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Design Report

Stress Test Detailed Methodology for Hard Core Components of ITER Plant

This document aims to define a comprehensive methodology to perform the stress test assessment for the ITER Hard Core Components.This document provides detailed technical guidelines and acceptable methods to perform the stress test assessment for the following SSCs:Civil (Concrete and Steel Structures including buildings) Mechanical (Piping and Pressure Components and associated supports: Component supports of piping, vessels, heat exchangers, pumps and valves)Electrical and HVAC Distribution... (Please see complete abstract on document metadata.)

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1 Purpose

This document aims to define a comprehensive methodology to perform the stress test assessment for the ITER Hard Core Components.

2 Scope

This document provides detailed technical guideline and acceptable methods to perform the stress test assessment for the following SSCs:

1. Civil (Concrete and Steel Structures including Buildings)
2. Mechanical (Piping and Pressure Components and associated supports: Component supports of piping, vessels, heat exchangers, pumps and valves)
3. Electrical and HVAC Distribution Systems.
4. Electrical and control cabinets, electrical components supports, cable trays and conduit supports, HVAC ducting supports and supports for fans, motors, engine-generators

This document doesn’t address the following external aggression such as, flooding, snow, ice, tornado, extreme wind, lightning and extreme temperature. This document only addresses the 2 hard core situations and the aggressions induced that really lead to cliff edge effect.

3 Definitions

SSC: System Structures and Components

HCC: Hard Core Component

ECS : Evaluation complémentaire de la sureté d’ITER

SMS: Séisme Majoré de Sûreté

Paleo: Paleosism (seismic ground spectra from the geological study of the Cadarache site).

ICPE: Installations Classées pour la Protection de l’Environnement

SL-3 or SND: Seisme Noyau Dur

ASBs: Anti-Seismic Bearings

FRS: Floor Response Spectra

PBS: Plant Breakdown Structure

CWS: Cooling Water System

TCWS: Tokamak Cooling Water System

CCWS: Component Cooling Water System

CHWS: Chilled water system

FEM: Finite Element Model

PIC: Protection Important Component

SR: Safety Related

NSC: Non Seismic Classified

BDBA: Beyond Design Basis Accident

For a complete list of ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations

4 Background

Considering the accident at the Fukushima nuclear power plant in Japan, the Council of the European Union declared that "the safety of all EU nuclear plants should be reviewed, on the basis of a comprehensive and transparent risk assessment ("stress tests").
The technical specifications for the stress test report prepared by WENRA (Western European Nuclear Regulators' Association) answers to the national requirements providing some extensions.
The "stress test" is a targeted reassessment of the safety margins of nuclear facilities: extreme natural events challenging the facility safety functions and leading to severe accident.
In France, the regulator (ASN – Autorité de Sûreté Nucléaire) has issued the decision asking IO to proceed with a complementary assessment of the safety of the facility taking into consideration the accident which occurred in Fukushima Daiichi nuclear power plant.
The reassessment consists of:

- an evaluation of the resistance of the nuclear facility when facing a set of extreme situations,
- a verification of the preventive and mitigation measures chosen following a defence-in-depth logic (noting any potential weak point and cliff-edge effect): initiating events, consequential loss of safety functions, severe accident management

In these extreme situations, sequential loss of the lines of defence is assumed, in a deterministic approach, irrespective of the probability of this loss.

The Nuclear operator, ITER Organization, was notified by ASN though an ASN decision in May 2011 to propose by 15th of January 2012 the safety strategy and methodology for first nuclear facility for fusion energy (in particular, the methodology for identification and analysis of the situations with cliff edge effect) and by 15th of October 2012 the exhaustive list of the situations with cliff edge effects and proposal of hard core components needed to reach and maintain the safe state. The *Evaluation Complémentaire de la Sureté d'ITER [R1]* document included the assessment of 12 accident scenarios and for each scenario the "essential components" required to limit the consequences of the specific scenario was generically described.

ITER stress test files were assessed by the regulator in July 2013.

In June 2014, with the letter CODEP-DRC-2014-02405 [R2], ASN declared that the overall approach was satisfactory, subject to the replay by IO to a set of 12 additional requests, spelled out in the Appendix 1 of the letter, and identified with the identifiers D-174-ND-xx (where D stands for "demand", ND for "*noyau dur*" (hard core), and xx is a progressive number from 1 to 12, excluding 11). The deadline for the reply to all questions is the 30 June 2015.

5 Hard Core Component (*Noyau dur*)

The hard core component is defined for each undesirable situation with cliff-edge effects. Such equipment is designed to prevent these situations, as well as to return to and maintain a safe state in the event such a situation occurs. All equipment crucial to emergency planning (rooms, management means, communication, instrumentation, etc.) is also considered as essential equipment. When the analysis highlights the need, auxiliary means for emergency management can be defined and classified as “essential equipment”.

According to ECS report (Evaluation Complémentaire de la Sureté), Hard Core Components (HCCs) are defined as those SSCs important for the safety of the plant (refined subset of the licensing basis SSCs) which are needed in extreme scenarios to prevent cliff edge effects, defined as:

- Dose to population above 10 mSv
- Contamination of the ground water
- High radiation field which avoids long term human intervention on the site

An existing HCC is a SSC that has been specified in the safety analysis presented in the preliminary safety report that was submitted as part of the licensing process. Afterwards it has been clarified that the comparison to determine if a Hard Core component is ‘new’ or ‘existing’ has to be done with respect to ECS. In other words, the existing HCC are those included in the ITER baseline when the ECS was submitted to the ASN. Any other SSCs have to be considered as new SSCs.

The detailed list of HCC is defined in the document ITER HARD CORE COMPONENTS – SUMMARY REPORT (PQR228) [R51].

6 General Approach

The general principles are discussed in this section and the detailed analyses are presented in section 8.

6.1 Stress Test Scenarios

6.1.1 Hard Core Situations

According to ECS report (Evaluation Complémentaire de la Sureté) ref. [R1], twelve (12) scenarios or *Hard Core situations* have been considered potentially dangerous to lead to cliff edge effects.

Further evaluation clarified that out of the 12 scenarios only 2 hard core situations can really lead to cliff edge effects unless HCCs are implemented to limit the consequences as follows:

- **Extreme earthquake (SL-3) in Tokamak Building (Scenario 11)**
- **Multiples fire in Tritium Building (Scenario 12) initiated by SL3**

6.1.2 Aggression Induced

In case of extreme earthquake (SL-3) the failure of the Cryogenic Tanks situated in the cryogenic fluid storage area (area 53) has been postulated, this risk can be the cause of an accidental situation with the cliff edge effect. From technical standpoint, the fact that SL-3 is considered for the mode 0 of the Tokamak machine makes some scenario of explosion very pessimistic or not very realistic (for example, the Quench tanks which have a major contribution to the blast load are not full in such a scenario – mode 0). It is important to remind that in the earthquake field investigation which is an important base of the seismic design standards, few example of tank burst is mentioned.

Hence, the HCCs have to be protected also from the "aggression induced" as the explosion in area 53. The solution that addresses the explosion of the storage tanks in area 53 is reported in the document "Strategy of the Stress Test Assessment on the Explosion in Area 53" (R3HWS5) [R59].

Another risk of explosion is related to the Area 31 (SF_6 storage system). The area 31 can be considered an aggressor of HCCs only in case that the location of the UEPS (Ultimate Emergency Power Supply) will be placed in the area of influence of the explosion. The current strategy is to locate the UEPS out of the area of influence of the explosion.

Finally, according to the document in reference [R33], Non-tritium gases will be admitted into the Tritium Plant process from a gases compound located outside the tritium plant building. The gases compound will include pressurized gas cylinders of flammable gases such as hydrogen. Thus, there is the potential for explosion which could have the potential to damage the Tritium Plant Building exterior wall which is a hard core component. Thus, the gases compound will be designed to prevent explosion under hard core conditions, and, if needed, mitigation measures such as a blast wall will be included.

6.2 Basis for the Methodology

The GP (Group Permanent) recommended to the Operator (IO) to consider the extreme situations as normal situations in sizing the new equipment of the Hard Core and taking into account appropriate criteria for the functional requirements of such equipment.

For the design verification of the new and existing Hard Core structures and components, the GP recommends to the Operator to select a conventional deterministic approach, including, on a case by case basis, the equipment qualification.

For what concerns the calculation methods and the criteria selected for the equipment of the Hard Core, distinguishing the new equipment from the existing ones, it is allowed to use:

- For the new equipment of Hard Core: different methods as follows: testing on shaking table, but also methods coming from IAEA documents [R56][R57][R58] or methods based on engineering evaluation, being allowable limit the criteria those of RCC-M or equivalent for the mechanical equipment, depending of the nature of the equipment and the functional requirements.

- For the existing equipment of the Hard Core: the reduction factors to take into account the ductility or the over strength of the equipment, being the allowable limit criteria a priori those of RCC-M or equivalent code, depending of the nature of the equipment and the functional requirements. This is also applicable for the aggressors of HCC.

The active components that belong to Hard Core and shall preserve their operability after the earthquake must be qualified by shaking table testing, taking into account the extreme earthquake forcing function. Active components that rely on electrical power to perform their "active" safety function will need a qualified power source or will need to be shown to fail in the desired position (i.e, fail closed) and maintain the desired position during the SL-3 earthquake. This concerns both existing and new equipment of the Hard Core.

Regarding the new equipment of the Hard Core, the design shall be defined in relation to the functional requirements. Thus, the new equipment of the Hard Core shall be operational in extreme situations selected in the ECS. They must be sized with the rules and criteria applicable to the Normal Situations. In fact, an extreme situation within the meaning of the ECS should be considered as a Normal Situation for the equipment of the Hard Core, they must remain operational under these conditions.

In other words, the use of Levels C or D criteria of RCC-M or equivalent for the new equipment of the Hard Core is not acceptable for the extreme situations selected in ECS. For the new equipment of the Hard Core, only Levels A/B criteria shall be maintained.

Regarding the existent equipment of the Hard Core, given an initial design realized for levels of "*Alea sismique*" less high, it is acceptable to implement the possibility of a graded approach, in which can be applied criteria corresponding to exceptional situations. These situations are those in which the components, in very infrequent circumstances, can be found. Less severe criteria are acceptable, as the RCC-M proposes. For the existent equipment, this approach remains consistent with the recommendations of RFS IV.2-a (Regle Fondamentale de Surete), where the application of Level C criteria is a general rule, demonstrating the integrity of the components for the exceptional situations and the functional capacity (deformations limits) of the static mechanical components.

The SQUG (Seismic Qualification Utility Group) method cannot be applied to demonstrate the operability (preservation of certain active functions) of the active components.

The use of a Levels C and D criterion for the tightness/confinement verification of an existent equipment of Hard Core is recommended.

The main difference in the acceptance criteria between new and existing HCC, is that for the new it is mandatory to use A/B service levels whilst for the existing HCC it is allowed to use C/D service levels.

The analysis methods to be used for the evaluation of the seismic margin in the Stress Test assessment have to strictly follow the indication of the ASN included in the ASN Guideline 2/01 ref. [R14] for civil structures.

The approaches generally used within the scope of design, rely on spectral methods and linear transient methods, for which the results may possibly be used to perform pseudo-static calculations.

Methods of analysis based on linear models are considered as reference methods in determining loads. These methods are particularly suitable to show that the requirements are met, such as requirements in terms of leak tightness, sub-critical geometry, and load-bearing capacity.
Nevertheless, methods of analysis aiming at representing an incursion into the post-elastic domain are deemed acceptable to meet integrity and stability requirements. Simplified non-linear static method can be used to verify stability requirements or absence of detrimental interaction. Transient methods applicable to non-linear models are also acceptable.

Finally, the realistic approach, considering an elastic behaviour with consideration of a reduction factor, is allowed but it should be reviewed prior to implementation and in any case can only be used when the verification of the design with Level C and D criteria cannot be achieved.

6.3 General Principles

6.3.1 Conventional and Realistic Approaches

The uses of different approaches are foreseen in the stress test methodology for the seismic qualification by analysis of:

- **New HCCs;**
- **Existing HCCs;**
- **Aggressors of HCCs;**
- **Initiators (or aggravators) components:** those components that can aggravate the accidental conditions if no prevention and/or mitigation provision are put in place.

A conventional approach can be used for the verification of New and Existing HCCs as well as for Aggressors and Initiator (or Aggravators) components. This approach follows the design basis methodology for what concern applicable standards, allowable stress and damping factor for seismic analyses. Only linear analysis has to be performed.

A realistic approach can be used for the verification of Existing HCCs, Aggressors and Initiators (or Aggravators) components, only when the verification under stress test load combinations cannot be achieved with conventional approach. The selected realistic approach shall be based on nuclear practises and recognized international Codes and Standards.

Such approach envisages the use of:

- Reduction factors to reduce the seismic demand for elastic analysis;
- Higher damping factor than those used in the design basis methodology for seismic analysis;
- Refined analysis (such as non-liner analysis).

In conclusion,

1. The reduction factor will not be used to meet the **Operability** requirement (Service Levels A and or B), where it will be taken equal to one. Furthermore, when performing these specific analyses for the Stress Test, the damping factors to be used will be the same as those utilized in the design basis and only elastic analyses will be allowed. As a result, this approach is equal to the conventional approach.
2. To meet the **Functional Capacity, Integrity and Stability** requirements (Service Levels C and/or D), a Realistic Approach will be used, with the use of reduction factor and higher damping factor (with respect the design basis USNRC RG1.61) according with EPRI [R7], ASCE [R6], IAEA Safety Report No.28 [R56] and others recognized codes and standards. Linear and non-linear analyses are allowed. **The Realistic Approach will be used only when the verification of the existent HCC components under Stress Test Load Combinations cannot be achieved with conventional approach**.

