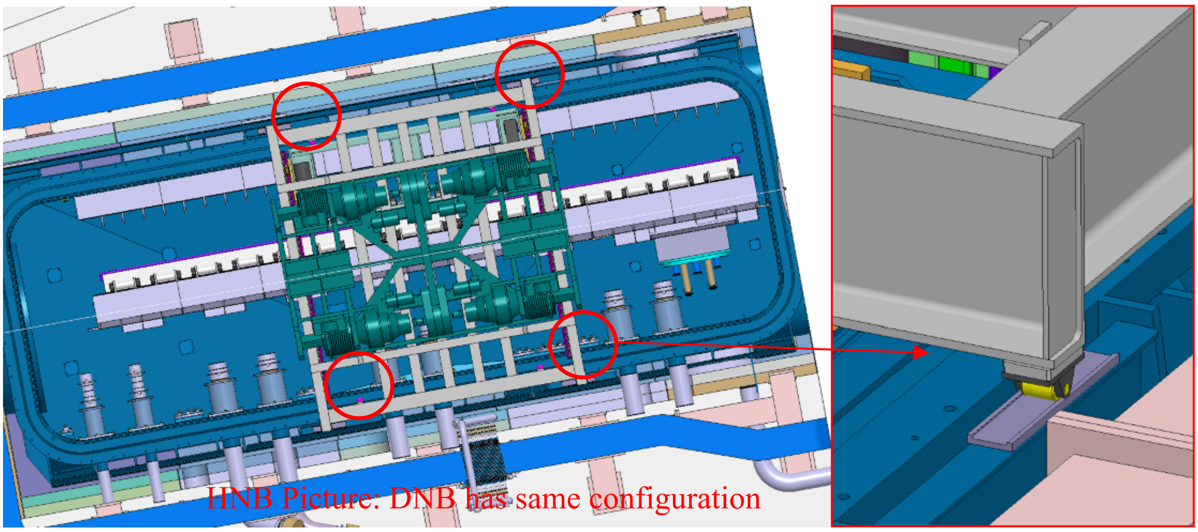


Figure 37 – Contact point of cryopump RH tool

When the pump is in middle position the weight of the pump (see 2.8.4.4), the weight of the tool (5890 Kg) and the mass of the crane lifting frame (5000 kg) are equally distributed on the four points.

The worst case, when the cryopump is about to touch is support, gives the following load distribution:

- On the side of the cryopump the load is 41,8 kN per support.
- On the other side the load is 12,6 kN per support.

Only the dissymmetric distribution is considered as it is the most critical for the vessel.

2.8.7.5 Other RH tools (load n°94)

2.8.7.5.1 Bolting and unbolting RH tool

- for the FS and HVB

The tool mass is supported by the RH rail and distributed among the wheels. A local check is needed to size the rail fixture. The torque is reacted by “torque reaction features” (holes on both sides of the bolt). The maximum torque applied is 662N.m (M20 bolt) generating a force on each reaction feature of 6.5kN. This interface load is considered negligible but local check shall be done.

This is to be considered only for the HVB. On the FS flange, the rail and the tool will be on the FS side (not DNB vessel).

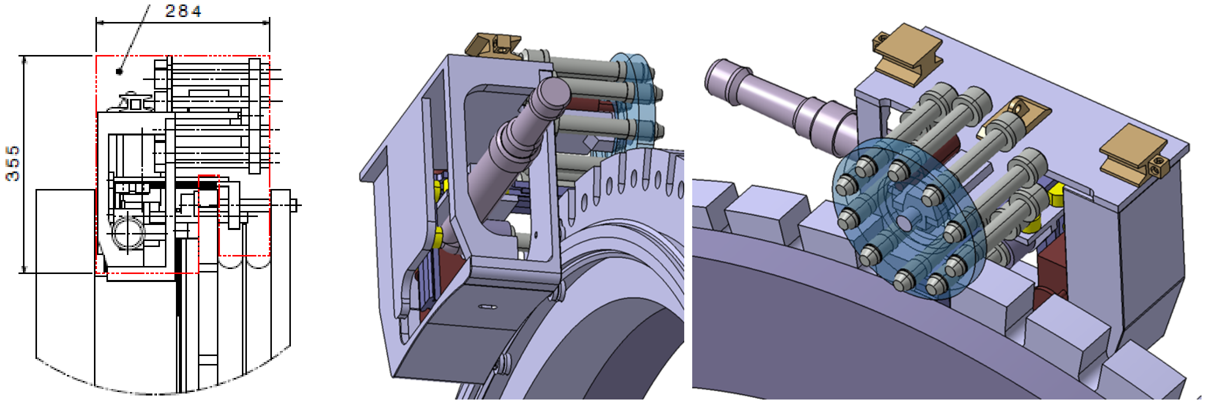
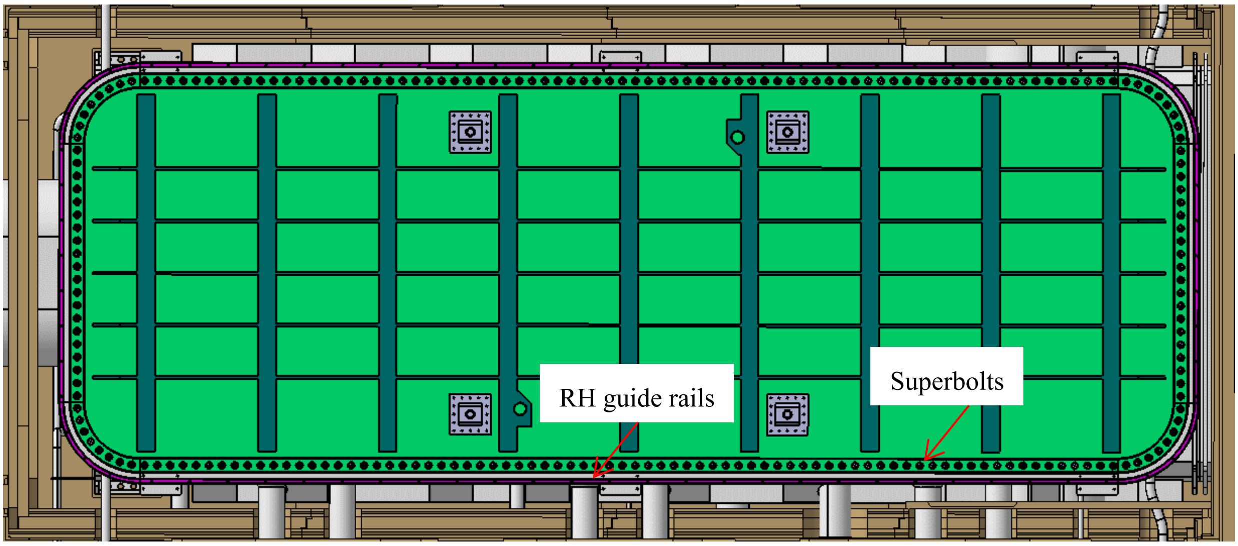


Figure 38 – Bolting tool for flange B

- for the top lid
  The RH bolting tool will move on the RH guide rails around the DNB vessel flange. THE Superbolts fixing the top lid to the DNB vessel will be tightened and untightened by using a kind of mobile flange bolting tool as shown in Figure 39. The reaction torque would be reacted on the flange. The interface loads to be defined.



