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Structural analysis of the ITER Vacuum Vessel regarding 2012 ITER Project-Level Loads

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HIGHLIGHTS

- ITER Vacuum Vessel is a part of the first barrier to confine the plasma.
- ITER Vacuum Vessel as Nuclear Pressure Equipment (NPE) necessitates a third party organization authorized by the French nuclear regulator to assure design, fabrication, conformance testing and quality assurance, i.e. Agreed Notified Body (ANB).
- A revision of the ITER Project-Level Load Specification was implemented in April 2012.
- ITER Vacuum Vessel Loads (seismic, pressure, thermal and electromagnetic loads) were summarized.
- ITER Vacuum Vessel Structural Margins with regards to RCC-MR code were summarized.

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ABSTRACT

A revision of the ITER Project-Level Load Specification (to be used for all systems of the ITER machine) was implemented in April 2012. This revision supports ITER's licensing by accommodating requests from the French regulator to maintain consistency with the plasma physics database and our present understanding of plasma transients and electro-magnetic (EM) loads, to investigate the possibility of removing unnecessary conservatism in the load requirements and to review the list and definition of incidental cases. The purpose of this paper is to present the impact of this 2012 revision of the ITER Project-Level Load Specification (LS) on the ITER Vacuum Vessel (VV) loads and the main structural margins required by the applicable French code, RCC-MR.

1. Introduction

In April 2012, the ITER Project-Level Load Specification (LS) [1] was revised per the ITER licensing (coming from French regulator) for consistency with most recent plasma physics database and to remove unnecessary conservatism in load requirements. Thus, it was important to perform an assessment of the impact of this ITER Project-level revision on the ITER Vacuum Vessel (VV) loads [2] and the main RCC-MR structural margins [1,4].

The VV is a double-walled structure that surrounds the plasma. It features a band of upper ports, equatorial ports, and lower (divertor) ports to allow access for plasma heating, fuelling, diagnostics, and in-vessel component services. It is supported off the lower ports. The interspace between the VV walls is filled with cooling water to remove heat deposited during plasma operation; to bake the vessel to promote ultra-high vacuum conditions in the plasma chamber; to maintain the VV temperature; and to remove decay heat loads in in-vessel components in the event of a loss of cooling or loss of flow to those components.

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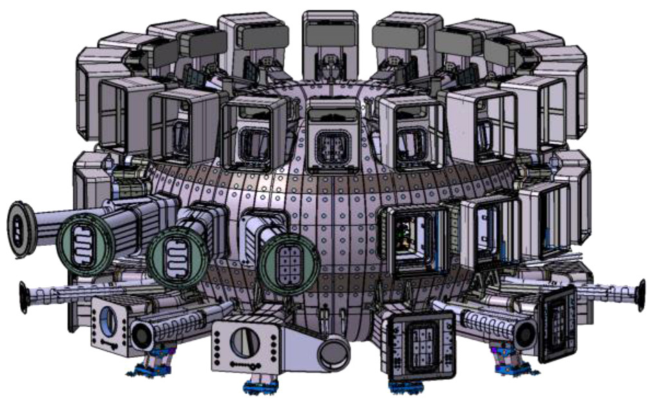

Fig. 1. Whole ITER VV baseline design (2010).

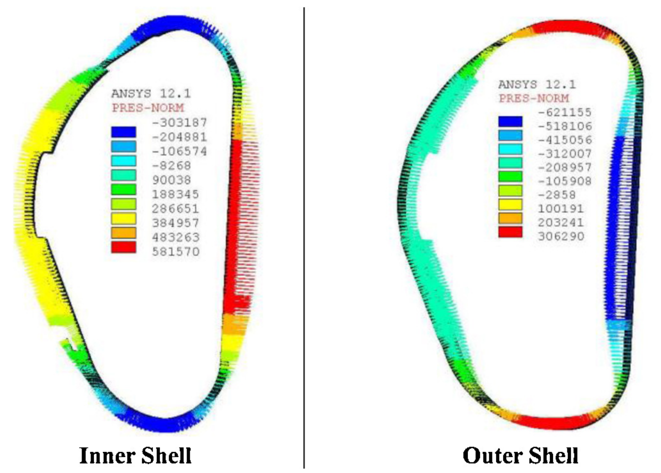

Fig. 2. Qualitative normal pressure distribution due to eddy current, MDII.