6.3.2 Requirements and Acceptance Criteria

The following requirements, according to the definitions reported in RCC-MRx (2012), have to be specified for each HCC.

- **Operability**: This requirement applies to non-static components. It ensures the proper operation of mechanisms or moving parts whose movement is required to accomplish the safety function of these components. Generally, this requirement is extended to all non-static electrical and mechanical components whose ability to maintain their safety function is required during and/or after the earthquake.

- **Functional Capacity**: This requirement applies to static mechanical components carrying fluids. For these components, it aims to ensure that deformations are limited to a minimum so that there is little reduction in fluid flow that would prevent accomplishing the safety function involved.

- **Integrity:** Structural integrity applies to checking geometric characteristics and in particular checking leak tightness of the shell (which may be pressurized) of static mechanical components. It aims to guarantee the confinement of the fluid carried by these components.

- **Stability**: This requirement consists of making sure that the components does not partially or totally collapse and does keep its place (for example avoiding falling, sliding, detachment of parts, etc.). The stability of a component requires the stability of its supports and anchor bolts.

The following acceptance criteria have to be verified for the New and Existing HCCs, Aggressors and Initiators (or Aggravators).

Table 6.1: Acceptance Criteria for New and Existing HCCs, Initiator and Aggressors Components

Components	Requirements	Acceptance Criteria (2)
New HCC	Operability	A/B
Existing HCC	Operability(1)	A/B
	Functional Capacity	C
	Integrity	C/D
	Stability	D
Aggressors of HCC	Stability	D
Initiators (or aggravators)	Stability	D
Notes: **(1) Applicable only for the parts of HCCs that must remain operable after the earthquake.** **(2) According to ASME Section III, RCC-M or equivalent**		

For active parts of HCCs that shall maintain the operability after the SL-3 earthquake, the shaking table is required for seismic qualification (i.e. valves actuators).

When shaking table is used for seismic qualification of active components (as required by the Authority), the requirements of the applicable codes and standards used for the qualification have to be strictly followed, depending on the type of item being qualified.

Some Codes & Standards (i.e. ASME VIII Div.2, ASME B31.3, EN13445, EN 13458 etc.) which have been selected for ITER mechanical components do not define structural service criteria for Level C or D. In general they define allowable values for normal, test and exceptional events. In this case the association of the of load category with the criteria/service levels shall be defined on a case by case basis, as reported in the references [R49] and [R19] for each single system or sub-system.

6.3.3 Stress Test Load Combinations

Load combinations to be used for the Hard Core situations do not consider seismic actions and accidental actions caused by the earthquake as concomitant. The seismic earthquake (SL-3) loading are only combined with Normal Operating loads (as defined in table 6.2) which would be expected to occur concurrently with the extreme earthquake and use load factors of unity for all loadings. Fundamentally, normal operating loads plus the extreme earthquake are combined.

The "Post SL-3" environmental conditions are not known to date, then the environmental conditions (in terms of temperature, pressure, humidity etc.) will be the same used in the baseline for the SL-2 seismic event, when verifying HCC for Operability, Integrity such as tightness/confinement and Functional Capacity."

Finally, according with ASN guideline, EPRI NP-6041 and IAEA documents, the following Load Combinations have been defined for the selected scenarios.

Table 6.2: Stress Test Load Combinations

Hard Core Situations	Load combinations
Scenario 11: **Extreme Earthquake in Tokamak Building**	SL-3 is combined with normal operating conditions for actuation of HCCs (e.g. isolation valves, fire dampers, relief panels in PC, NBI Cell Vault, drain tanks room etc.) and functional capacity, integrity, stability of passive HCCs. The Normal Operating Loads refers to operational mode 0.
Scenario 12: **Multiples Fire in Tritium Building**	The load combination for the Stress Test will be SL-3 + Int Fire, combined with normal operation conditions. The seismic and fire loads are not considered concomitant, even if correlated. The scenario is SL-3 followed by fire. The Normal Operating Loads refers to operational modes 0, 1 and 2.

The detailed load combinations that address the explosion in area 53 will be defined in the document "Strategy of the Stress Test Assessment on the Explosion in Area 53" (R3HWS5) [R59]. Currently the SL-3 and the over pressure due to the explosion are not considered concomitant even if correlated, so the scenario is SL-3 followed by the explosion.

6.3.4 Damping and Reduction Factors

The realistic approach in the stress test methodology for the seismic qualification by analysis of the existing HCCs, aggressors and initiators (or aggravators), envisages the use of specific damping factors and reduction factors (F).

Responses to earthquake levels beyond the design level are expected to result in levels of damping significantly greater than those used in the design. At this aim specific damping values to be used for seismic analysis have to be identified for an extreme earthquake corresponding to level SL-3.

Damping and reduction factors for Civil Structures have been identified according with European/France Code as reported in detail in Chapter 8.2.4.

Damping and reduction factors for mechanical equipment and distribution system have been identified according to ASCE/SEI and EPRI standards ref [R6] and [R7], as reported in the following paragraphs.

6.3.4.1 Damping Factors for Mechanical Equipment and Distribution Systems

The use of damping factors are envisaged in linear elastic analysis for determining seismic design loads for mechanical equipment and distribution systems. The realistic approach in the stress test methodology envisages the use of damping values higher than those proposed by the design basis methodology as summarized in the table below for the service levels C and D.

Table 6.3: Damping Factors Mechanical Equipment and Distribution Systems. Value based on ASCE/SEI and EPRI Standards

Mechanical Equipment and Distribution Systems	**Damping (% of Critical)**
	Service Level C and D
Equipment	
Welded or pre-stressed bolted Steel Structures (or supports)	5.0
Bolted (non-pre-stressed) Steel Structures (or supports)	7.0
Welded Steel Tanks	
- Impulsive Mode	3.0 to 5.0
- Convective (Sloshing) Mode	0.5
Pumps, Fans, Motors, Compressor	3.0
Pressure Vessel, Valves	5.0
Dampers	5.0
Filters	5.0
Electrical boards, cabinets, panels, Motor Control Centres	5.0
Lightly loaded Welded Instrumentation Racks	3.0
Distribution Systems	
Piping System	5.0
Conduit	7
Instrument tubing	7
Cable tray	15.0
HVAC Duct	7.0

For the HCCs that have to meet service levels A/B, damping values of SL-1 apply.

6.3.4.2 Reduction Factors for Mechanical Equipment and Distribution Systems

In using the table below to determine seismic design loads in linear elastic analysis for mechanical equipment and distribution systems, it has to be considered as follows:

- Mechanical equipment are supposed to be always static components or active components with no operability requirements after the earthquake.
- All active components with operability requirements after the earthquake have to be qualified considering reduction factor F=1.
- If the component contains brittle failure in the load path or brittle material is used that could affect its specified safety function, then F, values shall be taken F=1.

Table 6.4: Reduction Factors Mechanical Equipment and Distribution Systems. Values based on Table 8.1 in ASCE/SEI

Mechanical Equipment and Distribution Systems	**Reduction Factor F (1)**	
	Service Level C F_C	**Service Level D F_D**
Equipment		
Welded or pre-stressed bolted Steel Structures (or supports) (2)	1.5	2.0
Bolted (non-pre-stressed) Steel Structures (or supports) (2)	1.5	2.0
Welded Steel Tanks (Vertical)	1.25	1.25
Welded Steel Tanks (Horizontal)	1.25	1.5
Pumps, Fans, Motors, Compressor	1.25	1.5
Pressure Vessel, Valves	1.25	1.5
Dampers	1.25	1.5
Filters(2)	1.5	2.0
Electrical boards, cabinets, panels, Motor Control Centres(2)	1.5	2.0
Lightly loaded Welded Instrumentation Racks(2)	1.5	2.0
Distribution Systems		
Piping System		
- Butt joined groove welded pipe	1.5	1.75
- Socked welded pipe	1.25	1.5
Conduit	1.35	1.5
Instrument tubing	1.35	1.5
Cable tray	1.35	1.5
HVAC Duct	1.25	1.5

Mechanical Equipment and Distribution Systems	Reduction Factor F (1)	
	Service Level C F_C	Service Level D F_D

Notes:

(1) For mechanical equipment and distribution systems located inside the Tokamak complex (generally in buildings equipped with seismic isolator systems) the value has to be limited to 1.5, according to EN 1998-1 Eurocode 8.

(2) These components are normally designed to AISC allowable, which are typically limited to 0.8 to 1.0 Sy: hence, they are allowed a somewhat higher inelastic energy absorption factor as compared to ASME B&PVC allowable, where allowable stresses can be as high as 2.0 Sy.

7 Definition and Application of the Seismic Input

This chapter summarizes the seismic motion and some input data (damping and reduction factors) to be used for the analysis of the ITER Hard Core Components and technical information common to all the components:

- Definition of the seismic motion to be considered on the ground and in the building structures,
- Values of damping to be considered for the analysis taking into account the fact the structures are considered as existing,
- Reduction factor in order to take benefit of the margin associated to the ductility and the over-strength of the components

7.1 Definition of the SL-3 Ground Response Spectra

The SL-3 has to be the envelope of the two following spectra:

- The SMS spectra increased by a factor of 50%,
- The spectra corresponding to 20,000 years return period.

The 20,000 years return period spectra is not known and no comparison with the Paleo earthquake used to define SL-2 can be done.

It is important to remind that ITER Facility is in Cadarache site for which CEA has also to define a beyond design spectra (SND – Seisme Noyau Dur).

For the stress test analysis, as recommended by ITER IO management and safety (SQS) and in line with the current approach adopted by CEA, it is proposed to consider as a reference the spectrum envelope of the Paleo spectra (original spectra not increased by any factor) and the SMS spectra increased by 50% (Paleo +1.5xSMS Reference spectra).

Unless the FRS inside the Tokamak Complex are made available for the SL-3, at this stage of the stress test analysis, the floor response spectra for the Hard Core Components inside the Tokamak Complex will be assessed with the floor response spectra determined with SL2 increased by 50% (1.5xSL-2). The applicable SL-2 FRS will be used.

No additional measure is taken to cover uncertainties on the ground seismic motion and the outcomes from the discussion between the CEA and the regulator.

For information, the reference soil spectrum is given in Table 7.1 compared to the 1.5xSL2 soil spectrum.

	Accelerations (g)					
Damping	2%	5%	7%	10%	20%	30%
Frequency (Hz)						
0.1	0.0023	0.0023	0.0023	0.0023	0.0023	0.0023
0.25	0.0321	0.0260	0.0236	0.0211	0.0163	0.0141
0.4	0.0743	0.0619	0.0570	0.0515	0.0398	0.0330
1	0.2517	0.1971	0.1768	0.1558	0.1180	0.0976
1.42	0.3609	0.2939	0.2679	0.2382	0.1794	0.1493
2	0.5673	0.4482	0.4047	0.3572	0.2706	0.2235
2.82	0.8615	0.6761	0.6059	0.5316	0.3944	0.3236
3.98	1.1504	0.8816	0.7881	0.6885	0.5133	0.4193
5.62	1.4784	1.1060	0.9675	0.8406	0.6125	0.5040
7.94	1.4631	1.1082	0.9864	0.8589	0.6522	0.5487
11.22	1.2048	0.9455	0.8580	0.7742	0.6236	0.5480
15.84	0.9222	0.7469	0.6962	0.6464	0.5634	0.5177
22.38	0.6570	0.5880	0.5678	0.5466	0.5079	0.4860
31.62	0.4797	0.4772	0.4758	0.4742	0.4725	0.4725
34	0.4725	0.4725	0.4725	0.4725	0.4725	0.4725
100	0.4725	0.4725	0.4725	0.4725	0.4725	0.4725

a/ Paleo + 1.5xSMS Spectra (Reference spectra)

	Accelerations (g)					
Damping	2%	5%	7%	10%	20%	30%
Frequency (Hz)						
0.1	0.0035	0.0035	0.0035	0.0035	0.0035	0.0035
0.25	0.0482	0.0390	0.0354	0.0317	0.0245	0.0212
0.4	0.1115	0.0929	0.0855	0.0773	0.0597	0.0495
1	0.3776	0.2957	0.2652	0.2337	0.1770	0.1464
1.42	0.5183	0.4148	0.3753	0.3314	0.2448	0.2012
2	0.6947	0.5597	0.5003	0.4368	0.3246	0.2687
2.82	0.9389	0.7244	0.6519	0.5712	0.4221	0.3471
3.98	1.1504	0.8816	0.7881	0.6885	0.5133	0.4193
5.62	1.4784	1.1060	0.9675	0.8406	0.6125	0.5040
7.94	1.4631	1.1082	0.9864	0.8589	0.6522	0.5487
11.22	1.2048	0.9455	0.8580	0.7742	0.6236	0.5480
15.84	0.9222	0.7469	0.6962	0.6464	0.5634	0.5177
22.38	0.6570	0.5880	0.5678	0.5466	0.5079	0.4860
31.62	0.4797	0.4772	0.4758	0.4742	0.4725	0.4725
34	0.4725	0.4725	0.4725	0.4725	0.4725	0.4725
100	0.4725	0.4725	0.4725	0.4725	0.4725	0.4725

b/ 1.5xSL-2

Table 7.1: Spectral acceleration for the a) Paleo+1.5SMS and b) 1.5xSL2 spectra

7.2 Definition of the SL-3 Seismic Load for the Equipment in the Tokamak Complex

Unless FRS inside the Tokamak Complex are made available for the SL-3, the seismic loads to be considered for the Hard Core components in the Tokamak complex for SL-3 will be defined as the Floor Response Spectra for SL-2 increased by 50%.