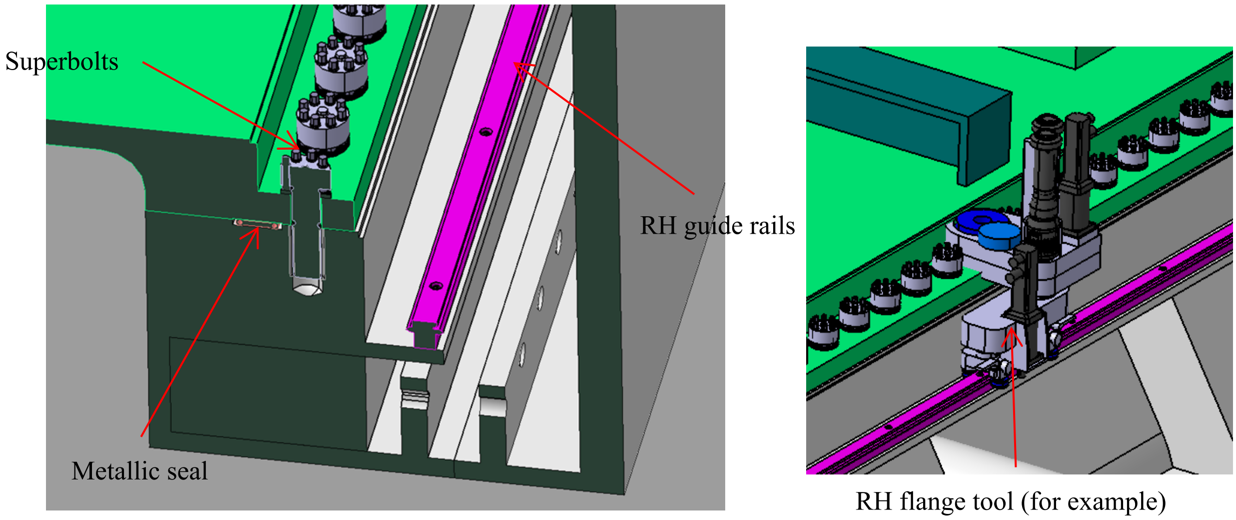


Figure 39 – RH bolting tools for the top lid.

2.8.7.5.2 Cooling pipes cutting and welding tool

The cooling pipes of the NED, RID and Calorimeter are cut and re-welded using specific RH tools. The mass of the tools and the bellow is less than 300kg to be shared between the vessel and the BLC. The interface load is considered negligible for the vessel.

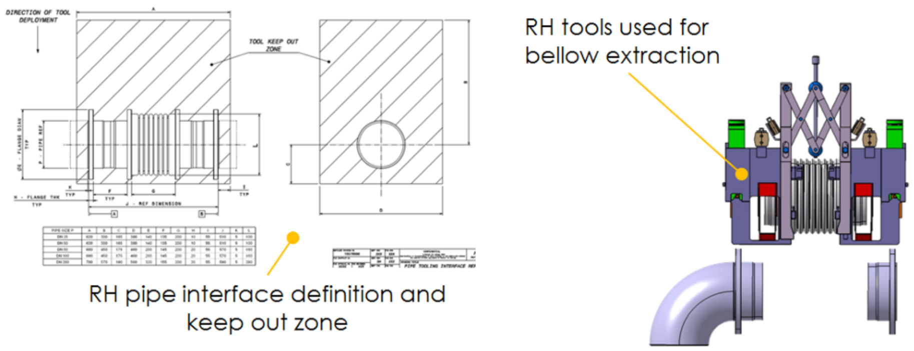


Figure 40 – Pipe cut and weld interface and tools for BLCs

2.8.7.5.3 Cryopumps flange RH

To remove or put in place the cryopumps flange, rails are needed to support the weight of the flange. To limit the mass hold by the manipulator (limited 100kg for the hoist), the flange is split in two parts: one holding the bolts and one holding the seals.

The two parts of the flange slide on the dedicated rails. These rails are bolted to the DNB vessel using the RH manipulator.

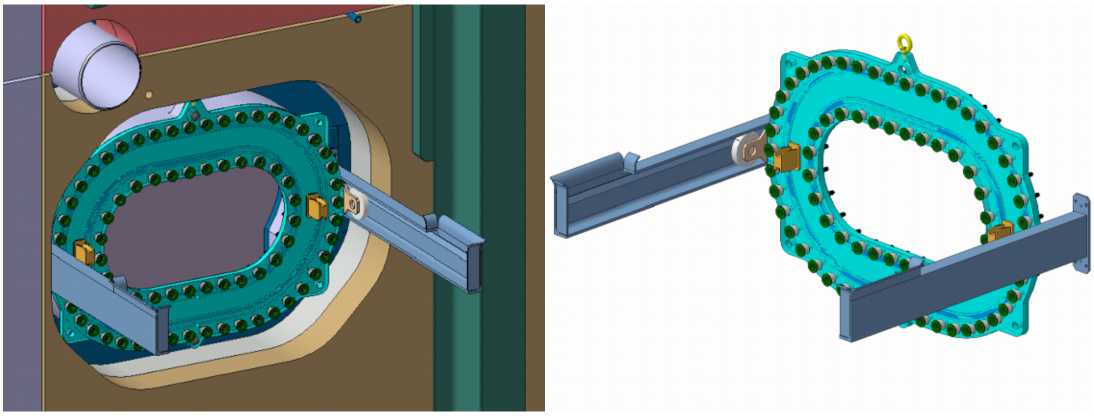


Figure 41 – RH system for cryopump flange extraction

The total mass of the flange is less than 180kg. The maximum load seen by the RH rails is when the flange holding the seal slides at the end of the rails. Its mass is 100kg with the mass centre located 950mm away from the rail interfaces on the vessel.

A local analysis for the rails and their fixation should be done considering SL-2 load.

2.8.7.5.4 RID HV feedthrough RH

The same concept of trolley than for the cryopump is used for the HV feedthrough.

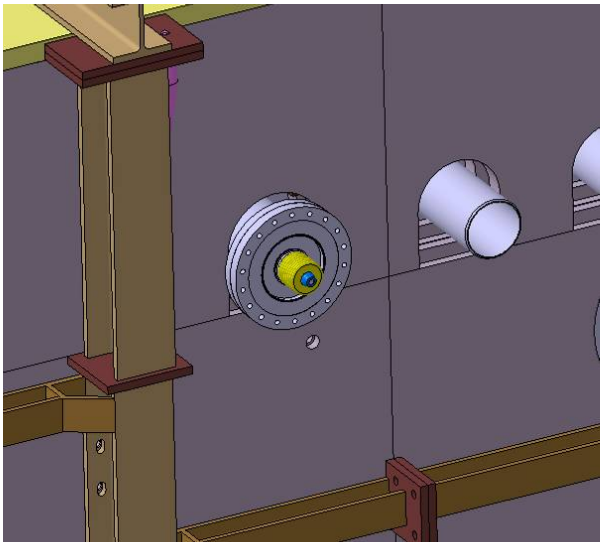


Figure 42 – RID HV feedthrough

The HV feedthrough weight is considered to be quite low (see 2.8.6.6). It has to be slided 1100 mm away from the PMS surface to be reachable by the manipulator hoist. When fully extracted, the gravity centre of the feedthrough is at 1000mm from the fixation point of the rail. This load is considered negligible for the vessel.

2.8.7.5.5 Calorimeter bellow RH

The calorimeter bellow weight will be less than 100kg. Rails will also be needed to guide its extraction (same strategy as above). When the bellows is fully extracted, its mass (less than 60kg) will be applied at the end of the rail (less than 600mm).