The VV is a part of the first barrier to confine plasma. It protects superconducting magnets (enveloping the VV) by shielding and also the environments against nuclear active materials. A coolant pressure at 0.8 ± 0.3 MPa during normal operation (2.1 ± 0.3 MPa during baking) classifies the VV as Nuclear Pressure Equipment (NPE) which necessitates a third party organization authorized by the French nuclear regulator to assure design, fabrication, conformance testing and quality assurance, i.e. Agreed Notified Body (ANB).

2. Design description [5]

The main components that make up the VV are the main vessel, the port structures and the VV supporting system; see Fig. 1. The VV is a torus-shaped, double wall structure with shielding and cooling water between the shells (with 13 m height and 20 m diameter). The basic vessel design is an all-welded structure. Only the inner shell serves as the plasma confinement barrier. The VV components are designed and manufactured consistent with an accepted code or standard. The VV is divided into 9 toroidal sectors (each on a 40 degrees toroidal angle) joined by field welding using splice plates at the central vertical plane of alternate ports (of the odd numbers). All sectors have approximately the same design of the ports including gravity support. Three sectors have different equatorial ports, however. These sectors are called “irregular sectors”. The main structural material of VV is Stainless Steel of 316L(N) IG, low Nitrogen ITER Grade stainless steel which is used for all components of the VV cooled by water.

3. Mechanical loads description [2]

The mechanical loads acting on the VV can be divided into five independent categories:

- *Inertial loads*: these are caused by accelerations due to gravity (DW) and seismic events (SL).
- *Electromagnetic (EM) loads*: these are normally a strong design driver and act upon nearly all conductive structures during transient events (e.g. Major Plasma Disruption MD, Vertical Displacement Events VDE, and Magnet current Fast Discharge MFD).
- *Pressure loads*: these include coolant (CP coolant pressure during operation, BK baking pressure and PT testing pressure), and incidental VV internal and external pressure (In vessel ingress of coolant events (VV ICE), due to a leak into the plasma chamber; Loss of coolant in port cell, LOCA_PCIII due to a leak of a blanket feeding pipe in the upper port duct; In Cryostat ingress of coolant or air/helium (Cr ICE), due to a leak into the cryostat).
- *Thermal loads*: these are caused by temperature gradients inside the VV structure caused by nuclear heating on one side and water cooling on the other side. The support systems are designed flexible enough to allow relative expansions between components (VV, Toroidal Field Coils, In-Vessel components).
- *Pretension loads*: these are caused by the pretension of the divertor cassettes and the pretension of the bolts (gravity supports, port plugs, in-wall shielding, blanket modules, sockets of the blanket electrical straps, in-vessel coil supports and others) (Table 1).

EM loads are due to Lorentz forces when an electric current crosses magnetic field lines. These loads are typically body loads since the electric current runs through the conductive structure in three dimensions. The structure of the VV is a shell box structure Thus for global assessment, in order to simplify this specification, the distribution of the load across the shell thickness is not given. Instead, a surface pressure load is given which corresponds to the mid-plane of the shell. It shall therefore be applied at the level of the mid-plane of the shell. For example, see pressure distribution for MDII in Fig. 2.

4. Structural integrity [4,6]

To demonstrate the structural integrity of the ITER VV is very challenging [6], not only due to various loads (and load combinations, see Section 3) and the complexity of the vessel design (see Section 2), but also due to RCC-MR [1] and Nuclear Pressure Equipment (NPE as ESPN for French pressure equipment) requirements.

The structural analyses were performed with many different global models [4]: 360-degree whole vessel model in shell elements (see Fig. 3), 180-degree half-sized model in shell-solid mixed model, 40-degree one sector shell model, and 20-degree half sector model in shell-solid mixed model. The difference in the analysis model sizes compromises between the level of detail and calculation time. A whole 360-degree model is used to apply asymmetric global loads, like a seismic load or unsymmetric electro-magnetic pressure due to one directional movement of the plasma.