The conservatism of such an approach will be checked looking at the following margins:

- Margin due to the effect of foundation embedment,
- Margin due to the spatial incoherency of the seismic motion,
- Margin due to the overestimation of the ground seismic motion in the low frequency range (complementary information received from CEA and to be confirmed by the outcomes of the discussion with the regulator).

7.2.1 Analysis with Advanced Soil-Structures Interaction (SSI)

In order to compute the Floor Response Spectra (FRSs), to take into account the effect of foundation embedment and to eventually perform non-linear analysis, a set of accelerograms will be used for the following spectra: signals for SMS increased by 50% and signals for Paleo earthquake (without increase by 50%) assuming they are representative of the 20,000 years return period spectrum.

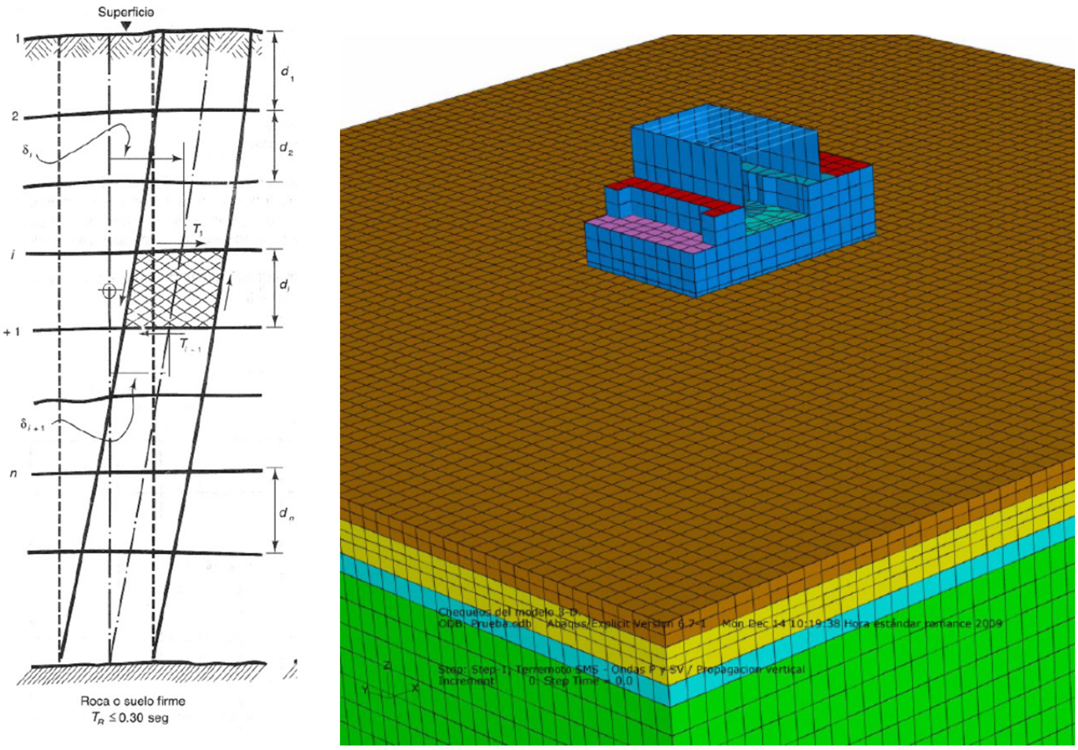
The effect of embedment will be taken into account with soil-structure interaction assuming that the incident waves are vertical. Deconvolution techniques and absorbing boundaries will be used with the values of wave velocities given in Table 7.2.

Table 7.2: Wave Velocities for ITER Site (best estimate values)

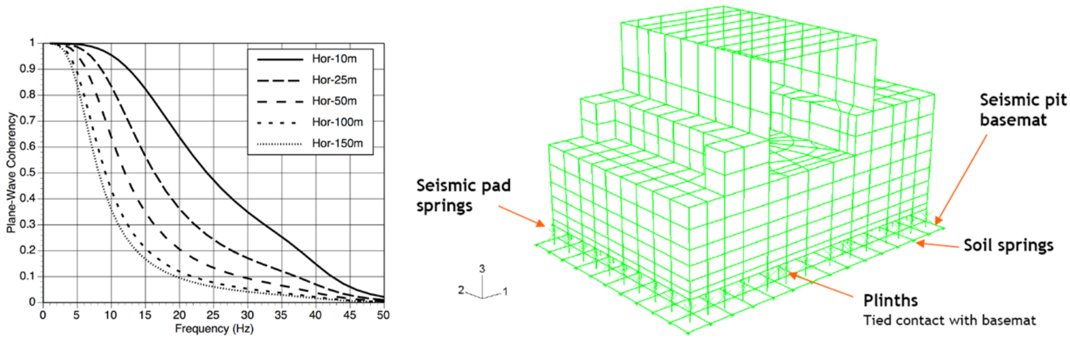
Depth (m)	Density (kg/m^3)	P wave velocity (m/s)	S wave velocity (m/s)
0 to 10	2500	2500	1200
10 to 25	2500	3500	1700
25 to 35	2500	4200	2000
> 35	2500	4600	2100

Depth is zero at 315 m NGF (platform level)

- **Figure 7.1: Model used in the Seismic Calculations with Advanced Soil-Structure Interactions**



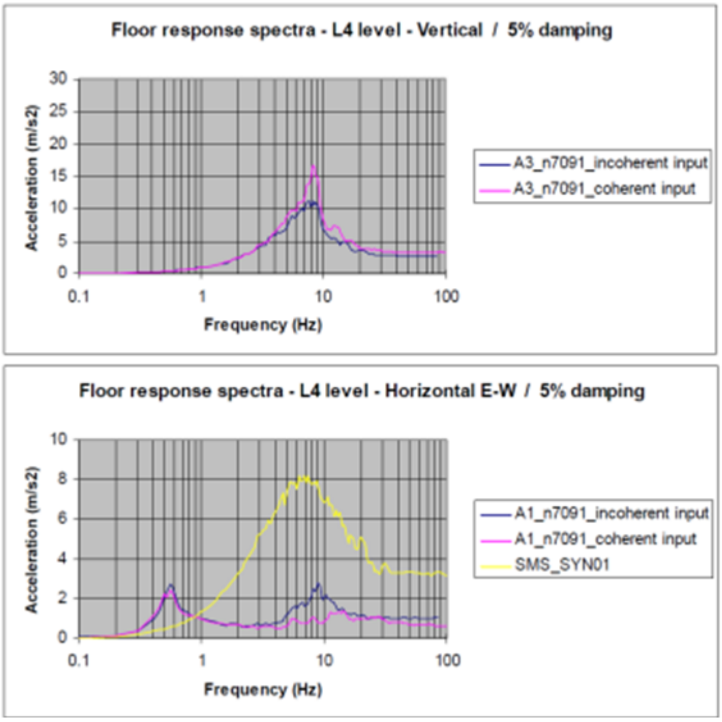
- a/ Effect of foundation embedment (signal deconvolution)



b/ Spatial incoherency of the seismic motion

The effect of the spatial incoherency of the seismic signal will be studied according the methodology of Reference [R3]. Results similar to [R4] are expected.

Figure 7.2: Example of Results from Reference [R4]



These calculations will provide an estimate of margins associated to the methods (in % of the seismic loads considered as the reference for the assessment).

For the heavy components such as the machine, the margins related to the interface loads will be assessed by taking into account the coupling between the equipment and the building structure.

7.2.2 Note about the Effect of Potential non-linearity on the FRSs

The risk of an uplift of the Tokamak building and an assessment of its consequences will have to be assessed. It has to be noted that, for some loading cases with SL-2, there are already uplift at the level of the 18 bearings of the Tokamak machine and linear models are considered to generate the FRSs in the Tokamak machine and close to the support.

For reinforced concrete structures which exhibit concrete cracking and yielding of the steel rebar, linear models are used for the generation of the FRSs. If non-linearity are included in the models (see SMART Benchmark), the main effect of the material non-linearity is to limit the accelerations (which do not increase linearly –but at a lower rate- with the ground motion) and to change the main natural frequencies (shift of the peaks toward the lowest frequencies). In the figure 7.2 it also shown the effect of material non-linearity on the seismic floor response spectra (SMART experiments)

7.3 Damping Ratio

The values given in this paragraph are only for information and guidance; the applicable values are given in paragraph 6.3.4. The values of damping from ASCE 04 [R5], ASCE 43-05 [R6] and EPRI [R7] standard, for existing components can be considered for seismic assessment (Response Level 3).

These values are higher than NRC Regulatory Guide 1.61 [R8], Damping Values for Seismic Design of Nuclear Power Plants which are used for design.

A summary of the values of damping proposed is given in Table 7.3.

As mentioned in EPRI report (page 2-48), the higher damping values in Reference[R4], i.e. 10% for concrete structure should only be used when fixed base linear elastic analyses are performed since these higher values are likely to incorporate some radiation of energy back into the foundation media (rock or soil) and some hysteretic energy dissipation from nonlinear behavior. For soil - structure - interaction analyses, the structure damping should generally be limited to the lower values in Reference [R4], i.e. 7% for concrete structures, to avoid double counting of the energy radiating back into the foundation media.

Table 7.3: Damping Values from ASCE-04

Table 3-1 Viscous Damping Expressed as a Fraction of Critical Damping

Structure Type	Response Level 1	Response Level 2	Response Level 3
Welded aluminum structures	0.02	0.04	0.04
Welded and friction-bolted steel structures	0.02	0.04	0.07
Bearing-bolted steel structures	0.04	0.07	0.10
Prestressed concrete structures (without complete loss of prestress)	0.02	0.05	0.07
Reinforced concrete structures	0.04	0.07	0.10
Reinforced masonry shear walls	0.04	0.07	0.10

Table 7.4: Damping Values from ASCE 43-05

Type of Component	Damping (% of Critical) Response Level 1	Response Level 2	Response Level 3
Welded and friction-bolted metal structures	2	4	7
Bearing-bolted metal structures	4	7	10
Prestressed concrete structures (without complete loss of prestress)	2	5	7
Reinforced concrete structures	4	7	10
Reinforced masonry shear walls	4	7	10
Piping	5	5	5
Distribution systems:			
• Cable trays 50% or more full and in-structure response spectrum Zero Period Acceleration of 0.25 g or greater	5	10	15
• For other cable trays, cable trays with rigid fireproofing and conduits	5	7	7
Massive, low-stressed mechanical components (pumps, compressors, fans, motors, etc.)	2	3	—*
Light welded instrument racks	2	3	—*
Electrical cabinets and other equipment	3	4	5**
Liquid containing metal tanks:			
• Impulsive mode	2	3	4
• Sloshing mode	0.5	0.5	0.5

Notes:
* Should not be stressed to Response Level 3. Use damping for Response Level 2.
** May be used for anchorage and structural failure modes that are accompanied by at least some inelastic response. Response Level 1 damping values shall be used for functional failure modes such as relay chatter or relative displacement issues that may occur at a low cabinet stress level.

Table 7.5: Damping Values from EPRI NP 6041 SLR1

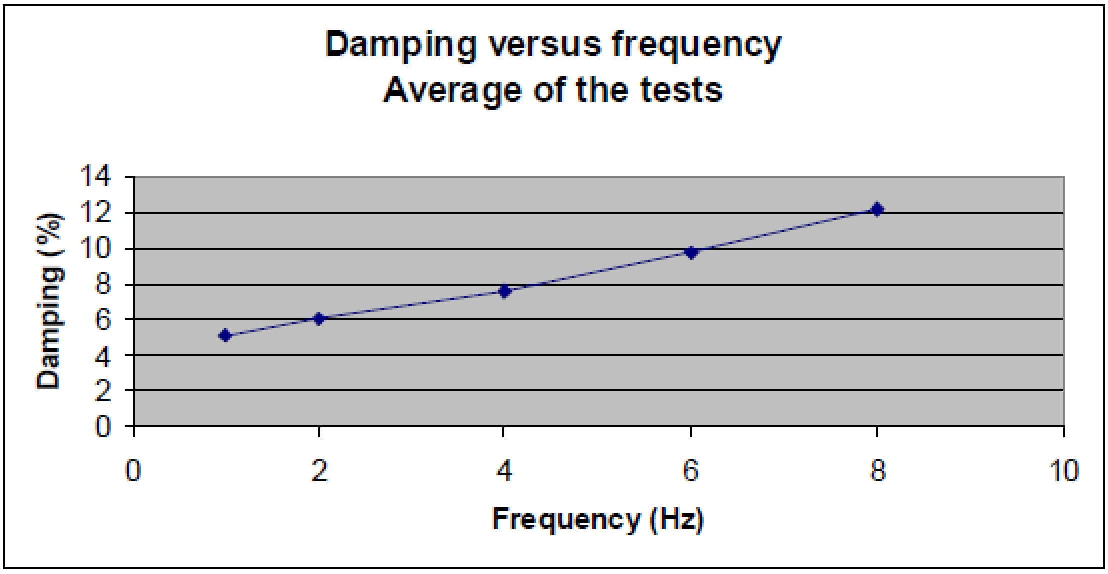
Electrical cabinets bolted or welded to floor		- 5%
Light, welded instrument racks		- 3%
Massive, low stressed, components (pumps, motors, etc.)		- 3%
Piping		- 5%
Cable trays		- 15%
Fluid containing tanks	- Impulsive Mode	- 3% to 5%
	- Sloshing Mode	- 0.5%