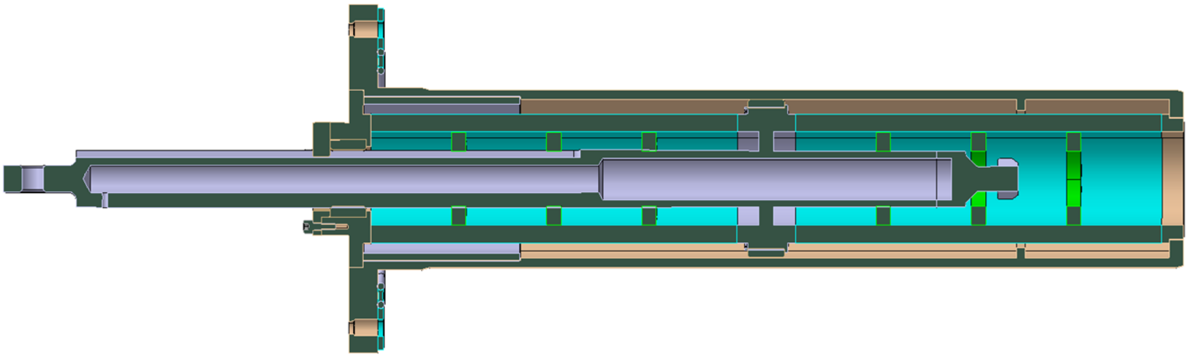


Figure 43 – Calorimeter actuator

2.8.7.5.6 Beam Source bellow RH

The same strategy is foreseen for the BS bellows maintenance. Their weight will be less than 100kg. The distance between the bellow gravity centre and the fixation of the rail will be less than 1000mm. Waiting for more precise value, the worst case must be considered.

This load is considered negligible compared to force needed to tilt the BS as described in paragraph 2.8.4.1.

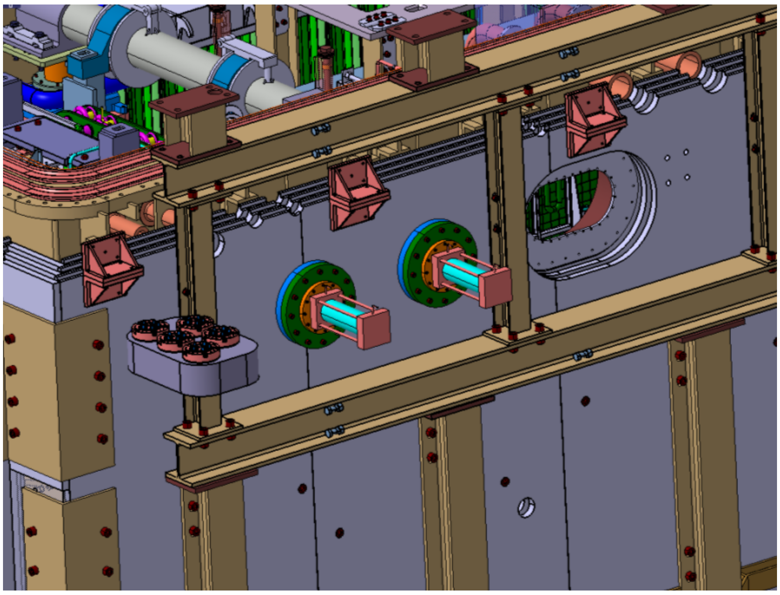


Figure 44 – BS actuator

2.8.7.5.7 Instrumentation feedthrough RH

Instrumentation feedthroughs are lifted vertically. During RH operation they will interface guiding dowels which are fixed to the box. The load generated on these dowels is considered as negligible for the box.

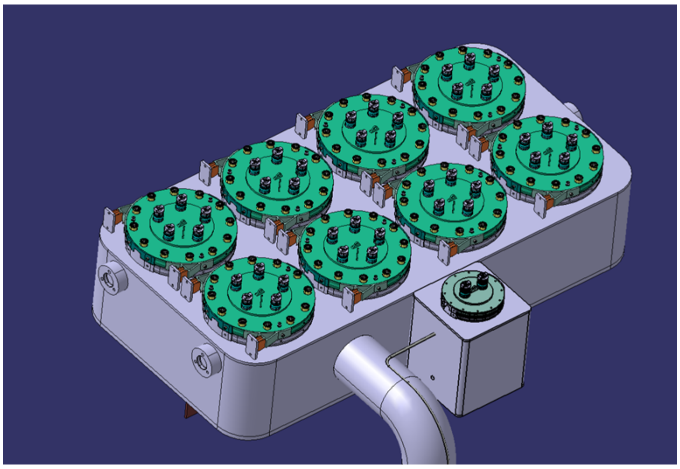


Figure 45 – Instrumentation feedthroughs mounted on the feedthrough box

2.8.8 Interface load with assembly tools

2.8.8.1 Assembly of the vessel (load n°100)

During assembly the DNB vessel is handled with two cranes or with a trolley. They generate loads on the vessel. When the DNB vessel is moved with the trolley, the load is similar to load n°3 (own weight applied on its stands). Therefore no specific single load was created.

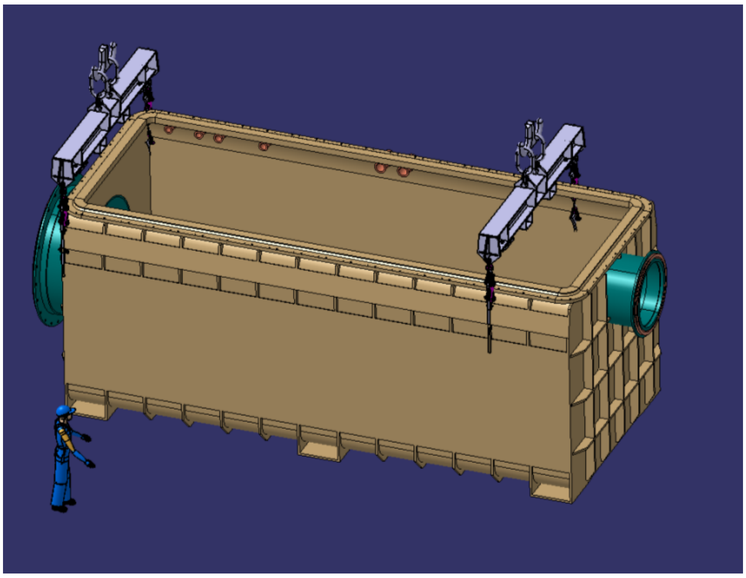


Figure 46 – DNB vessel during lifting

2.8.8.2 Assembly of the top lid (load n°101)

This chapter describes the loads which are applied only to the top lid. They need to be considered to check the mechanical behaviour of the lid alone.

- **Top lid lifted horizontally** refers to the following configuration:

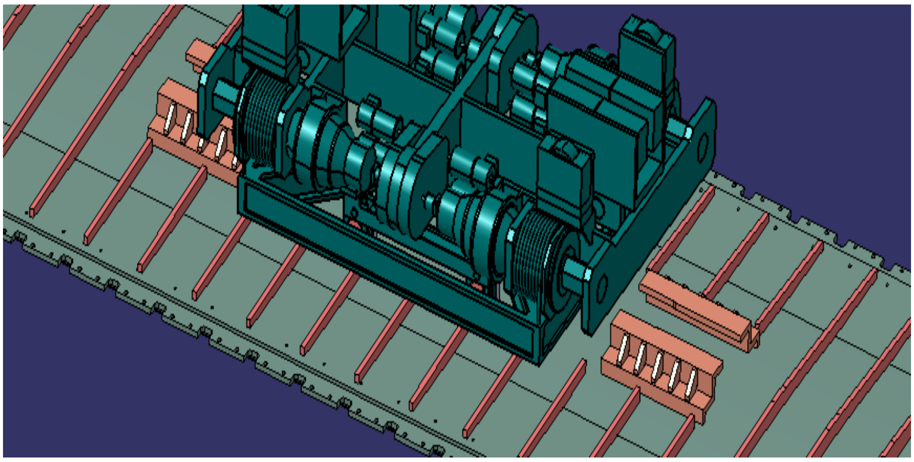


Figure 47 - Top lid lifted

- **Top lid on trolley** refers to the following configuration:

During assembly phase, the top lid will be fixed to this trolley to enter NB cell. There it can be reached by the RH crane.In addition during RH of BLCs the trolley is stored on the floor of the NB cell.