Because of many interfaces (Blanket, Divertor, In Vessel Coils, Manifolds, Plugs, Cryostat…), the VV has lots of attachments welded or bolted on its surface. To verify the structural integrity of the VV, the analyses of global models are not sufficient; some local assessments are necessary. Global analyses are mostly covered by shell elements and local analyses are performed by solid elements.

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Table 1
Main characteristics of the VV mechanical loads.

Load case	Characteristic loads	
DW	Total weight of VV: ≈8900 tons	
BK	**VV**: High temperature (200 °C) → thermal expansion. Highest coolant pressure → design pressure 2.6 MPa. **Blanket manifold**: High temperature (240 °C) → (different) thermal expansion. Highest coolant pressure → design pressure 5.0 MPa:	
PT	3.72 MPa + ambient pressure @ 20 °C	
Type II	SL-2 × 0.34	
SL-1		
Type IV	Radial/toroidal acceleration: ≈ 3.4 m/s^2	
SL-2	Vertical acceleration: ≈ 23.2 m/s^2	
MDI	Qualitatively the same as in a major disruption II	
MDII	Pressure on inboard wall: −1.2 MPa (neg. pressure) Pressure on top and bottom of VV: 0.6 MPa Forces on blanket modules.	
VDEII	Qualitatively the same as in a VDEIII	
VDEIII[a]	**VDE down**	**VDE up**
Peak vertical force	108 MN	−86 MN
Peak sideways force	22 MN	48 MN
Peak tilting moment	216 MNm	145 MNm
Max. pressure on inboard wall	≈3.56 MPa	≈3.67 MPa
VDEIV	Qualitatively the same as in a VDEIII	
MFD	Pressure on inboard wall: 1.55 MPa	
VV ICEII	1.06 bar in plasma chamber	
VV ICEIII	1.5 bar in plasma chamber	
VV ICEIV	2.0 bar in plasma chamber	
Large VV ex-vessel coolant pipe break	Decay heat of VV causes an increase of the VV temperature. Pressure in VV cooling circuit decays.	
VV LOFA	Decay heat of VV causes an increase of the VV temperature.	
LOCA_PCIII	1.2 bar/1.5 bar in upper port duct 1.0 bar/1.5 bar in plasma chamber	
Cr ICE	Abs. pressure in cryostat: 0.3 bar/2 bar	

[a] Forces on whole Vacuum Vessel components.

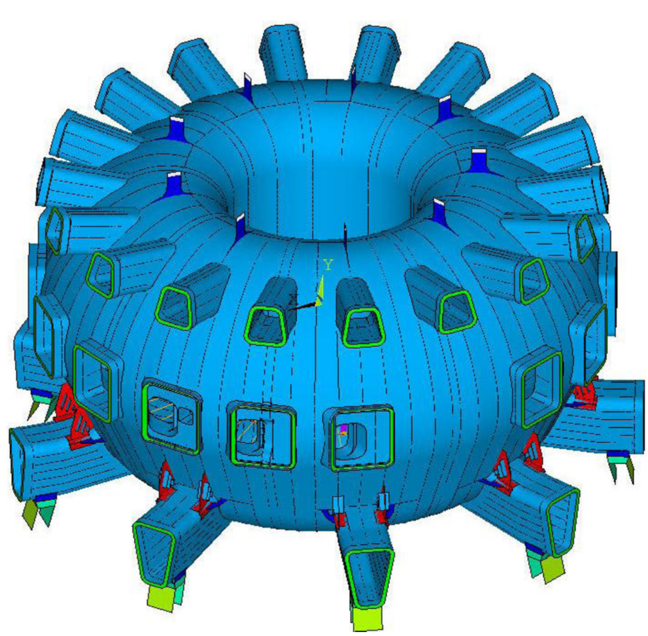

Fig. 3. Analysis model of full ITER vacuum vessel in shell elements with irregular sectors (port extensions from openings are not shown).