Structure or Component	Percent Critical Damping
Piping Systems	5.0
Welded Steel Structural Supports	5.0
Bolted Steel Structural Supports	7.0
Welded Steel Components Including Electrical Cabinets	5.0
Cable Trays	15.0
HVAC Ducting and Supports	7.0
Welded Steel Tanks	
Impulsive Mode	3.0 to 5.0
Convective (sloshing) Mode	0.5
Massive Low-Stress Equipment (e.g., pumps, motors, etc.)	3.0
Lightly Loaded Welded Instrumentation Racks	3.0

Table 7.6: Summary of Damping Values

System		SL-1	SMHV and SL-2	SL-3
General	Welded steel or bolted steel with friction connection	3%	4%	5%
	Bolted steel with bearing connection	5%	7%	7%
Piping	Piping System	3%	4%	5%
Electrical distribution	Cable tray System - Maximum Cable loading	7%	10%	15%
	Cable tray System - Empty	5%	7%	
	Conduit System - Maximum Fill	5%	7%	/
	Conduit System - Empty	3%	7%	
Mechanical and electrical components	Motors, Fans, protection housings	2%	3%	3%
	Pressure vessels, Heat exchangers, Pumps and Valves Bodies	2%	3%	3%
	Electrical Cabinets, Panels, Motor Control Centers	2%	3%	5%
	Metal Atmospheric Storage Tanks (containment, protection) - Impulsive Mode	2%	3%	3 to 5%
	Metal Atmospheric Storage Tanks (containment, protection) - Sloshing Mode	0.5%	0.5%	0.5%

Figure 7.3: Damping of the Anti-Seismic Bearing under Vertical Load, reference [R9]



The values of the dampings recorded during these tests increases with the frequency. This evolution is quasi linear with an equation $\xi = 0,9908.f + 3,9986$. At 12 Hz the damping would reach 16%.

7.4 Reduction Factor

Reduction factors will be used as a first step of the realistic approach as specified by ASN guideline [R14] for the justification of the hard core components under the beyond design seismic load (SL-3). The forces and stresses due to the seismic load will be reduced by this factor in order to take into account the ductility and over-strength capacities of the structural elements. It is equivalent to reduce the response spectra or the spectral acceleration before performing the seismic analysis. When using the reduction factor the ductility or over-strength of the civil structure and equipment shall be justified.

7.4.1 Reduction Factor for Building Structures

These reduction factors are similar to the behaviour factor used for the design of the conventional structures in order to exploit the capacity of the structural elements in the non-linear range.

For building structures, EN 1998-1 2.2.2 gives the minimum values of reduction factor q when the provisions for detailing and design from EC8 are considered:

The design of structures classified as low-dissipative, no account is taken of any hysteretic energy dissipation and the behaviour factor may not be taken, in general, as being greater than the value of 1.5 considered to account for over-strengths.

For steel or composite steel concrete buildings, this limiting value of the q factor may be taken as being between 1.5 and 2 (see Note 1 of Table 7.7).

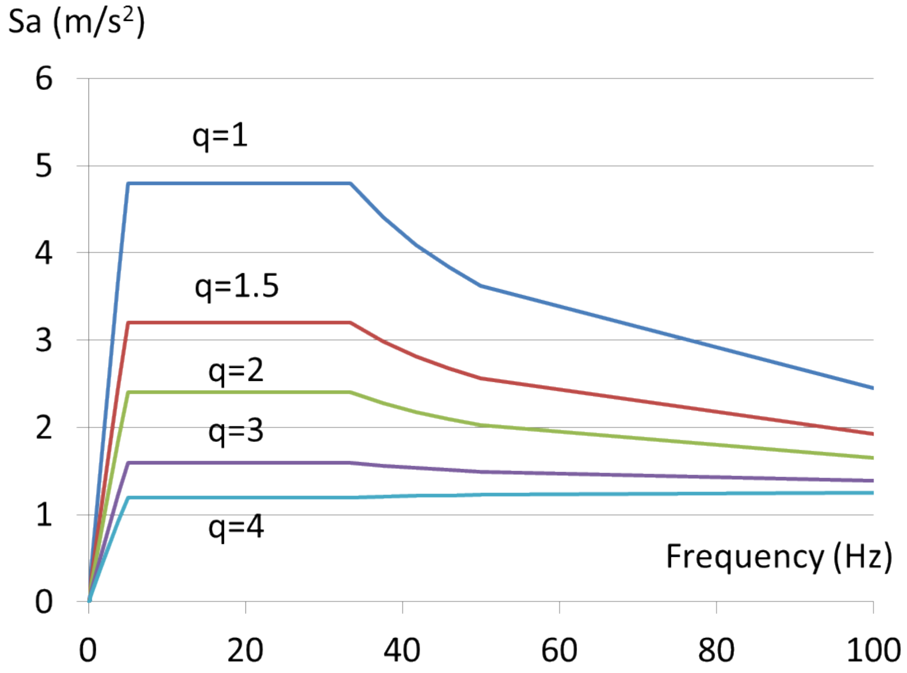
For dissipative structures the behaviour factor is taken as being greater than these limiting values accounting for the hysteretic energy dissipation that mainly occurs in specifically designed zones, called dissipative zones or critical regions.

The values of behaviour factor have to be reduced for structures with horizontal or vertical irregularities (for example, see 4.2.3.1 of EN 1998-1).

EN 1998-3 (Eurocode 8, Part 3: Assessment and retrofitting of buildings) includes the use of the same values of behaviour factor together with the non-linear analysis (push over, etc…).

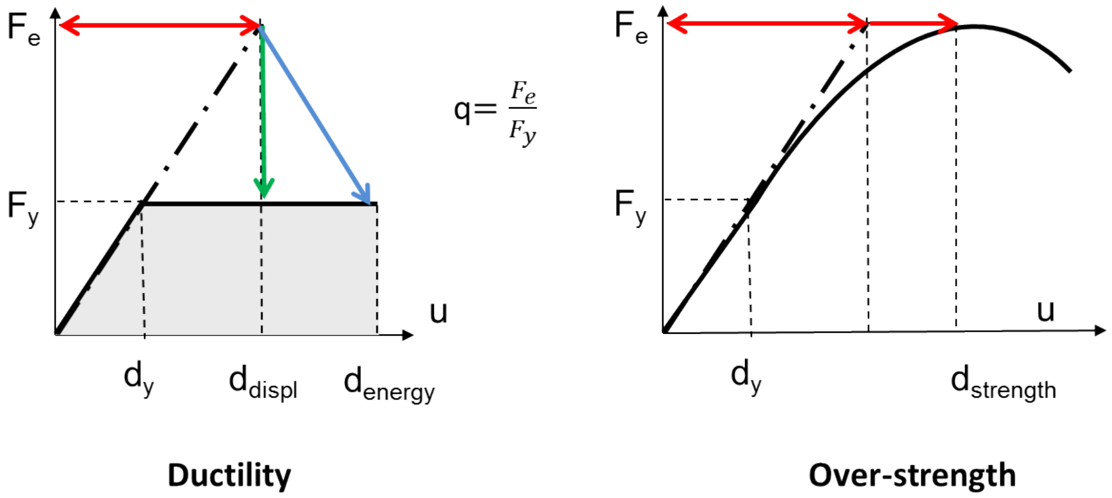
The behaviour factor modifies the EC8 design response spectra and the reduction of the spectral acceleration depends on the building natural frequency (Figure 7-4).

Figure 7-4: Influence of the behaviour factor q on the EC8 design response spectra



In Eurocode 8, at high frequency, the reduction of the spectral acceleration is bounded by a value of 1.5. No benefit from ductility but only the effect of over-strength can be taken into account for rigid structures. In this part of the spectra, the seismic load is a force-imposed load and the equivalences in displacement or energy cannot be considered. This property of the seismic load explains the specificity of the isolated structure: in the horizontal direction, the seismic load is a force imposed load and, in EC8, the superstructure supported by the isolators cannot be designed with reduction factor higher than 1.5.

Figure 7-5: Equivalence in Displacement, Energy and Force-imposed Load



F_e: Force or stresses from the SL-3 elastic calculation

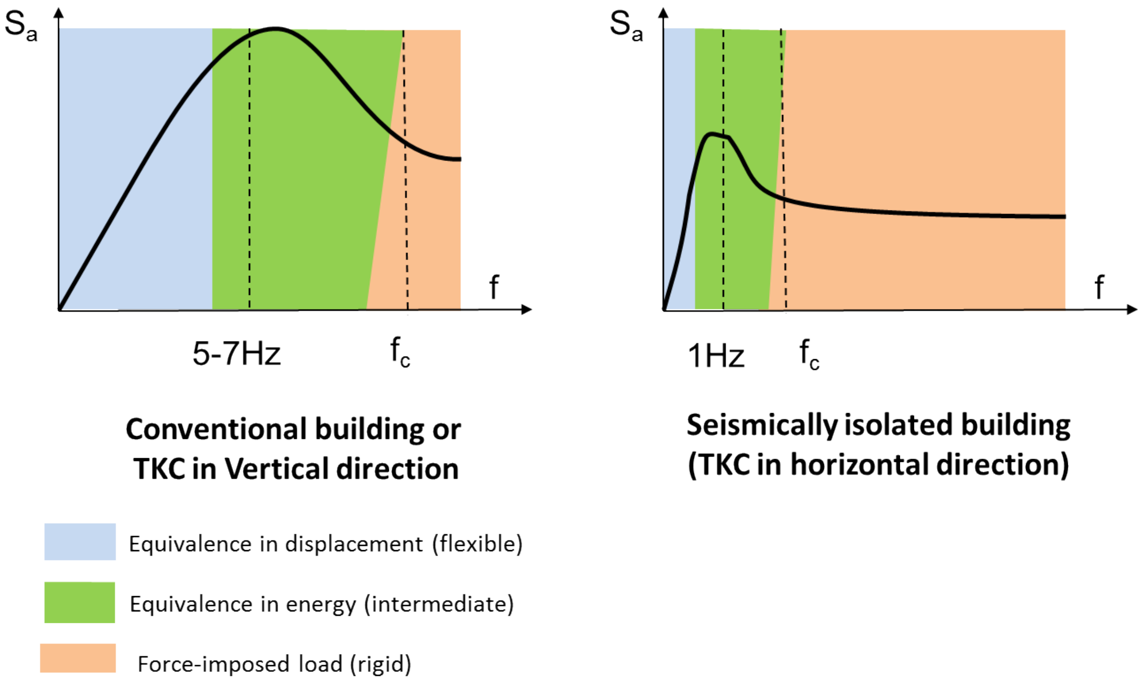
F_y: Capacity considered for the design

d_y: Displacement for design load (SL-2)

d_{displ}: Seismic displacement for the equivalence in displacement (flexible)

d_{energy} : Seismic displacement for the equivalence in energy (intermediate)

$d_{strenght}$: Seismic displacement for a force-imposed load (rigid)



7.4.2 Reduction Factor for Equipment

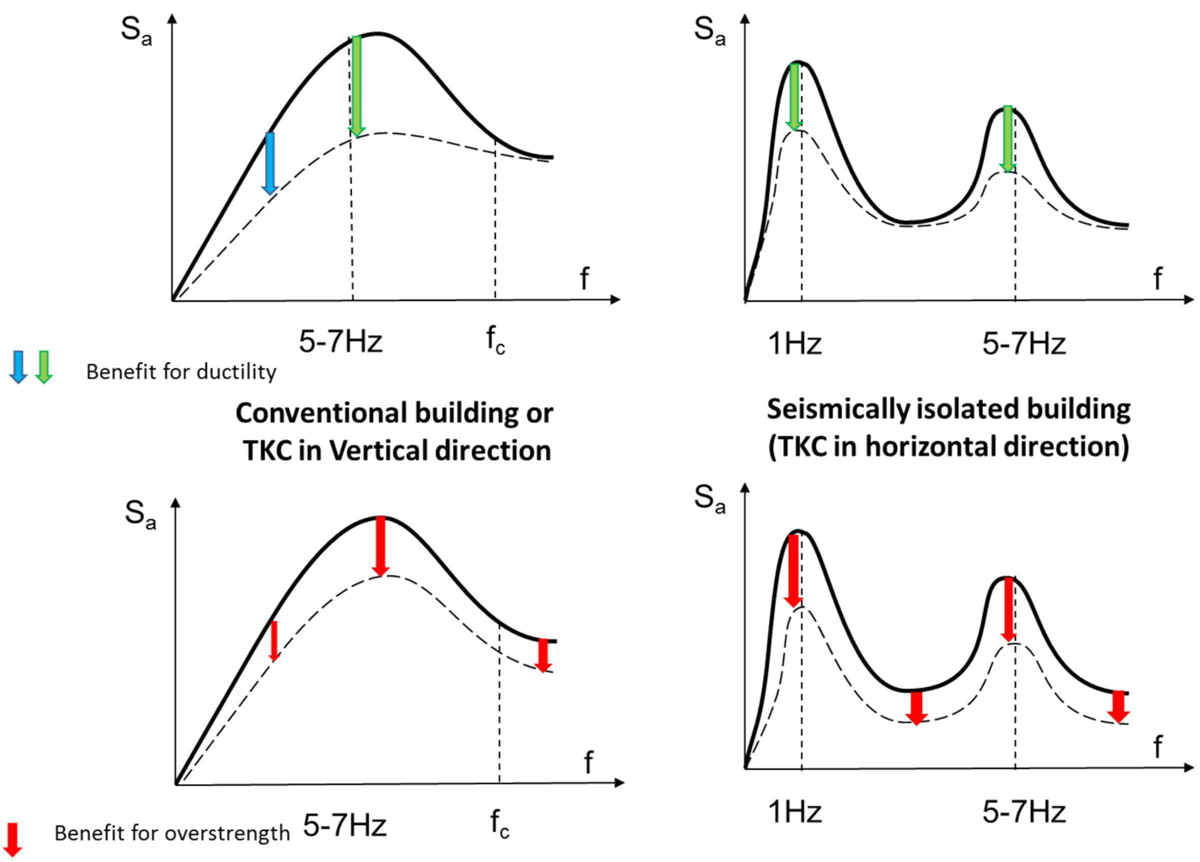
The values given in this paragraph are only for information and guidance; the applicable values are given in paragraph 6.3.4. The assessment of the equipment can also be performed using reduction factors (see AFPS-ICPE Guidelines [R15]). The forces and stresses from the seismic elastic calculations are divided by the reduction factor. The use of a reduction factor is justified when the structure has sufficient ductility and/or over-strength.