The weight of the lid is transferred to the rotating frame through four threaded pads located on the internal face of the lid. This interface is complemented by four guiding dowels.

2.8.9 List of interface loads

The following table sum up all the interface loads from the interfaces. If the value of the interface load change in function of parameter like temperature or pressure, different single load will be created.

DNB Interface loads		N°	Single load name	Cat.	Value (kg if not mentionned)	Application points	Comment
Metallic Seal		60	Metallic Seal interface load	I	See 2.8.1	Flanges of the vessel	
Front components		61	Fast Shutter Interface Load	I to IV	See chapter 2.8.2	Flange of the vessel	
Bushing and HV line		62	Normal operation	I	0.07 Mpa	Flange of Bushing	
BLCs	**Beam Source**	70	Beam Source	I	See chapter 2.8.4	5 differents points	
	NED	71	NED	I		Adjustable Bed	
	RID		RID	I			
	Calorimeter		Calorimeter	I			
	Exit Scraper		Exit Scraper	I		Brackets	
	Cryopumps	72	Cryopumps	I		Hook system on lateral walls	
NBI PHTS		73	NBI PHTS	I		Cooling lines feedthroughs	
PMS Load	**PMS**	80	PMS	I	See chapter 2.8.5	Vessel supports	
	Feedtrhough box	81	Feedthrough Box supports	I		Box supports points	
Annex Systems		82	Annex Systems	I	See chapter 2.8.6	Various	
RH Maintenance		90	Cryopumps RH	I	See chapter 2.8.7	Vessel flange	
		91	Others RH Tools	I		Various	
Assembly		100	Vessel Assembly	I	See chapter 2.8.8	Vessel lifting points	
		101	Top Lid Assembly	I		Lid lifting points	

Table 7 – Interface load table

2.9 Structural loads due to component operation

The DNB vessel is a passive component and does not create loads itself. It is only subjected to loads.

2.10 Loads in incident and accident events

Accident and incident events are pressure loads, described in chapter 2.2.3, seismic loads, described in chapter 2.4, and load drop described in chapter 2.8.4.5.1 and 2.8.4.5.2.

In addition thermal loads due to fire (assuming that insulation will limit the maximum temperature on vessel to 150°C) and LOCA NB III have to be considered (see chapter 2.6).

2.11 Negligible single loads

This chapter summarises the single loads that could be considered as negligible. The removal of these loads from the load specification is submitted to a justification to be provided and approved.

- Load 40: Inlet temperature
- Load 41: During pulse outlet temp.
- Load 42: Between pulse outlet temp.
- Load 44: HVB
- Load 45: PMS
- Load 46: Front component normal operation
- Load 47: Front component baking
- Load 48: BLCs
- Load 49:Exit Scraper
- Load 50: Nuclear heating
- Load 70: Beam Source
    - BS cooling (only)
- Load 82: Interface with annex systems
    - Fore vacuum pipe
    - Draining
    - Vacuum measurement boxes
    - Instrumentation cables
    - Feedthrough flange
- Load 91: Other RH tools (all of them)

Some of these loads affecting localized area of the vessel can be subjected to local calculation (like load 82 - instrumentation cable). Then, they will not be required for the combinations involving the whole vessel, simplifying calculations.

3 Load Combinations

3.1 Acceptable damage[11]

The Table 8 indicates the definition of different types of damage limits for components and plant depending on the load conditions.

Condition	Damage Limits to Component Level	Damage Limits in Plant Level and Recovery of the Plant (Plant Operational Condition)
Normal/ Design/ test	The component should maintain specified service function.	Within specified operational limit. No special inspection will be required other than routine maintenance and minor adjustment. For test condition inspections are required as specified in the selected C&S
Upset	The component must withstand these loadings without significant damage requiring special inspection or repair.	After minor adjustment, or replacement of the faulty component, the plant can be brought back to normal operation. No effect on other components that may call for special inspection or repair.
Emergency	Large deformations in areas of structural discontinuity, such as at nozzles, which may necessitate removal of the component from service for inspection or repair. Insignificant general permanent deformation that may affect safety function of the component concerned. General strains should be within elastic limits. Active components should be functional at least after transient.	The plant may require decontamination, major replacement of damaged component or major repair work. In addition to the damaged component, inspection may reveal localised large deformation in other components, which may call for the repair of the affected components. Nevertheless, the plant maintains the specified minimum safety function during and after the events.
Faulted	Gross general deformations with some consequent loss of dimensional stability and damage requiring repair, which may require removal of component from service. Nevertheless deformation should not lead to structural collapse which could damage other components. The fluid boundary is maintained but degraded; however the safety function is maintained. Active components may not be functional after transient.	Gross damage to the affected system or component. No loss of safety function which could lead to releases in excess of the guidelines established for Accidents. No design consideration will be given for recovery. The recovery of the plant may be judged from the severity of damage. This level of state is not expected to occur, but is postulated for safety assessment because its consequences would include the potential for the release of significant amounts of radioactive material.

Table 8 – Damage Limits in Plant and Component Level (from [12])

Table 9 indicates the relationship between load combination category (loads and likelihood categories) and acceptable damage limit as a function of the component safety class (SIC or non-SIC).

[11] From [5] Load Specification ITER_D_222QGL.

The selected C&S defines the service level or service criteria (allowable value) to satisfy the damage limits.

Loading Category		Category I: Operational/ Design Loading	Category II: Likely Loading	Category III: Unlikely Loading	Category IV: Extremely Unlikely Loading	Test Loading
Plant Level		Normal	Normal	Emergency	Faulted	Normal/test
Component	SIC-1	Normal	Normal (4)	Emergency (3)	Faulted (1), (3)	Normal/test
	SIC-2 (5)	Normal	Normal (4)	Emergency (3)	Faulted (3)	Normal/test
	Non-SIC	Normal	Upset (3)	Emergency (2), (3)	Faulted (2), (3)	Normal/test

Notes

(1) Faulted for passive components with no deformation limits. Emergency for active SIC-1 components and some passive components in which general deformations should be limited.

(2) Events need not to be considered from the safety point of view, but only for investment protection if required.

(3) Damage limits can be made more stringent either for investment protection reasons or to reduce delay/cost of post incident inspections, for components where the design is sufficiently robust. Normal for some SIC-1 active components and some passive ones which are required to function following Category III and IV accident (e.g. fire dampers and detritiation system)

(4) Normal damage limits are assumed to have a robust design for SIC components not only for category I event, but also for category II.

(5) Damage limits can be modified based on case by case considerations (systems classified as SIC-2 are not credited for bringing the plant into a safe status)

Table 9 – Damage Limits for Loading Condition Categories (from [12])

3.2 Combinations involving the vessel

The following combinations involve the DNB vessel (vessel and feedthrough box) and top lid for some combinations. See next chapter for combinations dedicated to top lid alone.

3.2.1 List of Combinations

This list of load combination describes all possible combination. The aim of these combinations is to test by calculation the design of the vessel.

- **A - Leak test**: this test is carried out just after manufacturing.
- **B - Handling phase 1 + SL-1**: the DNB vessel is on a trolley or lifted by its specific lifting tools (tool connected to crane). It is combined with a SL-1 event.
- **C - Spark Gap test**: the vessel is pressurized at atmospheric pressure. Internal components are not installed. Even if this combination is less severe than VV ICE III, it does not involve the same loads and the same damage limit.
- **D - Pulse**: this combination must be tested has it is cyclically applied 50 000 times (alternation with "between pulse" state).