To guarantee the structural integrity of the VV with regards to RCC-MR [1], the structure does not undergo certain types of structural damage such as P-type and S-type. The structural analysis consists of verifying compliance with criteria based on the analysis method considering the event category (I, II, III & IV) and the type of damage. Three types of analysis have been performed to determine stress, strain, and displacement of significant quantities and to compare them with the maximum allowable values: elastic analysis, limit analysis and elasto-plastic analysis.

First, the prevention of the P-type damage has been verified by elastic analyses. In this case, the highest (linearized) membrane (Pm) and membrane plus bending (Pm + Pb) stresses have to be more than the 1.2 allowable stress proposed in RCC-MR $f > 1.2$ with f the structural margin factor which is the minimum between the ratios Pm/Sm and Pm + Pb/1.5Sm (1.2 is a supplementary margin factor to compensate the lack of visual examination of the VV during In Service Inspection ISI). If necessary, limit analysis (elasto-(perfectly)plastic analysis) is performed to permit the stress distribution in the structure. In this case the margin factor f is the ratio between the collapse load factor and the RCC-MR allowable load factor.

Second, considering S-type damage, 3Sm rules have been used to prevent progressive deformation by elastic analysis. Then the fatigue is evaluated by fatigue usage fraction factor (V) which has

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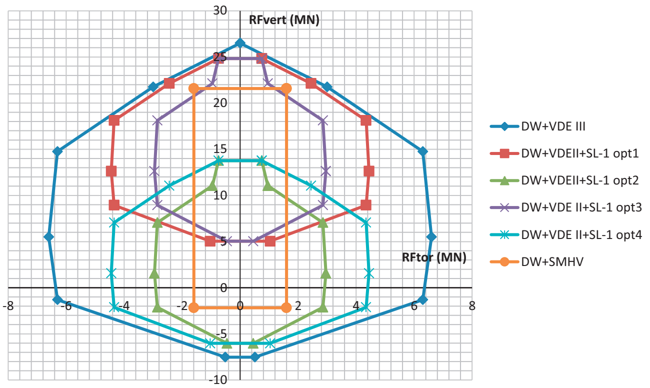

Fig. 4. Reaction forces envelop curves in toroidal and vertical direction in category III at the Vacuum Vessel Gravity Support.

to be lower than 0.1 instead of 1, as proposed in RCC-MR (0.1 is a supplementary margin fatigue usage ratio to compensate the lack of visual examination of the VV during In Service Inspection ISI). V is calculated considering the fatigue cycles from the load specification and dividing them by the obtained fatigue cycles for each load. This calculation is repeated for all loads and load combinations and the final sum is the V value. If necessary, elasto-plastic analysis of cyclic loading is performed, but this is very time consuming.

A summary of the minimum RCC-MR [3] structural margins considering all categories of events extracted from the VV stress report [4] is available in Table 2.

5. Revision of loads (2012) [1]

The main additional loads coming from this revision are the available in Table 3.

5.1. Seismic loads: type III SMHV load

The new seismic level SMHV (Seismes Maximaux Historiquement Vraisemblables = Maximum Historically Probable Earthquakes) is classified in load category III. As a first approximation, seismic response to SMHV event may be obtained multiplying the results from SL-2 by a factor 0.73. The ratio between SMHV and SL-2 is not constant at any frequency but 0.73 is the highest value reached at around 11 Hz. In order to evaluate the influence of the SMHV case on the reactions at the Vacuum Vessel Gravity Support, Fig. 4 has been plotted. Each point corresponds to a net load case combined (or not) with another one. It appears that the SMHV as well as the VDE II + SL-1 (considering the four reaction force combinations defined in VVLS) are enveloped by the most severe load, Type III VDE slow downward.

Following the revised load [1], SMHV can be combined also with the VV coolant pressure conditions (normal operating and baking), He in Gallery event, Internal Fire, Cr ICEIII event and simultaneously MFD I or II event.