When the equipment is not connected to the ground but to a building structure, two approaches are possible.

1- In case of heavy equipment, calculations with models including both the building and the equipment (coupled model) are necessary.
2- When the equipment does not interfere with the building structure (see ASN guidelines 2-01), elastic seismic floor response spectra are used for the assessment.

In order to take into account the relative frequency of the equipment and the supporting structure, different values of reduction factor can be considered (see for example, the reduction factors for rigid and flexible pumps in AFPS 90 Recommendations). The notion of rigid and flexible depends on the values of natural frequencies of the equipment but also of the supporting structure. In the isolated structures, the fundamental Eigen modes in the vertical direction and so the vertical seismic load has frequency content similar to those of the non-isolated structures. Figure 7-6 shows the effect of the equipment ductility and over-strength onto the reduction of the seismic forces in the Tokamak complex (horizontal and vertical direction).

Figure 7-6: Effect of the Equipment Ductility and Over-strength on the Effective Spectral Acceleration



7.5 Influence of the Failure Mode on the Reduction Factor

The reduction factor also depends on the main failure mode of the structure (ductile bending modes versus brittle shear or buckling modes): a reduction factor of 1 has to be considered for tanks which fail by buckling under seismic load but higher values are accepted for the other ductile mode (uplift, global bending, yielding of the anchors, etc…).

Table 7-7: Reduction Factor proposed by AFPS 90 Recommendations

Component	Reduction factor at zero frequency(1)			Behaviour factor(2)		
	E1	E2	E3	E1	E2	E3
Ductile piping	7	5	N/A	4	3	N/A
Non-ductile piping	1.5	1.5	N/A	1.5	1.5	N/A
Tanks	5	3	N/A	3	2	N/A
Tanks with buckling failure mode	1	1	N/A	1	1	N/A
Rigid pumps	1.5	1	1	1.5	1	1
Flexible pumps	5	3	1.5	3	2	1.2
Engines	1.5	1	1	1.5	1	1
Steel structure of lifting devices	6	4	N/A	5	3	N/A
Cable trays	7	5	N/A	4	3	N/A
Valves	2	1.5	1.2	1.5	1.2	1.0

Where:

E1: Stability to avoid that equipment become a missile

E2: Integrity for equipment and structures which need to keep passive function (ex.: confinement)

E3: Operability for equipment which need to keep active functions

(1) Reduction factor at zero frequency: Reduction factor of the FRSs for the equivalence in displacement noted ρ. For the frequency range with equivalence in energy, the reduction factor is equal to $(2\rho-1)^{0.5}$. At high frequency, the reduction factor is 1.

(2) Behaviour factor: Reduction factor for the equivalent static analysis.

7.6 Combination of Reduction Factor and Soil-Structure Interaction

When the benefit of soil-structure interaction is considered, the reduction factors generally allowed are limited because the energy cannot be simultaneously dissipated in the ground and in the structure, so in this case, according to Eurocode 8, the reduction factor cannot be larger than 1.5.

7.7 Justification of the Reduction Factor

When no value of reduction factor is available in guidelines used for seismic assessment or seismic design standard or when values higher than those available are considered, the justification of the values proposed by the system/equipment can be based on experimental results and/or non-linear calculations.

The following aspects need to be covered by adequate justification:

- Material ductility and over-strength
- Capacity of force redistribution in case of redundancy
- Determination of the failure mode and the critical sub-components where non-linearity may develop
- Lack of brittle failure mechanism (shear, buckling)

Non-linear calculations or/and experimental tests can be performed to identify the margins in the component that may suffer during a seismic event combined with the loads of normal conditions.

The distinction between over-strength and ductility capacity will be clearly made for the justification of the reduction factor.

The way how SL-2 is considered in the design basis, the calculations and the load combinations of the component will also be taken into account before the assessment of the component under SL-3 beyond design seismic load.

8 Evaluation of the Robustness and Margin Assessment

The general approach in the evaluation of the robustness and the margin assessment for the Stress Test analysis of the existing HCCs will be based on the conventional procedure. With this approach the different safety margins related to the conventional design procedure will be evaluated. If the existing HCCs cannot be verified through this approach a realistic approach will be used accounting for appropriate reduction and damping factors and/or using different types of analyses depending on the HCC requirements to be satisfied.

For the design of the new HCCs a conventional approach will be used, taking into account appropriate criteria according to the functional requirements of each equipment.

When determining the margin values for an SSC, there are several safety margins that can be considered, which include:

1) material strength
2) conservatism in analysis method
3) margin to the code allowable (so called design margin)
4) increased damping
5) ductility in structural system

It is recognized that the inherent resistance of a well-designed and constructed SSC is usually much greater than that expected based on elastic analysis. This occurs largely because nonlinear behaviour is mobilized to limit the imposed forces and increase the accompanying deformations. It is anticipated that stresses above yield may occur for some structures as the result of a SL-3, and the nonlinear effects should be accounted for, in such cases.

The strength acceptance criteria applied to the seismic margin assessment are based in general on current codes and standards. The use of actual material properties rather than the design value is also accommodated in the criteria. Where actual material properties are available, it is permissible to use a conservative value of the range of actual test data.

Two general methods currently exist for treating the nonlinear behaviour of a structure. One approach is to perform a time history nonlinear analysis and compare the maximum element, demand ductility to a conservative estimate of its ductility capacity.

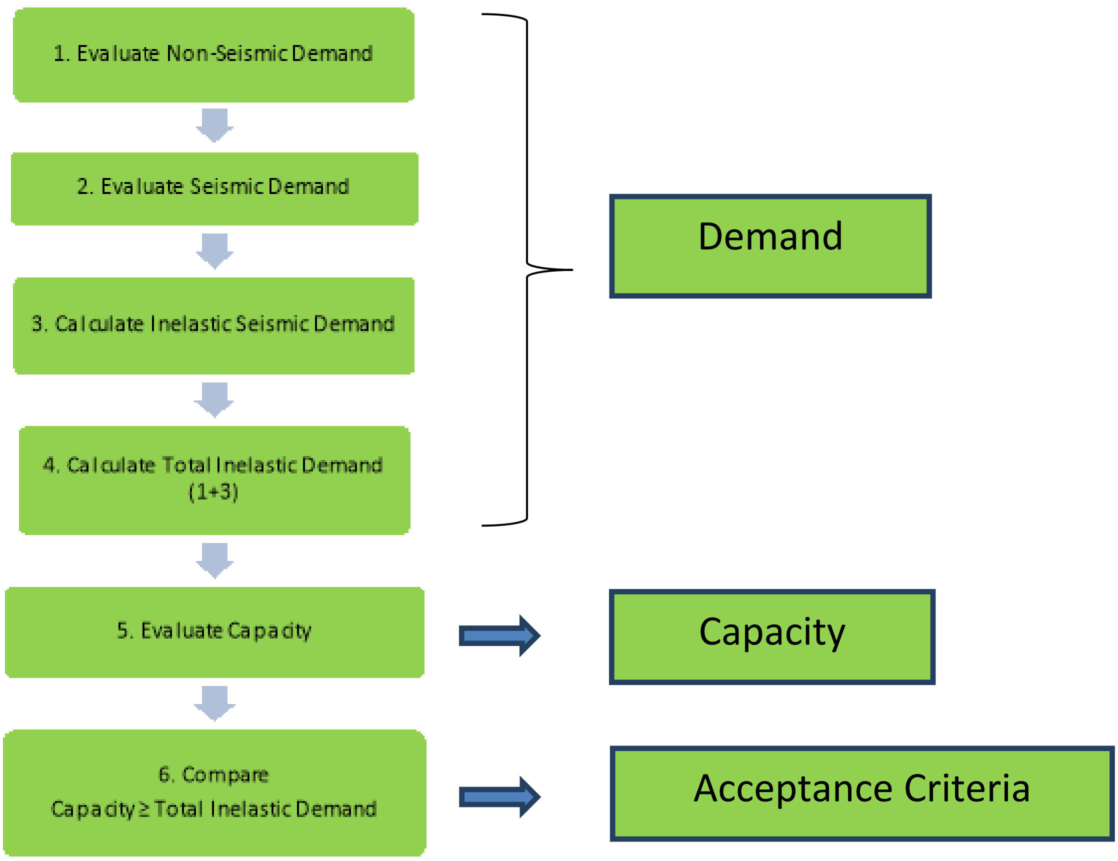
An alternate means of accounting for the inelastic energy dissipation of SSCs at response levels above yield is the use of an inelastic energy absorption factor *F (reduction factor)*, based on a ductility modified response spectrum approach. This method is presented hereafter where the "reduced" earthquake forces are obtained multiplying the elastically calculated forces by the reduction factor, as explained in chapter 7.4 and 7.5.

8.1 Realistic Approach

In the following the steps for the evaluation of the robustness of a SCC:

1. Definition of the requirements for the equipment given its role in the Hard Core
2. Collect the relevant documentation of the equipment (construction drawings, calculation note, technical specification, codes reference, etc.)
3. Visual inspection of the equipment (if built) in the environment, to verify its compliance to the documentation
4. Analysis of the documents and extracting the necessary elements to perform the evaluation.

The procedure to perform the evaluation is presented in the following flow chart:



Seismic load combinations, for strength-based acceptance criteria, shall consider the energy dissipation factor. For elastic analysis, the total demand acting on a structural element shall be the sum of non-seismic demand, D_{NS}, and seismic demand, D_S, per the following load combination, as appropriate:

$\mathbf{D = D_{NS} + D_S/F}$ (Eq.1)

Where:

- D_{NS} is the Non Seismic demand calculated considering the load combinations defined in the design basis methodology.
- D_S is the Seismic demand due to the seismic inertia loads generated by the seismic event of reference, calculated taking into account specific damping factors for the equipment to verify. The calculated seismic response of the component, Ds, shall be based on its effective natural frequency, f_e, as defined in Eq.2.
  When $f_n \leq f_{PEAK}$ then $f_e = f_n$
  When $f_n > f_{PEAK}$ then

  $$f_e = f_n \sqrt{\frac{2}{(F^2+1)}} \geq f_{PEAK} \quad \text{(Eq.2)}$$

  f_n : the frequency of the predominant structural mode
  f_{PEAK} is the upper frequency of the peak acceleration of the FRS

- F is a reduction factor specific for the equipment to verify as reported in chapter 6.3.4

- When displacements need to be calculated as part of the seismic qualification by analysis, the demand given in Eq. 1 shall be changed by replacing Ds/F by Ds

The qualification by analysis of the SSC has to clearly demonstrate that the capacity *C* exceeds the total demand *D.* In order to calculate the total demand *D*, the realistic approach envisages the use of reduction factors and damping factors specific for the equipment to verify as described above.

$$\mathbf{D} \leq \mathbf{C} \quad \text{(Eq.3)}$$

8.2 Nuclear and Non-Nuclear Buildings (PBS 62 and 63)

This paragraph provides detailed technical guidelines to perform structural analysis of concrete and steel civil structures (PBS 62 and 63) credited as Hard Core Components within the framework of the Stress Tests analysis. See also reference [R41].

8.2.1 Load Combinations

The load combinations for the stress test assessment are those associated to the following scenarios

a) Extreme Earthquake in Tokamak Complex (so called SL-3)
b) Multiples Fire event in Tritium Building

The selection of the load combinations for the Extreme Earthquake scenario shall be made in regards to the operation mode during which the seismic event SL-3 shall be considered. The assumption considered is that the SL-3 event could occur during mode 0 i.e. plasma operation.

The load combinations to select are the one considered with the SL-1 in Normal situation CAT.II (in accordance with ASN guideline referred [R14], "*seismic action and accidental action caused by the earthquake are not considered as concomitant"*) and are captured within the section 3.4 of the document referenced [R17]. On that basis and in regards to the Matrix #2 and #3.1 the following combinations shall be considered.

It shall be noted that the combinations are to be considered in conjunction with the appropriate permanent or quasi-permanent actions. The appropriate factors shall be taken from Matrix 2 of the document referenced [R17].