- **E - Test of cooling circuit**: this combination can create a higher stress on cooling pipe feedthroughs. The water temperature is the same on inlets and outlets.
- **F - BLCs' draining**: this combination tests the pressure load during draining.
- **G - BLCs' drying**: this combination tests the pressure and thermal loads during drying.
- **H - VV ICE II + VDE II + Shutter closed**: this combination involves a rise of pressure in the VV. The injector is still under vacuum with the fast shutter closed. This case needs to be checked only because the interface load from the front component could be a design driving value for the front part of the vessel (highest load in cat I/II events). The combination involving an ICE II event has the highest value when a VDEII occur at the same time.
- **I - VV ICE III + Pulse**: this combination involves a rise of pressure in the vessel while the injector operates.
- **J - VV ICE III + VDE III + Shutter closed**: this combination involves a rise of pressure in the VV. The injector is still under vacuum with the fast shutter closed. This load has to be verified because of the high load at the front component interface. This load is highest when a VDE III happens at the same time.
- **K_a - LOCA NB II + Pulse**: this combination involves a rise of pressure and temperature in the NB Cell while the injector operates. This case represents the highest pressure difference seen by the vessel with stress criteria at level A.
- **K_b - LOCA NB III + Pulse**: this combination involves a rise of pressure and temperature in the NB Cell while the injector operates. This case represents the highest pressure difference seen by the vessel.
- **L - VV ICE IV +Pulse**: this combination is similar to combination P. Only the value of the pressure changes as well as the damage rate. Plastic deformation is tolerated as long as the vessel remains leakthight.
- **M - VV ICE IV + VDE III + Shutter closed**: this combination is similar to combination I. Only the value of the pressure changes as well as the damage rate. Plastic deformation is tolerated as long as the vessel remains leaktight.
- **N - VV ICE IV + VDE IV + Shutter closed**: this combination is similar to combination L. Only the value of the pressure changes.

The following combinations involve seismic events. Their aim is to make sure that the confinement boundary is never damage in all possible scenarios. As usual, the level of damage corresponds to the category of the combination. Even in worst cases, the confinement shall not be lost.

Without calculation, it is not possible to know which type of seismic event is design-driving for each combination, the three seismic events (SL-1, SMHV and SL-2) have been grouped under the name: SLs. The three seismic events have to be tested or compared. After justification, only the most severe one can be calculated.

- **O - SLs + Baking**: this combination involves a possible higher temperature of the vessel due to the baking of the front end components during a seismic event. This combination could be removed after justification.
- **P - SLs + Pulse:** this combination describes a seismic event during pulse.

- **Q - SLs + BLCs Maintenance**: The top lid is opened. The VV is under vacuum and the absolute valve is closed. The vessel is loaded with all internal components and a SLs seism is applied (SL-1, SMHV, and SL-2).
- **R - SLs + CP maintenance**: top lid and all components inside the DNB vessel are removed except one cryopump on one side. The other one on the cryopump is hanging on the RH tool. During this maintenance the VV is under vacuum.
  This combination involves a seismic event (SL-1, SMHV, and SL-2).
- **S - SL2 + Fire + Pulse:** Similar to load combination P with the temperature of DNB vessel as per defined during fire event.
- **T - Outgassing:** DNB vessels is closed and empty. Temperature of walls is increased to outgas for final cleaning.

Note:

Single load cases are often specified with several options to be selected depending on the scope of the assessment, e.g. load directions or location of load peaks. The different single load cases shall be combined conservatively in order for the resulting load to be the most conservative.

	DNB	Load combinations		Single loads																																																			
				Inertial				Pressure													Seism			Thermal																	Interface														
	Name	Cat.	Nb of cycle	Vessel	Top lid	Temp. lids for testing	Feedtrough box	Pulse pressure	Test pressure	Min Outlet Pressure	Draining	Drying	Vacuum	Vessel at atmospheric pres.	Spark Gap Test	VV ICE II	VV ICE III	VV ICE IV	LOCA NB II	LOCA NB III	SL-1	SMHV	SL-2	Room temp. max	Room temp. min	Inlet temperature	Outlet Max Temp.	Drying	Pumping	HVB	PMS	FECs normal temp.	FECs Baking	BLCs	Exit Scraper	Nuclear Heating	Fire	LOCA NB II	LOCA NB III	Outgassing	Metallic Seal	Fast Shutter	HVB	BS	BLCs + ES	Cryopumps	NBI PHTS	PMS	Feedthrough Box	Annex Systems	Vesel RH Jacking	Cryopumps RH	Others RH Tools	Vessel Assembly	Top Lid Assembly
				1	2	3	4	20	21	22	23	24	25	26	27	28	29	30	31	32	35	36	37	40	41	42	43	44	45	47	48	49	50	51	52	53	54	55	56	57	60	61	62	70	71	72	73	80	81	82	92	93	94	100	101
A	Leak Test	I	10																																																				
B	Handling Phase + SL-1	II	5																																																				
C	Spark gap test	I	5																																																				
D	Pulse	I	50 000																																							I													
E	Test of cooling circuit	I	50																																							I													
F	BLCs draining	I	TBD																																							I													
G	BLCs drying	I	TBD																																							I													
H	VV ICE II + VDE II + SC	II	300																																							II													
I	VV ICE III + Pulse	III	-																																							III													
J	VV ICE III + VDE III + SC	III	-																																							III													
K_a	LOCA NB II + Pulse	II	-																																							II													
K_b	LOCA NB III + Pulse	III	-																																							III													
L	VV ICE IV + Pulse	IV	-																																							IV													
M	VV ICE IV + VDE III + SC	IV	-																																							III													
N	VV ICE IV + VDE IV + SC	IV	-																																							IV													
O	SLs + Baking	II to IV	-																																							II-IV													
P	SLs + Pulse	II to IV	-																																							II-IV													
Q	SLs + RH	II to IV	-																																							II-IV		*	*										
R	SLs + CP RH	II to IV	-																																							II-IV													
S	SL2 + Fire + Pulse	IV	-																																																				
T	Outgassing	I	1																																																				

* Each BLCs may be remove, which creates 3 cases to combine with seismic events. An additional mass of 5 tons (RH tools) must be added to the BLCs removed

Table 10 – List of loads combination for DNB vessel

3.2.2 *Not significant combinations*

In the list of possible combinations of loads, the following are considered as not design driving. The solicitations used or their combinations are smaller than the ones listed above:

Combination	Justification
Leak test after assembly	The "during pulse" state involves more severe loads in addition to vacuum and atmospheric pressure.
Set-up / maintenance	This case involves only dead weights. We find the same configuration in the "during pulse" state with pressure loads in addition.
Between pulse	This case is very similar to "during pulse" state. Same frequency but with lower thermal load.
Cryopump regeneration at 100K	During this regeneration the pressure rises to 2kPa which can be considered as vacuum for mechanical calculations. The vessel temperature reaches 10°C which is equivalent to the 12°C during normal operation for stainless steel behaviour.
Cryopump regeneration at 300K	During this regeneration the difference of temperature between the vessel and the pump is negligible. This combination is less severe than "during pulse".
Cryopump regeneration at 400K	This thermal load is less severe than normal operation.
Baking	Verifying the baking load alone is not significant because confinement function must be kept in case of seismic event and DNB vessel itself is not baked.
VV LOVA III: Loss of vacuum through penetration line	This event corresponds to the ITER Reference Event V3 reported in [12]. This event creates a depressurisation of port cell. NB cell has a much bigger volume; consequently the depressurization will be low. Moreover, depressurisation reduces the stress on the vessel. Therefore it is not considered.
SL-1 + Pulse + VV ICE III	Even if SL-1 initiates a leak the effect of the leak (pressure and temperature) is seen much later after the seismic load. Therefore they don't occur at the same time.
100K regen. + VV ICE III	This combination is very similar to "Pulse + VV ICE III" combination. The only difference is the starting temperature of the scenario which might differ slightly. Final pressure and temperature are identical. Therefore it is not considered.
100K regen. + LOCA NB III	This combination is similar to "Pulse + LOCA NB III combination". The difference is the starting temperature of the scenario (like above) and the pressure which is less severe for the vessel. Therefore it is not considered.
400K regen. + VV ICE III	400K regeneration will not be carried out during plasma.
400K regen. + LOCA NB III	400K regeneration will not be carried out during plasma.
Cryopump leaks	If a cryopump leaks, the flow of cryogenic coolant is limited by safety valves. Maximum He mass that can be spilled is 20 kg (simultaneous break of the 4 cryogenic circuits of an HNB). This case is encompassed by ICE events