These load conditions do not add any relevant stresses in the worst VV zone affected by a seismic load. The only effect is related to the higher temperature (during baking) that causes a small change in the allowable stress. For the main VV material (316 LN-IG) the allowable reduction (Sm) from the operating temperature to baking is only 16%. Thus the RCC-MR structural margins specified in VV SR are sufficient to cover it. Nevertheless, it has to be quantified by analyses.

Therefore, the new type III seismic load SMHV does not affect the RCC-MR structural margin [4]. Nevertheless, an update of VV Stress Report is planned to quantify the structural margin.

5.2. VDE description based on plasma physics

The understanding of VDE phenomena is not fully clear and their modeling is still somewhat primitive. Nevertheless, the design guidelines have been proposed in the LS based on phenomenological observations and the statistic database; see [1] Appendix I: Application of asymmetric loads onto structural models in asymmetric VDEs.

In the VV Load requirements [2], the directions of these two moments are assumed to be perpendicular and thus vector summation is performed. This was based on initial consideration that the most deeply wetted region receives largest halo current. Since then, however, new data for simultaneous measurement of poloidal halo and toroidal plasma currents has been provided by JET. These data clearly indicates that the $M_{\mathrm{tilt,TPF}}$ and $M_{\mathrm{tilt},\Delta\mathrm{Ip}}$, must be an algebraic sum [1]. This is the physics guideline:

$$M_{\mathrm{tilt,total}}(t) = M_{\mathrm{tilt},\Delta\mathrm{Ip}}(t) + M_{\mathrm{tilt,TPF}}(t) \quad (1)$$

The modification of the tilting moment has an impact on the vertical reaction force at the single VV supports during a VDE load. According to preliminary global tokamak dynamic analysis, the maximum vertical force on VV support reaches a maximum value at a rotation frequency of 0 Hz (2 Hz in VV LS) which is less than 1% lower than the specified value given in VV LS; this value will be justified later with updated global tokamak dynamic analysis, particularly taking into account the new pedestal ring design.

Thus, it is proposed while waiting forthcoming analysis to keep the reaction forces proposed in [2]. This modification does not affect the RCC-MR structural margin [4].

5.3. Extreme VDE type IV

5.3.1. Type IV slow fast current quench VDE (VDE/SF)

The revision of [1] specifies that some experiments show that there are discharges, which exhibit 'slow_fast' type current quench waveforms. In this VDE, the plasma current decays very slowly during the initial quench phase (quench rate similar to Type III slow). At some transition current, I_{trans}, the plasma current starts to decay very fast (similar quench rate of Type III fast). Large halo and large eddy currents could occur simultaneously, which leads to overlapping of large EM load due to halo and eddy currents. This type of VDE waveforms is categorized as 'slow_fast'.

Following the main specifications of VDEs specified in [1], the VDE IV Slow_fast has the same characteristics as the VDE III slow except the typical current quench duration, which is the same as MD III fast and affects principally the Vacuum Vessel Triangular Support (VV TrS).

Previous electromagnetic analyses on the VV TrS in disruption events have shown that the equivalent pressure from the Type IV VDE slow_fast (Maximum at +0.6 MPa) associated with the coolant pressure (1.1 MPa) is smaller than the baking pressure (2.4 MPa), which is less than the design pressure load (2.6 MPa) of TrS already verified for Category II in VV SR (in the specific case of the sector 4, during the thermal quench the pressure is +1.5 MPa: thus 1.5 + 1.1 = 2.6 MPa which is equal to the design pressure).

Thus, the new type IV VDE slow_fast does not affect the RCC-MR structural margin [4]. Nevertheless, an update of VV Stress Report is planned to quantify the structural margin, especially for TrS.

5.3.2. Type IV rotating asymmetric VDE

The revision of [1] specifies: "The rotation of the plasma halo current asymmetry in VDEs has been observed in present experiments, but a full characterization of this phenomenon has not been completed as experimental observations are very limited. As a safety measure and for investment protection this condition shall,

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Table 2
Structural margins (all categories of events) with regards to RCC-MR [3] of the VV components; envelop results from [4] following the loads defined in [2].