The selection of the significant load cases is also done in regards to the section 5.4 of the document referenced [R18] where are listed the cases considered as not significant loads cases for the buildings.

In addition, as part of the potential scenario occurring during a SL-3 event within the Tokamak Complex in particular in the Tritium Building, a combination with the Fire event shall be considered. For that particular case, it shall be noted that the fire and the seismic events shall not be considered as concomitant as per the Supplier Deviation Request #85 – AE PA 6.2.P2.EU.02 – PBS 61, 62, 63 – Proposal to Refine the Requirements for Stability after an Earthquake Event Followed by a Fire Event Followed by an Earthquake Event (P54LBV)

On the basis of above consideration, the Seismic Load Combinations are the following:

a) $G_k + Q_{qp} + T_{qp}$ + SL-3/F
b) $G_k + Q_{qp} + T_{qp}$ + SL-3/F + Int Fire

Nota:
G above collectively represents all the permanents actions, as applicable for the structure or part of the structure considered. It includes notably G_0, G_e, G_{sr}, G_s, G_w, G_p, G_T,G_{sh}, G_c as defined in the section 3.1.1 of the document referenced [R17]. For the particular load case shrinkage G_{sh}, it shall be considered in a realistic manner in regard to the actual construction sequences. The quantitative definition of the shrinkage will be defined during the margin assessment activity.
Fr is the reduction factor as explained in the paragraph 8.2.4.

8.2.2 Type of Analysis

The analysis performed on the HCCs constituted by the concrete and steel frame structures, including penetrations, shall be done in accordance with the document referenced [R17]. Some other methods with qualified and appropriated tools for the structural analysis of existing structure can be proposed.

In particular it shall be noted that the seismic analysis shall be done in accordance with the Appendix A of the document referenced [R17].

Buildings classified SC2 according to their currently requirement:

- stability of structures,
- no detrimental interaction with adjacent buildings

can be designed with non-linear calculation methods (static and/or dynamic), in accordance with the requirements of ASN/GUIDE/2/01, Sect. 2.5.3.2 [R14]. The design shall provide a ductility level equivalent to Ductility Class Medium (DCM), according to EC8 classification.

Non-linear calculation methods are also allowed for the stress test assessment. For the push-over analysis, the FEMA 356 “Prestandard and commentary for the seismic rehabilitation of buildings” shall be considered.

8.2.3 Requirements, Acceptance Criteria and Seismic Classification

The criteria are defined within document referenced [R17] and shall be complaint with the safety requirement associated to the HCCs.

Where a combination of actions is required, the combined group of safety requirements considering each action shall apply to the combination.

The criteria are defined within the section 4.5.3 of the document referenced [R17] and recalled hereafter:

Table 8-1: Groups of Acceptance Criteria for the Design

	ULS							SLS				Application
Group of criteria	ULS.R1	ULS.R2	ULS.R3	ULS.R4	ULS.R5	ULS.R6	ULS.R7	SLS.R1	SLS.R2	SLS.R3	SLS.R4	
C1	X	X		X					X			All structures
C2	X	X		X				X	X			Structural elements where crack limitation is strictly required in normal situation
C3	X		X	X	X							Accidental situations. See § 4.8
C4	X			X		X						General aviation plane impact. See § 4.8.3.
C5	X	X		X				X	X	X		Confinement barriers. See § 4.6.1.
C6	X	X		X					X		X	Peripheral walls of all buildings
C7	X			X			X					Load drops

The required margins when considering the support of the Cryostat defined in the Matrix #2 and #3.1 in the document referenced [R17] i.e. 1.2 in Normal situation and 1.5 in Accidental situation shall not be considered.

The demonstration of the Hard Core Component must rely, for what concerns the civil structure, on the justification of:

- The structures of the Hard Core
- The structures sheltering and protecting the Hard Core
- The structures that can aggress the equipment or structures of the Hard Core

The nuclear and non-nuclear buildings that can be considered aggressors to the HCCs are required to meet stability requirement.

In particular for the penetrations that are considered HCC, the environmental conditions (in terms of temperature, pressure, humidity, radiation etc.) generated by the accidental situation (such as SL-3) are not known. The environmental conditions to be considered will be the same used in the baseline for the SL-2 seismic event when verifying the requirement of tightness/confinement to be assured by the HCC penetrations.

8.2.4 Seismic Input

Earthquake ground motion of SL-3 has been assumed as the envelope of Paleo + 1.5 × SMS.

The damping ratios to be considered are the one defined in the document references [R17].

For what concerns the Tokamak Complex stress test assessment that is on the anti-seismic bearings, the damping factor to be considered is 5% for horizontal accelerations and 10% for the vertical accelerations.

According to the document referenced [R17], the Seismic design is done in the elastic domain for all SIC structures and for non-SIC structures that house SIC systems. No behaviour factor is taken into account (q = 1). Nonetheless, it is proposed to use a reduction factor (over-strength or ductility coefficient Fr) as proposed in the Eurocode 8 as follows:

Table 8-2: Reduction Factor for Buildings

Type of structure	**F**
Structure on anti-seismic bearings	1,0 (*)
Bearing walls structures with provisions for steel reinforcement to avoid brittle failure mode	≥2,0
Steel structure designed with EC8 detailing provisions and a behaviour factor equal to1.5	≥2,5

(*) the structure remains within the elastic domain. It could be nonetheless considered an over-strength coefficient equal to 1.5 for the upper structure which shall be designed with the minimal rebar ratio according to the Eurocode 8.

For structural types not mentioned above, Eurocode 8 applies, as reported in the Table 8.3.

Table 8-3: Reduction Factor for Buildings, extracted from EC8

STRUCTURAL TYPE	DCM	DCH
Frame system, dual system, coupled wall system	$3,0\alpha_u/\alpha_1$	$4,5\alpha_u/\alpha_1$
Uncoupled wall system	3,0	$4,0\alpha_u/\alpha_1$
Torsionally flexible system	2,0	3,0
Inverted pendulum system	1,5	2,0

An over-strength coefficient is also considered for the verification of the embedded parts (i.e. embedded plates) in concrete with a value bounded to 1.5.

8.2.5 Qualification

The justification of some of the HCCs could be done based on qualification campaign results.

For what concern the specific case of the concrete and steel frame civil structures, the qualification results of the anti-seismic bearings may be considered to justify the damping factor and the strength capacity.

In addition, the verification of the embedded parts within the concrete considers an over-strength coefficient which shall be justified by implementation of appropriated qualification.

8.3 Mechanical Systems

This paragraph provides detailed technical guidelines to perform the stress test for Hard Core Components (HCCs) of mechanical systems covering loading, method of analysis and acceptance criteria for:

- Piping and pipes penetrations
- Piping supports
- Valves
- Pressure components (Vessels and Heat Exchangers)
- Rotating machines (pumps, compressors, fans)

In the following are reported the guidelines and criteria for the Cooling Water System (PBS 26), Vacuum System (PBS 31), Cryogenic System (PBS 34) Tritium Plant (PBS 32 and PBS 64), HVAC, Fire Suppression Systems, Air Mixing System, Compressed Air, Demineralized Water, and Breathing Air (PBS 65).

For the others PBS systems where the HCCs have been identified (see reference [R51]) with the requirement to meet confinement function in terms of isolation valves and penetrations such as Fuelling and Wall Conditioning (PBS18), VVPSS (PBS 24) Heating & Current Drive Systems (PBS 51, 52, 53 and 54), Diagnostic (PBS 55) and Test Blanket Modules (PBS 56), the rules and criteria defined in this document to perform the stress test assessment will be applicable. The Codes & Standards selected for the design of those systems are also covered in this chapter.

8.3.1 Cooling Water System (PBS 26)

In the following the guidelines and criteria to perform the stress test for Hard Core Components (HCCs) of cooling water system (PBS 26). The inputs, methodology, acceptance criteria and margin of the testing actions are presented here. The list of HCC for CWS includes piping and its supports, penetrations and its supports and valves and its actuators, however there is no pressure vessel, heat exchanger or rotating machine listed as HCC for CWS. See also ref. [R42].

8.3.1.1 Codes and Standards

For CWS, the codes and standards used in design are

- Basic Design code for piping systems: B31.3 2012
- Basic Design code for Pressure Vessels and Heat Exchangers: ASME Section VIII Div 1 & 2
- Basic code and Standard for valves is ASME B16.34. For the qualification of valve bodies by analysis ASME section III NC-3520 for SIC valves is used.
- Basic Design code for piping and components supports: AISC N690 for SIC-1 and SIC-2 components supports. For Non – SIC supports, the applicable code is AISC N360, though Eurocode can be used for CCWS, CHWS and HRS supports.

8.3.1.2 Load Combinations

Here below it is reported the load combinations used for the stress test assessment

For the earthquake scenario (Earthquake Tokamak Building) the SL-3 is combined with normal operation conditions, where normal operation Loads is the Operational Mode 0 (plasma operation).

AREA	LOAD CASE
For TCWS Inside and outside Cryostat:	P+Dw+T+SL3/F
For CCWS and CHWS:	P+Dw+T+SL3/F
For TCWS supports inside and outside Cryostat:	Dw+Tmax+SL3/F
For CCWS and CHWS supports:	Dw+T+SL3/F

Table 8-4: Earthquake Scenario Load Combinations

Where:

Dw: Dead Weight

T_{max}: Load due to Maximum temperature expected in the design of the component

T: Operating temperature of the component

P: Design pressure

For the fire scenario (Multiples fire in Tritium Building) the seismic load SL-3 and the fire loads are not considered concomitant.
The load combinations used in the design basis are the following:

AREA	LOAD CASE	Cat.
For TCWS <u>Outside Cryostat:</u>	P+Dw+SL2+T+Internal fire	IV

Table 8.5: Fire Load Combinations in Design Basis

Where, the internal Fire is intended to be combined with the SL-2 only as a consequence but not at the same time.

The multiple fire load condition doesn't introduce additional loads to the HCC of the CWS HCCs with respect to those in the design basis.

<u>The load combinations used for the stress test are the following:</u>

AREA	LOAD CASE
For TCWS <u>Outside Cryostat:</u>	P+Dw+T+SL3/F + Multiples Internal fire

Table 8.6: Multiple Fire Scenario Load Combinations

In the Multiples Fire scenario the NO correspond to the operational modes including mode 0 (plasma operation) mode 1 (shutdown, maintenance phase) and mode 2 (maintenance with equipment transfer phase).

8.3.1.3 Type of Analysis

For CWS HCC linear elastic spectral analyses are used for piping, supports and components during design phase and for the verification as per a conventional approach. If the verification is not possible through conventional approach, other type of analyses such as time – history analyses will be used for a more realistic approach.

8.3.1.4 Requirement, Acceptance Criteria and Seismic Classification

- PIPING

Design Code ASME B31.3 for piping provides only acceptance criteria for sustained loads, occasional loads and for displacement range (expansion); however it does not consider something such as “operating stress”. Therefore the acceptance criterion to be used is that for sustained loads (that consider the pipe at operating temperature), which can be combined with occasional loads that depend on the event category as below.

Furthermore ASME B31.3 doesn’t provide 4 service levels as ASME BPVC does. To cope with this, ITER document 3G3SYJ [R19] assigns acceptance criteria to service levels C and D for piping design under ASME B31.3.

Reduction factors are not used in design phase, but for the so called “realistic” approach this factors could be introduced to reduce the seismic demand.

The following table shows the acceptance criteria for each load category. The load case shown is an example of the combinations in that category. For the detailed list of combination, refers to reference [R20].

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA FOR PIPING					
Category	**Load Combination**	**Service Level**	**Acceptance Criterion**	**Damping factor (US NRC RG.1.61)**	**Reduction factor**
I	P+Dw+Tb (or other Cat I load combinations)	A	$\frac{PD_0}{4t} + \frac{IM_{SUS}}{Z} \leq 1{,}0S_h$	N/A	N/A
II	P+Dw+Tb+SL1 (or other Cat. II events combinations)	B	$\frac{PD_0}{4t} + \frac{I(M_{SUS} + M_{OCC})}{Z} \leq 1{,}0S_h$	3%	N/A
III	P+Dw+Tb+SHMV (or other Cat. III events combinations)	C	$\frac{PD_0}{4t} + \frac{I(M_{SUS} + M_{OCC})}{Z} \leq 1{,}5S_h$	4%	N/A
IV	P+Dw+Tb+SL2 (or other Cat. IV events combinations)	D	$\frac{PD_0}{4t} + \frac{I(M_{SUS} + M_{OCC})}{Z} \leq 2{,}0S_h$	4%	N/A

Table 8.7: Categories, Load Combinations, Service Level and Acceptance Criteria used for Piping in Design Basis

- SUPPORT

Linear-type supports made of beams and columns are widely used in the design of piping systems. According to ASME III NF3300, linear-type supports shall be evaluated by comparing several types of stresses (tension, compression, bending, etc.) with allowable stresses (e.g. NF3322). The calculation methods of these allowable stresses are different depending on what type of cross section of the beams and even what kind of material is used.

Stresses for Design and Level A Service shall not exceed the allowable values of NF-3322.

For Level B, C and D Service, allowable stresses may be increased by factors shown in Table NF-3312.1(b)-1

Reduction factors are not used in design phase, but for the so called "realistic" approach this factors could be introduced to reduce the seismic demand.