Gas leak	A leak of gas (helium or deuterium) in the vessel is a negligible event compared to other leaks
MFD / VDE / MD	The effect of these EM loads is negligible for the vessel (see chapter 2.5).
VV ICE IV + vessel opened	The difference of pressure between VV and DNB vessel is only 1 bar. This combination is less severe than VV ICE III and IV + valve closed.
VV ICE III + VDE IV + SC	As the pressure is lower than the ICE IV event, this combination is less severe than the combination involving ICE IV and VDEs.
Cryopump maintenance (alone)	Less severe than "SLs + CP maintenance" using SL-1.
DL NS maintenance (alone)	Less severe than "SLs + DL NS maintenance" using SL-1
SLs + vessel opened	Considered as less severe than "SLs + CP maintenance" because in the latter case, the mass resting on the flange is higher and generates more stress when accelerated. Also considered as less severe than "SLs + BS maintenance".
Internal flooding + related combinations	The quantity of water spilled in the NB cell is limited by valves. Considering the surface of the NB cell (1100m^2), no load is expected from this case. According to the document (IDM_D_QV4FYF) the flood height in the NB cell will reach 0.92m. Considering the area of the DNB vessel and its elevation a buoyancy force of 8.2tons will be applied on the DNB vessel. This force is considered negligible compared to the mass of the DNB vessel and the BLCs.

Table 11 – Not significant combinations

Other combinations present in the table could be classified as not significant. But considering the diversity of loads applied and the geometry of the vessel, calculations are necessary to determine if a combination is more severe than another.

3.3 Combinations for lids

The following combinations involve only the top lid (not the DNB vessel).

3.3.1 List of combinations

- **L1 - Top lid lifted + SL-1:** this combination describes the top lid lifted by the crane during assembly or manufacturing. It is combined with a SL-1 event.
- **L2 - Top lid on trolley + SL-1:** the top lid lies on the dedicated trolley to enter NB cell. It is supported on the inner side. It is combined with a SL-1 event.

As, without calculation, it is not possible to know which type of seismic event is design-driving for each combination, the three seismic events (SL-1, SMHV and SL-2) have been grouped under the name: SLs. The three seismic events have to be tested and compared. After justification, only the most severe one can be calculated.

- **L3 - Top lid lifted + SLs:** this combination describes the top lid lifted by the crane during RH maintenance. It is combined with a SL-1, SMHV or SL-2 event.

- **L4 - Top lid on trolley + SLs:** the top lid lies on the temporary storage frame inside the NB cell RH of BLCs. It is supported on the inner side. It is combined with a SL-1, SMHV, or SL-2 event.
- **L5 - Top lid opening (opened) + SLs:** this combination is identical to L1 combined with a SL event.
- **L6 – Top lid opening (closed) + SLs:** this combination is identical to L2 combined with a SL event.

These two last combinations are required to make sure that interface point with the opening tools will support the highest accelerations (to avoid the fall of the lid), and to make sure that plastic deformation will be small enough to guarantee the leak-tightness of the lid when put back in place after the event.

DNB		Load combinations		Single loads						
				Inertial	Seism			Interface		
	Name	Cat.	Nb of cycle	Top Lid	SL-1	SMHV	SL-2	RH Crane Interface	RH Crane Interface	Top Lid Assembly
				1	35	36	37	91	92	101
L1	Top lid lifted + SL-1	II	5							
L2	Top lid on trolley + SL-1	II	5							
L3	Top lid lifted + SLs	II to IV	-							
L4	Top lid on trolley + SLs	II to IV	-							
L5	Top lid opening (opened) + SLs	II to IV	-							
L6	Top lid opening (closed) + SLs	II to IV	-							

Table 12 – List of Loads combination for DNB top lid

4 References

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[25] PED conformity assessment and MD329-04 regulation for the MITICA Beam Line Components v1.0, ITER_D_QYMZ3C

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[34] Assessment of ice load to the HNB/MITICA cryopump v1.0, ITER_D_KMLR9L

[35] IS-53-31-102-DNB-Interface between the cryopump and the DNB injector vacuum vessel v1.4, ITER_D_UVGSPA

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APPENDIX A: Reaction forces of fore vacuum pumping line

ITER_D_UMXBJA v1.1 US_D_23AQXW v1.2

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Table-8.4, Equipment Interface Loads (ABS)

A complete set of interface loads can be obtained from Attachment D.

DNB (Node 15200)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.3	0.3	1.4	0.6	1.1	0.5
DW+P+T	L28	7.9	0.9	4.0	3.2	1.3	11.1
DW+P+T+SL2	Dyn12	12.8	3.4	7.9	9.3	6.2	15.6
DW+P+T_{FIRE}+SL2	Dyn13	20.0	3.9	10.1	11.6	5.6	25.0

HNB1 (Node 15900)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.6	1.1	5.6	4.0	6.2	1.1
DW+P+T	L28	28.1	8.3	13.9	12.0	17.1	9.7
DW+P+T+SL2	Dyn12	44.8	18.1	30.1	26.7	42.2	20.6
DW+P+T_{FIRE}+SL2	Dyn13	69.5	24.5	37.5	33.8	51.9	28.3

HNB2 (Node 13000)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.1	0.1	3.4	1.2	3.1	0.1
DW+P+T	L28	2.0	2.4	3.7	1.4	3.4	4.5
DW+P+T+SL2	Dyn12	7.0	8.1	9.4	3.0	12.0	14.3
DW+P+T_{FIRE}+SL2	Dyn13	8.7	10.2	6.5	3.1	8.8	18.2

HNB3 (Node 11000)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.6	0.1	4.0	1.6	3.1	0.2
DW+P+T	L28	9.3	0.6	10.3	4.7	13.1	4.2
DW+P+T+SL2	Dyn12	21.8	3.5	16.1	8.3	20.7	11.8
DW+P+T_{FIRE}+SL2	Dyn13	30.6	4.0	21.7	11.1	29.7	15.6

APPENDIX B: Reaction forces of the vent lines

ITER_D_UP3DQ6 v1.1 US_D_23KDTQ v1.1

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Table-8.4, Equipment Interface Loads (ABS)

A complete set of interface loads can be obtained from Attachment D.