RCC-MR structural margins of 2010 VV conceptual baseline design	P-type (f)	S-type: Progressive deformation (f)	S-type:Fatigue (V)
Inner shell	>1.9* (L)-A	>1.39*	≪0.1*
Outer shell	>1.9* (L)-A	>1.2*	≪0.1*
Lower port Poloidal gussets	1.21(NLB)-D	–	0.08
Lower port Toroidal gussets	>2.05* (L)-C	–	–
Inter modular Keys	1.32 (L)-A	1.25	0.17
Stub keys	1.35 (L)-C	1.27	<0.1**
Triangular Support	1.9 (L)-A	1.43	<0.1**
In vessel coils Supports	1.25 -A	1.2	0.077
VV hook	1.13*** -A	–	–

* Conservative value obtained in a VV zone which is not a part of first confinement barrier.
** Extrapolated value obtained by analogy with other components results.
*** Conservative value which does not take into account the classification of the primary stresses. Some recent investigations have given a margin factor of 1.60.
(f) structural margin factor.
(V) fatigue usage ratio.
-A,- C & -D are the RCC-MR levels of loads (respectively Cat. -I/II, -III & -IV ITER events).
(L) results obtained by limit analysis.
(NLB) results obtained by non-linear buckling analysis.

anyway, be taken into account with the most pessimistic assumptions. This event is classified in category IV. During operation ITER will operate following a progressive approach to high machine and plasma performance in order to verify that the specified design conditions are not exceeded. For the VV and magnet the total asymmetric forces and moments including the time functions evolution and the values in the cases of the rotating kink modes."

The asymmetric loads on the ITER Vacuum Vessel due to sink and source model mentioned in [1] are similar to those specified in the VV load requirements [2].

Thus, it is proposed in the forthcoming analysis to keep the Cat. IV reaction forces specified in [2]. This present data is calculated considering severe fault modes of the VV gravity Support (complete failure of one support) during a Type III VDE. Based on this consideration, the Type IV rotating asymmetric VDE does not affect the RCC-MR structural margin [4].

5.4. *Halo current in in vessel components*

The revision of [1] specifies: The maximum poloidal halo current density calculated at the first wall surface perpendicular to the magnetic poloidal field lines in slow VDE III and VDE II cases are 300 and 200 kA/m^2, respectively. This value has to be used for the analysis of small part of components. Increase of the local halo current by TPF can be introduced by the increase of the wetted area by the halo plasma due to the increase of halo width. The design values of the intercepted poloidal halo current (envelop of many possible VDE cases) are available in [1].

The VV Load requirements [2] give the maximum halo current in single blanket module for slow VDE III, which is consistent with the data proposed in [1] except for the Blanket Module #01. In this case the current is reduced by −24.5%.

Table 3
Impact overview of the revision of [1].

Loads from LS [1]	Category	Impact on the VV LS [2]
Seismic loads	II, III & IV	To be updated with: – SMHV; see Section 5.1 – 5 times SL-1 during ITER life
Electromagnetic loads	I, II, III & IV	To be updated with: – VDE description; see Section 5.2 – Extreme VDEIV; see Section 5.3 – Halo current on IVC; see Section 5.4
Nuclear heating loads	I & II	No (already inserted)
VV ingress of coolant events, VV ICE	II, III & IV	No (already inserted)
Cryostat ingress of coolant events, Cr ICE	II, III & IV	No (already inserted)
Loss of vacuum inside the VV, VV LOVA	III	To be added for information only due to a negligible effect on VV or smaller than other events; see Section 5.9
Loss of vacuum inside the cryostat, Cr LOVA	III	To be added for information only due to a negligible effect on VV or smaller than other events; see Section 5.10
Loss of coolant accident outside the cryostat, LOCA	III & IV	To be updated; see Section 5.5
Loss of forced flow accidents in VV and in-vessel components, LOFA	III	To be added; see Section 5.11
Internal explosion	IV	To be added for information only due to a negligible effect on VV or smaller than other events; see Section 5.8
Helium ingress in galleries	III & IV	To be added; see Section 5.6
Internal fire	IV	To be added for information only due to a negligible effect on VV or smaller than other events; see Section 5.12
Internal flooding	IV	To be added for information only due to a negligible effect on VV or smaller than other events; see Section 5.13
Load drop	IV	Blanket Module Drop will be added; see Section 5.7
(Damaged) Equipment	IV	No (already inserted)
System fault conditions	IV	No (already inserted)
External loads acting on the nuclear buildings	IV	No
New load combination	I, II, III & IV	New load combinations will be added

Table 4
Defined types of ex-cryostat LOCA events.