Table 8.8: Categories, Load Combinations, Service Level and Acceptance Criteria used for Supports in Design Basis

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA FOR SUPPORTS					
Category	**Load Combinations**	**Service Level**	**Stress limit Factors Ks, Kv, Kbk (*)**	**Damping factor (US NRC RG1.61)**	**Reduction Factor**
I	Dw + Tmax	A	1.0	N/A	N/A
II	Dw+Tmax+SL1 Dw+Tmax+SL1 +TR	A	1.33	3%	N/A
III	Dw+Tmax+Dy Dw+Tmax+SHMV+Dy Dw+Tmax+SHMV+TR	C	1.5	4%	N/A
IV	Dw+Tmax+SL2+Dy+TR	D	1.66	4%	N/A

(*) Further details on acceptance criteria can be found in ASME III Appendix F.

- VALVES

The valves listed as HCC for the CWS that have an operability requirement won't be qualified by analysis. Valves and its actuators will be then qualified by test, subjecting the assembly to shaking table. See section 8.3.1.6 for more details.

The valves listed as HCC for the CWS that have functional or integrity requirements can be qualified separately from the actuator by analysis, based on static forces resulting from equivalent earthquake accelerations acting at the centres of gravity of the extended masses. The valve bodies shall conform to the stress limits listed I ASME III NC-3522.

LOAD COMBINATIONS AND ACCEPTANCE CRITERIA FOR VALVES					
Category	**Load Combination**	**Service Level**	**Acceptance Criterion**	**Damping factor (US NRC RG.1.61)**	**Reduction factor**
I	P+Dw+Tb (or other Cat I load combinations)	A	$\sigma_m \leq 1{,}0S$ $(\sigma_m or\ \sigma_L) + \sigma_b \leq 1{,}5S$	N/A	N/A
II	P+Dw+Tb+SL1 (or other Cat. II events combinations)	B	$\sigma_m \leq 1{,}1S$ $(\sigma_m or\ \sigma_L) + \sigma_b \leq 1{,}6S$	2%	N/A
III	P+Dw+Tb+SHMV (or other Cat. III events combinations)	C	$\sigma_m \leq 1{,}5S$ $(\sigma_m or\ \sigma_L) + \sigma_b \leq 1{,}8S$	3%	N/A
IV	P+Dw+Tb+SL2 (or other Cat. IV events combinations)	D	$\sigma_m \leq 1{,}0S$ $(\sigma_m or\ \sigma_L) + \sigma_b \leq 2{,}4S$	3%	N/A

Table 8.9: Categories, Load Combinations, Service Levels and Acceptance Criteria used for Valves in Design Basis

- PRESSURE VESSELS

CWS does not list any pressure vessel or heat exchanger as HCC.

CWS does not list any rotating equipment as HCC.

- REQUIREMENTS for the Cooling Water HCCs

For the CWS HCC, the following requirements are applied depending on the type of component and its function during and after the accident.

Operability is required for active components, such as valves and actuators whose operation has to be performed during and after the accident.

Functional Capacity is required to static components that have to preserve a particular function during and after the accident, such as cooling flow rate capacity for a pipe or nozzle.

Integrity is required when the confinement or leak tightness has to be guaranteed but other functions can be lost.

Stability is required when the component has to keep in place, though larger deformation appears and confinement is degraded.

Each requirement is associated with a service level to guarantee that components meet the requirements under the stress test conditions.

Requirement	Service level	HCC affected
Operability	A or B	- Valves to be operated during and after the accident.
Functional Capacity	C	- Not operated valves.
Integrity	C	- Piping. - Penetration closure plates.
Stability	D	- Pipe supports. - Guards (confinement can be degraded).

Table 8.10: Requirements and Service Levels for HCC of CWS

8.3.1.5 Seismic Input

Earthquake ground motion of SL-3 shall be assumed as the envelope of Paleo + 1.5 × SMS. Unless building FRS are evaluated from the SL-3 ground motion, they shall be assumed equal to the FRS calculated for the SL-2 event scaled by a factor 1.5 (1.5 x SL-2FRS)

Based on paragraph 6.3.4, the following damping factors will be used for the SL-3 FRS:

TYPE OF COMPONENT	DAMPING FACTOR
Piping and individual piping supports:	5%
Massive steel bolted (non – pre stressed) secondary structures	7%
Massive steel welded or pre – stressed secondary structures	5%
Pressure vessels and valves	5%
Pumps, fans, motors and compressors	3%

Table 8.11: Damping Factors for SL-3 Level

Based on paragraph 6.3.4, the following reduction factors will be used for the SL-3 load:

TYPE OF COMPONENT	SERVICE LEVEL C	SERVICE LEVEL D
Butt welded piping	1,5	1,75
Socket Welded piping	1,25	1,5
Steel bolted (non – pre stressed) secondary structures	1,5	2
Steel welded or pre – stressed secondary structures	1,5	2
Pumps, fans, motors and compressors	1,25	1,5
Pressure vessels and valves	1,25	1,5

Table 8.12: Reduction Factors for SL-3 Load

Note: Inside the Tokamak building the reduction factor will be limited to 1.5, according to EN 1998-1 Eurocode 8[R40].

The use of a reduction factor is justified by the ductility in material and the capacity to redistribute stress and loads when stress yield point is reached. In case of dynamic load, this also results in energy dissipation by the structure. These properties are taken into account by the implementation of the reduction factors presented in the table. In case of risk of brittle failure or in case the plastic energy dissipation is limited with respect to the accumulated dynamic energy in the structure (i.e. support with little deformation capacity) the application of a reduction factor is not recommended unless properly justified.

8.3.1.6 Qualification

Some components, particularly valve + valve actuators, will be subjected to shaking table to qualify the component if it has not been supplied yet. To qualify these active components for operability, it is normally required to ensure some maximum bending on the stem, maximum deformations on the disc or seat rings, keep bending within some tolerances and similar parameters which are normally difficult to be qualified by analysis. By analysis the structural integrity and stability can be checked, but for operability it is required to submit the assembly valve + actuator to shaking table.

8.3.2 Vacuum System (PBS 31)

In the following, a compilation of guidelines and criteria for Vacuum system (PBS 31) to comply with the stress test approach. See also ref. [R43].

For PBS31 the Hard Core Components have been defined in [R21] and are all Torus & Neutral Beam: Roughing and Regeneration (TNRR) or Torus & Neutral Beam: Type 2 Diagnostic (TNTD) system pipework that pass through penetrations. These penetrations have to assure confinement requirement. There are no active components in these systems that are classified HCC.

These following vacuum components are defined as Hard Core Components:

1. Neutral Beam Absolute Valve Roughing Line.
2. Neutral Beam Roughing and Regeneration Line.
3. Neutral Beam Vent and Purge Line.
4. Torus Regeneration Line.
5. Torus Roughing Line.
6. Type 2 Diagnostics Roughing Line

These different system lines use a single design code, ASME B31.3 2010 CAT M.

8.3.2.1 Codes and Standards

The design code used is ASME B31.3 2010 CAT M for the pipework. Supports are designed to ANSI/AISC N690-12, 2012 and ANSI/MSS SP-58-2009. This is justified in reference [R22] for the pipework and in reference [R23] section 6.2.2 component supports for the associated supports.

All pipework in the PBS31 HCC list above is at PDR level of maturity except the Torus Regeneration Line. This is at a design maturity level of Final Design Review (FDR) and is used as the model for the other components.

8.3.2.2 Load Combinations

The load combinations associated with the defined hard core components fall into two groups:

- SL-3 seismic event in the Tokamak Complex
- SL-3 followed by Multiple fire events in the Tritium Building

In the load case of SL-3 the combination is:

Normal Operation Loads + SL-3/**F**

Where

F is the reduction factor defined in 8.3.2.5.

Normal Operation Loads is the Operational Mode (Loads) 0 (plasma operation)

The seismic load SL-3 and the fire loads are not considered to be concomitant. SL-3 can cause a fire, but the temperature effects of the fire develop as the seismic event is finished.
In the design basis the concomitance of seismic load with thermal load from fire is considered due to the case of a seismic after-shock equivalent to SL-2 or SMHV.
The multiple fire load condition doesn't introduce additional loads to the HCC of the vacuum system with respect to those in the design basis.

The following load cases considered in the design basis, which include fire event, will be applicable for the multiple fire load combination:

<u>For Pipework</u>
P + Dw + SMHV + Internal Fire
P + Dw + SL-2 + Internal Fire

<u>For Supports</u> – From AISC N690-12 Load Combinations NB2-6 & NB2-9,
Load Combination (*Dw + 0.8 L + C + To + Ro + Es*) reduces to:
= NO + Baking + SMHV
Load Combination (*Dw + 0.8 L + (Pa + Ra + Ta) + (Yr + Yj + Ym) + 0.7 Es*) reduces to:
= NO + Fire + 0.7SL-2
Where NO is: Operational Modes (Loads) including mode 0 (plasma operation) mode 1 (shutdown, maintenance phase) and mode 2 (maintenance with equipment transfer phase).

8.3.2.3 Type of Analysis

The design phase elastic analysis performed using B31.3-2010 took into account no benefit of plasticity for the analysis of the piping. Support analysis is purely elastic, except that the plasticity of the piping is used to determine an upper limit for the reaction loads due to thermal expansion of the piping. All non-thermal loads are analysed as purely elastic. HCC will be verified using the same methodology used for the assessment to SL-2. If it is found by this approach that the HCC design has no margin for the SL-3 event then the reduction factors specified in 8.3.2.5 or time history (linear analysis or non-linear) analysis will be used to make a more realistic assessment of the structural margins.

8.3.2.4 Requirement, Acceptance Criteria and Seismic Classification

PIPING

ASME B31.3 does not provide four service levels, ITER document 3G3SYJ [R19] assigns acceptance criteria to service levels C and D for piping design under ASME B31.3.

Service level D limits are enough to prevent plastic collapse, buckling, and ratcheting, and so ensure stability of the pipe.

System	Requirements to be met	Seismic Class
PBS31 HCC	Confinement after and during Event, Leak tight to Safety leak rate requirement [R24][PR1192-R]	SC1 (SF)

Table 8.13: Pipework Requirements

<table>
<tr><td>Category</td><td>Load Case</td><td>Acceptance Criteria</td></tr>
<tr><td>CAT III & IV
(Design Basis)</td><td>P + Dw + Internal Fire + SMHV
P + Dw + Internal Fire + SL-2</td><td rowspan="3">No breach of confinement or loss of stability (plastic collapse)</td></tr>
<tr><td>BDB
(Scenario 11)</td><td>Normal Operation Loads + SL-3/F
Normal Operation Loads is the Operational Mode (Loads) 0 (plasma operation)</td></tr>
<tr><td>BDB
(Scenario 12)</td><td>Normal Operation Loads + Multiples Fire + SL-3/F

Normal Operation Loads is the Operational Mode (Loads) 0 (plasma operation) (shutdown, maintenance phase) and mode 2 (maintenance with equipment transfer phase).</td></tr>
</table>

Table 8.14: Pipework Load Combination and associated Acceptance Criteria

Category	Load Combination	Service Level	Acceptance Criteria	Damping factor	Reduction factor
III	P + Dw +Tb + SMHV	C	$\frac{PD}{4t} + \frac{0.75i(M_{Sustained} + M_{Seismic})}{Z} \leq 1.33\ S_H$	4%	Not Used in Design Phase
IV	P+Dw+To+SL-2	D	$\frac{PD}{4t} + \frac{0.75i(M_{Sustained} + M_{Seismic})}{Z} \leq n$		
BDB (Scenario 11)	P+Dw+To+SL-3/F	D	$\frac{PD}{4t} + \frac{0.75i(M_{Sustained} + M_{Seismic})}{Z} \leq n$	5%	See ref. 6.3.4

Table 8.15: Pipework Design Acceptance Criteria

SUPPORTS

Supports are designed to ANSI/AISC N690-12, 2012 and ANSI/MSS SP-58-2009. The Load and Resistance Factor Design [LRFD] method is used. Loads are derived from reaction forces in the Caesar II ASME B31.3 analysis to determine the bounding loads for the pipe supports.

System	Requirements to be met.	Seismic Class
PBS31 HCC Supports	Stability, [24] PR1193-R	SC1 (S)

Table 8.16: Support Requirements

Category	Load Combination	Service Level	Acceptance Criteria	Damping factor	Reduction factor
III	NB2-6 [ANSI/AISC N690-12] Dw + To + Ro + SMHV	C	Ru ≤ ϕRn	4%	Not Used in Design Phase.
IV	NB2-9 [ANSI/AISC N690-12] Dw + Ra + Ta + 0.7SL-2	D	Ru ≤ ϕRn		
BDB (Scenario 11)	Dw + Ro + To + SL-3/F	D	Ru ≤ ϕRn	See ref. 6.3.4	See ref. 6.3.4
BDB (Scenario 12)	Dw +Ro+To + Fire + SL-3/F	D	Ru ≤ ϕRn	See ref. 6.3.4	See ref. 6.3.4

Table 8.17: Support Design Acceptance Criteria

8.3.2.5 Seismic Input

The SL-3 seismic event is assumed to be Paleo+1.5SMS.

Unless building FRS are evaluated from the SL-3 ground motion, they shall be assumed to be equal to 1.5SL-2 FRS.

Damping factors used in the design are as follows, taken from table section 5.9 in reference [R26]:

Seismic Level	Category	Damping
SL-1	II	3%
SMHV	III	4%
SL-2	IV	4%

Table 8.18: Damping Factors for Design Basis

Damping factors for the SL-3 load combinations are listed in chapter 6.3.4.