DNB (Node 9300)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.1	0.1	0.1	-	0.1	0.1
DW+P+T	L28	0.1	0.1	0.2	0.1	0.1	0.1
DW+P+T+SL2	Dyn12	0.6	0.8	0.5	0.5	0.4	0.2
DW+P+T_{FIRE}+SL2	Dyn13	1.0	1.0	0.8	0.6	0.4	0.3

HNB1 (Node 24100)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.1	0.1	0.1	0.1	0.1	-
DW+P+T	L28	0.1	0.2	0.2	0.1	0.1	0.1
DW+P+T+SL2	Dyn12	0.3	0.4	0.5	0.4	0.3	0.3
DW+P+T_{FIRE}+SL2	Dyn13	0.4	0.8	0.5	0.4	0.4	0.4

HNB2 (Node 28900)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.1	0.1	0.1	0.1	0.1	0.1
DW+P+T	L28	0.1	0.2	0.1	0.1	0.1	0.1
DW+P+T+SL2	Dyn12	0.4	0.4	0.4	0.3	0.2	0.5
DW+P+T_{FIRE}+SL2	Dyn13	0.5	0.6	0.4	0.3	0.3	0.5

HNB3 (Node 19200)							
		X (kN)	Y (kN)	Z (kN)	MX (kNm)	MY (kNm)	MZ (kNm)
DW+P	L3	0.1	-	0.1	0.1	0.1	-
DW+P+T	L28	0.1	0.1	0.1	0.1	0.1	0.1
DW+P+T+SL2	Dyn12	0.4	0.4	0.3	0.2	0.3	0.3
DW+P+T_{FIRE}+SL2	Dyn13	0.5	0.4	0.3	0.2	0.4	0.3

APPENDIX C: Bolting force of top lid

Issued by	gklinuski	Design number	FT2392
Date	05-11-2019	Customer's name	ITER
Version	0	Asked by	

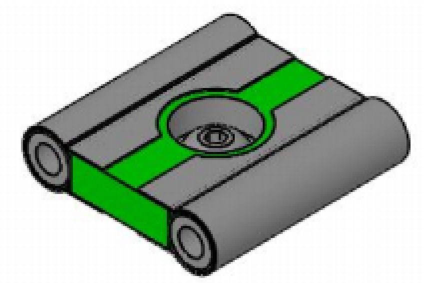
HELICOFLEX® HNRD205U Sp
Cross section=10.20 - Outer jacket made of Ag

Rectangular seal

Representative datasheet for HNRD205U SP Drawing 111-0109429 rev C

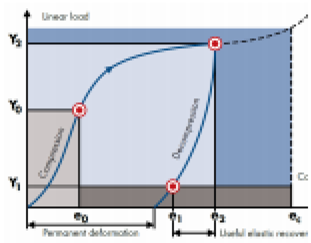
Working Conditions

Application	Nuclear
Media to be sealed	
Working pressure [bar]	0.0
Working or baking temperature [°C]	20.0
Media side	Internal



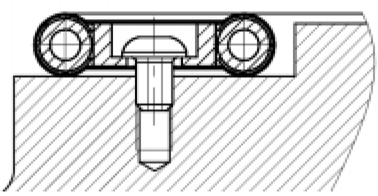
Seal Data

	Seal [Ext]	Seal [Int]
Seal style	HNRD205U SP	
Cross section [mm]	10.20	10.20
Diameter at seal load reaction (DJ) [mm]	9321.8x3196.8 R498.4	9242.2x3117.2 R458.6
Seal ID (A) [mm]		9232x3107 R453.5
Seal OD (B) [mm]	9332x3207 R503.5	
Sealing material	Ag	Ag
Plating	No	No
Inner material	Alloy_600	Alloy_600
Spring material	Alloy_718	Alloy_718
Internal limiter	No	No
Leak tightness	Helium	
Compression load (Y2) [N/mm]	655 ±10%	655 ±10%



Groove Data

	Seal #1	Seal #2
Groove ID [mm]		9225x3100 -/+1 R450 -0/+0.5
Groove OD [mm]	9339x3214 -/+1 R507 -0.5/0	
Groove depth (h) [mm]	8.60 +/-0.100	8.60 +/-0.100
Compression value (e2) [mm]	1.60	1.60
Diametrical clearance (j) [mm]	0.90	0.90
Roughness obtained as per Technetics' specification	Ra1.6 - Ra3.2	Ra1.6 - Ra3.2
Minimum hardness [HV]		
Minimum seating load (Fj) [N]	34663507.1	



Technetics GROUP (EnPro Industries companies)	Issued by	gklinuski	Design number	FT2392
	Date	05-11-2019	Customer's name	ITER
	Version	0	Asked by	

HELICOFLEX® seal - Loads and torques calculation

Seal Data

	Seal #1	Seal #2		Seal #1	Seal #2
Seal style	HNRD205U SP		Compression load (Y2) [N/mm]	655	655
Cross section [mm]	10.20	10.20	Y1 [N/mm]	130	130
			Puθ [bar][20°C,T]	[1000,1000]	[1000,1000]
Représentative Diameter at seal load reaction (DJ) [mm]	7697.00	7617.00	Ym [N/mm][20°C,T]	[130,130]	[130,130]

Ym=max{Y1;Y2.P/Puθ} if P.DJ≥32.Ym → Ym=Y2

Bolting Data

Type of bolting	ISO	Material	
Nominal diameter (ND) [mm]	60	Pitch of the thread [mm]	5.50
Cross-sectional area of one bolt (Sr) [mm²]	2362.04	Quantity of bolts (nb)	224
Effective friction diameter of the bolt head (Dm)	78.00	Friction coefficient (μ)	0.20/0.25/0.30
Young modulus variation (E/ET) [Operating,Proof test]	[1.000,1.000]	Allowable stress (σbmax) [Operating,Proof test]	[200,250]

Working Conditions

	Operating	Proof test
Pressure (P) [bar]	0.0	0.0
Temperature [°C]	20.0	20.0
Safety coefficient (k)	1.0	1.0

Loads calculation

Minimum seating load (Fj)	Fj = π.(DJ1+DJ2).Y2max	34663507 N	34663507 N
Hydrostatic end thrust	Ff = π.min(DJ1,DJ2)².P / 4	0 N	0 N
Min. working load	Fm = π.(DJ1+DJ2).Ym or π.(DJ1+DJ2).Y2	6254346 N	6254346 N
Min. load @20°C	Fs = Ff + Fm	6254346 N	6254346 N
Min. load @ working temp.	Fs* = Fs x E / ET	6254346 N	6254346 N
Min. load to apply on the seal	**Fb1 = k.max{Fs*,Fj}**	**34663507 N**	**34663507 N**

Fb1 is the minimum load to be applied on the assembly in order to reach the target leak rate.

Min. load for metal-to-metal contact	**Fb2**	**34663507 N**	**34663507 N**

Fb2 = k.max{Fs*,Fj1+Fj2} with Fs=Ff+Fj+Fj2 => Fb2 = k.(Ff+Fj1+Fj2).E/ET
The tightening load Fb2 ensure the metal-to-metal contact (flange to flange) in operating condition. If allowed by the assembly, this is the recommended tightening load.

The load above is not the only parameter to take into account to design the assembly.
For instance, the calculations do not take into account any other external load (e.g. Moment on the assembly).
--- In doubt, feel free to reach our engineering department. ---

Stresses and torques

		Operating (Fb1)	Operating (Fb2)	Proof test (Fb1)
Tensile stress	σ0 = Fb/(nb.Sr)	66 [MPa]✓	66 [MPa]✓	66 [MPa]✓
Min. torque value [μ=0.20]	C0 = (Fb/nb)[0.16p+μ(0.583d2+Dm/2)]	2360.7 [N.m]	2360.7 [N.m]	2360.7 [N.m]
Min. torque value [μ=0.25]	C0 = (Fb/nb)[0.16p+μ(0.583d2+Dm/2)]	2916.9 [N.m]	2916.9 [N.m]	2916.9 [N.m]
Min. torque value [μ=0.30]	C0 = (Fb/nb)[0.16p+μ(0.583d2+Dm/2)]	3473.2 [N.m]	3473.2 [N.m]	3473.2 [N.m]

The friction coefficient depends on the bolting, the lubrication and if there is washers. This is a critical parameter and must be double-checked. Also, the friction depends on the diameter of the bolts.
For information, 0.15 = bolts in really good condition, lubricated, with washers ; 0.20 = bolts in good condition with washers 0.25 = bolts in fairly good condition with washers ; 0.3 = bolts with an elevated friction coefficient.