Ex-vessel LOCA	Cat.	Type of break	Max. pressure
LOCA in galleries	III	VV cooling pipe break (baking)	Galleries: 106 kPa Vault: 102 kPa
In port cell – LOCA_PC	III	Blanket cooling pipe (plasma operation)	Port cell: 120 kPa VV chamber: 94.3 kPa Port duct: 120 kPa Vault: 100 kPa
		Blanket cooling pipe, (baking)	Port cell: 160 kPa VV chamber: 0 kPa Port duct: 150 kPa Vault: 102 kPa
In NB cell – LOCA_NB	III	Bounding case (in terms of safety) for this event is a cooling pipe break in a port cell	
In vault – LOCA_Vault	IV	In-vessel divertor cooling pipe	VV chamber: 151 kPa Vault: 120 kPa
		Divertor cooling pipe break	Vault: 191 kPa

Thus, it is proposed to update the VV load requirements [2] with the revised maximum intercepted halo current in Module #01. This modification does not affect the RCC-MR structural margin [4].

5.5. Loss of Coolant Accident (LOCA) outside the Cryostat

Four different types of LOCAs outside the cryostat are considered in the revision of [1] depending on the location of leak:

- Ex-vessel LOCA in galleries (VV coolant)
- Ex-vessel LOCA in port cell (blanket coolant)
- Ex-vessel LOCA in NB cell
- Ex-vessel LOCA in vault (divertor coolant)

Table 4 reports a summary of main characteristics of the loss of coolant accident outside Cryostat.

Thus, it is proposed to update the VV Load requirements with the loss of coolant accident outside Cryostat. The LOCA is assumed to not affect the RCC-MR structural margin [4]. Nevertheless, peculiar attention will be paid to the Port Connecting Ducts for LOCA_PC III.

5.6. Helium ingress in galleries

This event is a spillage of cryogenic coolant from the magnet cryogenic cooling loop inside the cryostat space room, which is assumed to be connected to the gallery. This event may occur during plasma operation, between pulses or during a shut-down period with vacuum in the cryostat being maintained.

Table 5 reports a summary of main characteristics of the Helium (He) ingress in galleries load.

Thus, it is proposed to update the VV Load requirements with Helium ingress in galleries. This additional load does not affect the RCC-MR structural margin [4]. Nevertheless, an update is planned to quantify the structural margin when data becomes available, e.g. gradient temperature in VV.

5.7. Load drop

The revision of [1] specifies: “Appropriate measures will be taken in the design of the components in the tokamak building, the assembly and remote handling tools to ensure that components will be protected from load drop.”

This event is not yet considered in the VV Load requirements [2]. It is assumed that the worst load drop impacting the VV will be a blanket module drop. This will be included in the next update of the VV LS.

It is assumed that the load drop does not reduce the category IV VV structural margins [2]. Nevertheless, an analysis is planned to quantify the structural margin.

5.8. Internal explosion

The revision of [1] specifies: “An internal explosion affecting tokamak and first confinement barrier components is defined as beyond design.

In case of air ingress inside the VV, deflagration or detonation of the hydrogen/air mixture is not studied, as it is proposed that the ITER design will contain provision for prevention of such an explosion, for example by injection of an inert gas into the vessel.”

The IO Safety group is studying an additional line of defense based on explosions at low pressure.

Thus the internal explosion is considered as beyond basis and does not affect the structural margin.

5.9. Loss of Vacuum Inside the Vacuum Vessel (VV LOVA)

The large number of penetrations inside the VV has motivated the investigation of a loss of vacuum with air ingress through a confinement bypass as a possible accident. The generic bypass assumes an opening of 0.02 m^2, representative of the sizes of ICRF, ECRF, fuelling lines, in vessel viewer, and some diagnostics.

In this event the air ingress through one horizontal VV/cryostat penetration line causes pressurization in the VV. The calculated pressure in the VV never exceeds atmospheric pressure, which is lower than the plasma chamber pressure (1.5 bars) during VV ingress of coolant event (VV ICE) at the same category III.

Thus, the loss of vacuum inside the Vacuum Vessel is considered as insignificant load.

5.10. Loss of Vacuum Inside the Cryostat (Cr LOVA)

Cryostat leaks are investigated as accidents. A maximum leakage is postulated to be 0.2 m^2 that is estimated on the basis of a bellow failure.

Table 5
Helium ingress in galleries.

	Cat.	Ingress of	Event parameters	Max. pressure in galleries
Helium ingress in galleries	III	He	He spilled: 2.6 tons	118 kPa

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A postulated cryostat air ingress event was analyzed in order to evaluate the depressurization of the cryostat and gallery, temperature inside both volumes, and the magnet temperature, as well as the weight of the air-ice condensed on the coil surfaces. Pressure in the cryostat and in the gallery never exceeds the 110 kPa absolute pressure, which is lower than the pressure in Cryostat (140 kPa) during Cryostat ingress of coolant event (Cr ICE) at the same category III.

Thus, the loss of vacuum inside the Cryostat is considered as insignificant load. Nevertheless, an update of the VV load requirements is planned to quantify the structural margin when data becomes available, e.g. gradient temperature in VV.

5.11. Loss of Forced Flow Accidents (LOFA) in VV and In-Vessel components

As described in the revision of [1] there is no loss of forced flow accident considered for the design of the VV as this event is classified in category V. A category III event is considered for the loss of forced flow in the blanket and divertor cooling circuits. As the amount of residual heat to be removed is limited, no large temperature excursion is expected in these events.

Thus, it is proposed to update the VV Load requirements [2] with the loss of forced flow accidents in VV and to specify the amount residual heat when it will be available. In the meantime, it is assumed that LOFA does not significantly affect the RCC-MR structural margin [4].

5.12. Internal fire

The severity of the event of an internal fire will be specified individually for each room following an adequate assessment of the materials present in each room. The severity of a fire event is defined by the expected maximum temperature and the duration of the event. Simultaneous fires in more than one room do not need to be considered. Since it is specified that no fire event will occur inside the bioshield, only the following first confinement barrier systems are affected:

- VVPSS tank, relief line, oblong pipe, rupture discs and safety valves on “bleed bypass lines”
- NB injector and bellows to VV duct
- TCWS pipes
- Regeneration/roughing lines
- Pellet injector
- EC launcher – equatorial/upper port plug

Thus, an internal fire is considered a load with a negligible effect on the VV or smaller than the other events, pending confirmation from the above systems.

5.13. Internal flooding

The revision of ITER Project-level loads [1] specifies: “Internal flooding does not affect the design of the components inside the tokamak complex.”

Thus internal flooding is considered an insignificant load.

6. Conclusion

An overview of the impact of the loads defined in the 2012 revised ITER Project-Level Load requirements [1] on the VV loads specifications [2] and structural margins [4] has been presented in this paper.

In summary, three load conditions have been updated (seismic load with category III seismic load SMHV, electromagnetic load with one of category IV vertical displacement event and loss of coolant accident outside the cryostat LOCA) and new loads/load combinations have been considered such as loss of vacuum inside the VV (VV LOVA), loss of vacuum inside the Cryostat (Cr LOVA), loss of forced flow accidents in VV and in-vessel components (LOFA), internal explosion, helium ingress in galleries, internal fire, internal flooding and load drop.

The preliminary assessment of the impact of these events has been performed on the structural margins calculated to guarantee the Vacuum Vessel's structural integrity with regards to the RCC-MR code [1]. The main Vessel and also several critical components such as Triangular Support, Blanket Module Attachment Keys, Gravity Supports and Ports have been considered and no relevant impacts have been found on the RCC-MR structural margins [4].

ITER disclaimer

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