Assembly according to Technetics Group specification FT921-15 or FT921-45 for UHV application.

APPENDIX D: Bolting forces of fast shutter flange

Issued by	gklinuski	Design number	FT1339-Bride2
Date	26-03-2019	Customer's name	ITER ORGANIZATION [16756]
Version	0	Asked by	

HELICOFLEX® HN200 - Cross section=9.50 - Outer jacket made of Ag

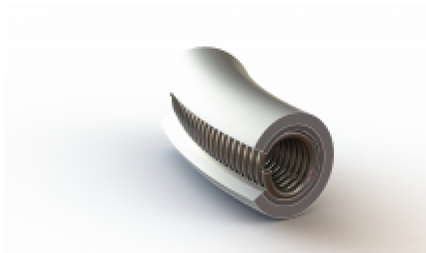
HELICOFLEX® HN200 - Cross section=9.50 - Outer jacket made of Ag

Seal#1:Ø2468.30 x Ø2487.30 - Seal#2:Ø2438.70 x Ø2457.70

Data sheet for drawing 111-0214207

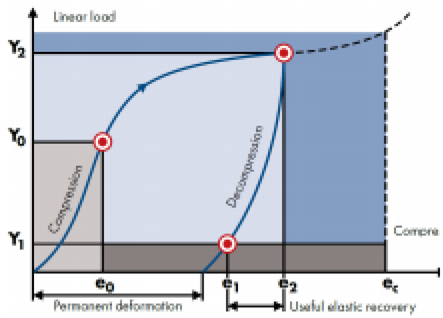
Working Conditions

Application	Vacuum
Media to be sealed	Hélium
Working pressure [bar]	2.0
Working or baking temperature	250.0
Media side	Internal



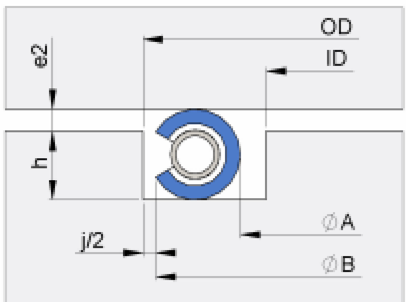
Seal Data

	Seal [#1]	Seal [#2]
Seal style	HN200	HN200
Cross section [mm]	9.50	9.50
Diameter at seal load reaction (DJ) [mm]	2477.80	2448.20
Seal ID (A) [mm]	2468.30	2438.70
Seal OD (B) [mm]	2487.30	2457.70
Sealing material	Ag	Ag
Plating	No	No
Inner material	SS304L	SS304L
Spring material	Alloy_718	Alloy_718
Leak tightness	Helium	
Compression load (Y2) [N/mm]	$570^{\pm 10\%}$	$570^{\pm 10\%}$



Groove Data

	Seal #1	Seal #2
Groove ID [mm]	2465.40^{max}	2435.80^{max}
Groove OD [mm]	$2488.00^{-0/+0.300}$	$2458.40^{-0/+0.300}$
Groove depth (h) [mm]	$8.30^{+/-0.100}$	$8.30^{+/-0.100}$
Compression value (e2) [mm]	1.20	1.20
Diametrical clearance (j) [mm]	0.70	0.70
Roughness obtained as per Technetics' specification	Ra1.6 - Ra3.2	Ra1.6 - Ra3.2
Minimum hardness [HV]		
Minimum seating load (Fj) [N]	9703129.4	



Technetics GROUP EnPro Industries companies	Date	26-03-2019	Customer's name	ITER ORGANIZATION [16756]
	Version	0	Asked by	

HELICOFLEX® seal - Loads and torques calculation

Seal Data

	Seal #1	Seal #2		Seal #1	Seal #2
Seal style	HN200	HN200	Compression load (Y2) [N/mm]	570	570
Cross section [mm]	9.50	9.50	Y1 [N/mm]	200	200
Diameter at seal load reaction (DJ) [mm]	2477.80	2448.20	Puθ [bar][20°C,T]	[1000,670]	[1000,670]
Seal ID (A) [mm]	2468.30	2438.70	Ym [N/mm][20°C,T]	[200,200]	[200,200]
Seal OD (B) [mm]	2487.30	2457.70	Ym=max{Y1;Y2.P/Puθ} if P.DJ≥32.Ym → Ym=Y2		

Bolting Data

Type of bolting	ISO	Material	
Nominal diameter (ND) [mm]	20	Pitch of the thread [mm]	2.50
Cross-sectional area of one bolt (Sr) [mm²]	244.80	Quantity of bolts (nb)	120
Effective friction diameter of the bolt head (Dm)	26.00	Friction coefficient (µ)	0.15/0.20/0.25
Young modulus variation (E/ET) [Operating,Proof test]	[1.000,1.000]	Allowable stress (σbmax) [Operating,Proof test]	[0,0]

Working Conditions

	Operating	*Proof test*
Pressure (P) [bar]	2.0	2.0
Temperature [°C]	250.0	20.0
Safety coefficient (k)	1.0	1.0

Loads calculation

Minimum seating load (Fj)	Fj = π.(DJ1+DJ2).Y2max	9703129 N	9703129 N
Hydrostatic end thrust	Ff = π.min(DJ1,DJ2)².P / 4	941486 N	941486 N
Min. working load	Fm = π.(DJ1+DJ2).Ym or π.(DJ1+DJ2).Y2	3095097 N	3095097 N
Min. load @20°C	Fs = Ff + Fm	4036583 N	4036583 N
Min. load @ working temp.	Fs* = Fs x E / ET	4036583 N	4036583 N
Min. load to apply on the seal	**Fb1 = k.max{Fs*,Fj}**	**9703129 N**	**9703129 N**

Fb1 is the minimum load to be applied on the assembly in order to reach the target leak rate.

Min. load for metal-to-metal contact	**Fb2**	**10644615 N**	**10644615 N**

Fb2 = k.max{Fs*,Fj1+Fj2} with Fs=Ff+Fj+Fj2 => Fb2 = k.(Ff+Fj1+Fj2).E/ET
The tightening load Fb2 ensure the metal-to-metal contact (flange to flange) in operating condition. If allowed by the assembly, this is the recommended tightening load.

The load above is not the only parameter to take into account to design the assembly.
For instance, the calculations do not take into account any other external load (e.g. Moment on the assembly).
--- In doubt, feel free to reach our engineering department. ---

Stresses and torques

		Operating (Fb1)	Operating (Fb2)	Proof test (Fb1)
Tensile stress	σ0 = Fb/(nb.Sr)	0 [MPa] ✘	0 [MPa] ✘	0 [MPa] ✘
Min. torque value [µ=0.15]	C0 = (Fb/nb)[0.16p+µ(0.583d2+Dm/2)]	0.0 [N.m]	0.0 [N.m]	0.0 [N.m]
Min. torque value [µ=0.20]	C0 = (Fb/nb)[0.16p+µ(0.583d2+Dm/2)]	0.0 [N.m]	0.0 [N.m]	0.0 [N.m]
Min. torque value [µ=0.25]	C0 = (Fb/nb)[0.16p+µ(0.583d2+Dm/2)]	0.0 [N.m]	0.0 [N.m]	0.0 [N.m]

The friction coefficient depends on the bolting, the lubrication and if there is washers. This is a critical parameter and must be double-checked. Also, the friction depends on the diameter of the bolts.
For information, 0.15 = bolts in really good condition, lubricated, with washers ; 0.20 = bolts in good condition with washers 0.25 = bolts in fairly good condition with washers ; 0.3 = bolts with an elevated friction coefficient.

Assembly according to Technetics Group specification FT921-15 or FT921-45 for UHV application.