The following reduction factors will be used for the SL-3 seismic event:

TYPE OF COMPONENT	SERVICE LEVEL C	SERVICE LEVEL D
Butt welded piping	1,5	1,75
Steel bolted (non – pre stressed) secondary structures	1,5	2
Steel welded or pre – stressed secondary structures	1,5	2

Table 8.19: Reduction Factors for SL-3 Load

Note: Inside the Tokamak building the reduction factor will be limited to 1.5.

The use of a reduction factor is justified by the ductility in material and the capacity to redistribute stress and loads when stress yield point is reached. In case of dynamic load, this also results in energy dissipation by the structure. These properties are taken into account by the implementation of the reduction factors presented in the table. In case of risk of brittle failure or in case the plastic energy dissipation is limited with respect to the accumulated dynamic energy in the structure (i.e. support with little deformation capacity) the application of a reduction factor is not recommended unless properly justified

8.3.2.6 Qualification

No qualification by testing is required for these HCC as the pipework functional requirement post SL-3 event is containment only.

8.3.3 Cryogenic System (PBS 34)

This section describes the current approach applied for the design of the Hard Core Components of the Cryogenic system (PBS-34), focusing in particular on:

- Codes & Standards applied for the HCC design
- Loading Combination and related Service Level to be verified
- Damping and Reduction Factors applied for each kind of equipment
- Design approach, i.e. quasi-static method vs stress analysis / FEM
- Qualification by Test, if any.

Moreover, this section summarizes the requirements for the assessment of HCCs. See also ref. [R44].

8.3.3.1 Codes and Standards

The Codes applied for the design of the HCCs identified for the Cryogenic systems (PBS-34) are defined in the Functional Specifications, Ref. [R26] and [R27]: the EN standards are applied.

8.3.3.2 Load Combinations

The loading conditions applied for the design of the HCCs of PBS 34, are detailed in the Loading Specifications Ref. [R28], [R29] and [R30].

Focusing at the particular case of seismic event, the current loading combination to be verified is the following:

$$NO + DW + SL-2$$

where:

NO	Normal Operating Conditions
DW	Dead Weight
SL-2	Seismic Level 2

Concerning the HCCs assessment at SL-3, as required in the frame of the Stress Test scenario, the “realistic approach” shall be applied. Focusing on the HCCs identified for the PBS-34 the loading combination to be verified is the following:

$$NO + DW + \frac{SL-3}{F}$$

where:

SL-3	is currently defined as the envelope of Paleo + 1.5SMS. The Floor Response Spectra at SL-3 seismic level will be obtained as 1.5 x Floor Response Spectra at SL-2
F	Reduction Factor, in compliance with chapter 6.3.4.
NO:	Normal Operating Loads correspond to operational mode 0 (plasma operation)

No fire load is applied to the HCC identified for PBS-34

8.3.3.3 Type of Analysis

The design of the HCCs identified for Cryogenic system (PBS-34) is based on the approaches listed hereafter:

- Extra-Flange Sleeve: Refined FEM analysis
- Vacuum Barrier: Refined FEM analysis
- Vacuum Jacket: Piping Stress Analysis plus refined FEM analysis for particular parts of the Jacket
- Process Pipe: Piping Stress Analysis
- Valves: Piping Stress Analysis and refined FEM analysis
- Safety Relief Panel: Piping Stress Analysis
- Purge Line: Piping Stress Analysis
- Cod Boxes: Refined FEM Analysis and Piping Stress Analysis

In the frame of the Stress Test, the assessment of HCCs at SL-3 will be based on the results of the above mentioned analysis. Additional, more refined and realistic analyses could be deemed necessary.

All the details are given in reference [R44].

8.3.3.4 Requirement, Acceptance Criteria and Seismic Classification

As far as the PBS-34 is concerned, two cases have to be distinguished:

- the Hard Core Components belonging to the scope of the Cryolines and Warm Lines, PBS 34.20
- the Hard Core Components belonging to the scope of the Cryodistribution, PBS-34.30
- the aggressors located in Area 53, PBS-34.10.

The HCCs and the aggressors included in the scope of the PBS34.20 (see Ref. [R26] and [R31]) are classified as indicated below:

- Manifold Cryolines (34.2C.A0, 34.2C.F0, 342CK0, 34.2C.HS, 34.2C.HN, 34.2S.OU and 34.2S.OL)
    - Safety Class: SR, except for Vacuum Barrier classified PIC-2
    - Seismic Class: SC1-S
- Quench Line (34.2S.QU)
    - Safety Class SIC-2
    - Seismic Class SC1-SF
- Relief Header (34.2S.R0)
    - Safety Class SR
    - Seismic Class SC1-SF
- Warm Lines (34.2W.xx)
    - Safety Class SR
    - Seismic Class SC1-S, except for Pneumatic Valves classified PIC-2

The HCCs included in the scope of the PBS34.30 (see Ref. [R27]) are classified as indicated below:

- Safety Class Non-PIC
- Seismic Class NSC

However, the SL-2 is considered in the Loading Combination as a Faulted Condition, to be verified in compliance with Service Level D.

The Tanks located in Area 53 (see Ref. [R32]) are classified as indicated below:

- Safety Class Non-PIC
- Seismic Class SC2.

As far as the Loading Combination including the SL-2, the design criteria applied for all the HCCs of PBS-34 are:

- Design Category
  - Faulted Condition in Category IV
- Design Criterion
  - Service Level D, except for the Quench Line (34.2S.QU) and the Relief Header (34.2S.R0) where a more stringent criterion will be applied: currently Service Level A is required, but a Service Level corresponding to "Test" condition could be accepted.

All the details are given in reference [R44].

8.3.3.5 Seismic Input

At the current state, the SL-3 has to be considered as the envelope of Paleo + 1.5 SMS. As indicated in 8.3.3.2, the Floor Response Spectra at SL-3 seismic level will be obtained as 1.5 x Floor Response Spectra at SL-2.

The damping factors applied for the current seismic design at SL-2 of the HCCs identified for PBS-34 are those specified at the Ref. [R29]. In particular, the following values are used:

- Extra-Flange Sleeve 4%
- Vacuum Jacket 4%
- Vacuum Barrier 4%
- Process Pipes 4%
- Valves 3%
- Boxes 3%

All the details are given in reference [R44].

In the frame of the Stress Test, the "realistic approach" shall be applied and the SL-3 Floor Response Spectra to be considered are those corresponding to the following values of Damping:

- Extra-Flange Sleeve 5%
- Vacuum Jacket 5%
- Vacuum Barrier 5%
- Process Pipes 5%
- Valves 5% (3% in case of Service level A)
- Boxes 5% (no convective mode is foreseen for this boxes)

As shown in reference [R44], no reduction factor is used for the current seismic design of the HCC identified for PBS-34 at SL-2.

In the frame of the Stress Test, the "realistic approach" shall be applied and the Reduction Factors (or over-strength value) to be considered are:

- Extra-Flange Sleeve 1.5
- Vacuum Jacket 1.5
- Vacuum Barrier 1.5
- Process Pipes 1.5
- Valves 1 (Service Level A to be verified)
- Boxes 1.5

The use of reduction factor is justified by the ductility in material and the capacity to redistribute stress and loads when stress yield point is reached. In case of dynamic load, this also results in energy dissipation by the structure. These properties are taken into account by the implementation of the reduction factors presented above. In case of risk of brittle failure or in case the plastic energy dissipation is limited with respect to the accumulated dynamic energy in the structure (i.e. support with little deformation capacity) the application of a reduction factor is not recommended unless properly justified.

8.3.3.6 Qualification

As shown in reference in Annex A of reference [R44], no qualification by test is foreseen for the current verification at SL-2 of the HCCs identified in PBS-34.

In the frame of the Stress Test, the qualification of the valves listed in Annex A of reference [R44], shall be performed through shaking table test. Since the valves are fail-safe the following is highlighted:

- the capability of valves to close after SL-3 loads has to be assessed considering a configuration representative of the on-site installation
- no special requirement is given on the actuator, which will be considered as an off-centred mass only.

8.3.4 Tritium Plant (PBS 32 and PBS 64)

This section provides detailed technical guidelines to perform the stress test evaluation of the Hard Core Components (HCCs) of Tritium Plant (PBS 32 and PBS64). This section covers loading, method of analysis and acceptance criteria for:

1. Piping
2. Piping supports
3. Valves

of Tritium Plant HCCs. See also ref. [R45].

8.3.4.1 Codes and Standards

The codes and standards used for the design of Tritium Plant HCCs are:

- Piping systems: ASME B31.3 2012
- Supports: ANSI/AISC N690
- Valves: ASME B16.34

8.3.4.2 Load Combinations

According to the rules defined for the stress test load combinations, the stress test events are to be combined with the normal operation conditions. After the SL-3 event, the environmental conditions resulting from the load combination SL-2 + cat. IV event shall be considered. The seismic load SL-3 and the fire loads are not considered to be concomitant. SL-3 can cause a fire, but the temperature effects of the fire develop as the seismic event is finished. The multiple fire load condition doesn't introduce additional loads to the HCC.

HCC	Load Case	Design Loading Combinations (DLC)	LC	Number of events
Piping Supports Valves REMS panels/skids	BDBA (Scenario 11)	Normal Operation (2) + SL-3/F	V.1	1(1)
	BDBA (Scenario 12)	Normal Operation (3) + SL-3/F + Multiple Internal Fire	V.2	1(1)

Table 8.20: Load Combinations for the Stress Test Assessment

(1) It is assumed for each event 10 equivalent maximum stress cycle whenever a fatigue or cycle load analysis is required.
(2) Normal Operation corresponds to operational mode 0
(3) Normal Operation corresponds to the three operational modes (mode 0, mode 1 and mode 2). The most severe of the three shall be considered.

8.3.4.3 Type of Analysis

For Tritium Plant HCCs linear elastic spectral analysis will be used for piping, supports and components during design phase and for the verification as per a conventional approach. For the stress test assessment when the verification will not be satisfied through conventional approach, other type of analyses such as, time-history analyses will be used for a more realistic approach. Non-linear analysis can also be performed in order to better assess the reduction factor.

8.3.4.4 Requirement, Acceptance Criteria and Seismic Classification

The requirements applied to the HCCs depend on the type of component and its function during and after the stress test accidental event. Four different requirements have been defined (operability, functional capacity, integrity, and stability) and associated service levels (A, B, C, or D).

For the Tritium Plant HCCs, the requirements and service levels are summarised in the table below. The Definition of the requirement is based on the document [R33].

Equipment	Requirement	Service Level
Piping	Integrity	C or D
Support	Stability	D
Valves	Operability	A or B

Table 8.21: Requirement and Service Levels for the HCC of Tritium Plant

PIPING

ASME B31.3 doesn't provide acceptance criteria for service levels C and D. In the document [19], ITER has defined the acceptance criteria for service levels C and D. In accordance with table B-1 of this document, the acceptance criterion for the Tritium Plant HCC piping is:

Service Level	Acceptance Criteria	Damping factor for SL-2	Reduction factor
C	$\frac{PD}{4t} + \frac{0.75i(M_{Sustained} + M_{Seismic})}{Z} \leq 1.33\ S_h$ (*)	4% For	Not Used in Design Phase
D	$\frac{PD}{4t} + \frac{0.75i(M_{Sustained} + M_{Seismic})}{Z} \leq min[2.4Sh;1.5Sy$	BDBA see 8.3.4.5	For BDBA see 8.3.4.5

(*) Symbols in the formulae are based on B31.3 definition. S_h is the allowable stress defined in B31.3

Table 8.22/b Pipework Design Acceptance Criteria for Service Levels C and D (*)

<u>SUPPORTS</u>

Supports acceptance criteria are given in ANSI/AISC N690.
According to the documents [R33], the Tritium Plant HCCs seismic class is SC1-SF.

8.3.4.5 Seismic Input

Currently, the official definition of SL-3 is unavailable.
It has been assumed equal to the envelope of Paleo +1.5SMS.

In accordance with the chapter 6.3.4, the damping factors used in the realistic approach of the stress test methodology are higher than those proposed by the design basis methodology for service levels C and D.
For the Tritium Plant HCCs, the damping factors are summarised in the table below.

Equipment	Service level	Damping (%)
Piping	C or D	5.0
Welded or pre-stressed bolted structure (or support)	D	5.0
Bolted (non-pre-stressed) bolted structure (or support)	D	7.0
Valves	A or B	3.0

Table 8.22: Damping Factors for the HCC of Tritium Plant SL-3 Earthquake

In the conventional approach, the reduction factor is 1.

In case the verification of the HCC cannot be achieved with the conventional approach, the realistic approach will be used, considering ductility factors as follow in accordance with the chapter 6.3.4.

Equipment	Reduction Factor F
Piping	1.5
Welded or pre-stressed bolted structure (or support)	2.0
Bolted (non-pre-stressed) bolted structure (or support)	2.0

Table 8.23: Reduction Factors for the HCC of Tritium Plant

For mechanical equipment and distribution systems located inside the Tokamak complex (generally in buildings equipped with seismic isolator systems) the value has to be limited to 1.5, according to EN 1998-1 Eurocode 8.

The reduction factor will not be used to meet the operability requirement (service level B).

The use of reduction factor is justified by the ductility in material and the capacity to redistribute stress and loads when stress yield point is reached. In case of dynamic load, this also results in energy dissipation by the structure. These properties are taken into account by the implementation of the reduction factors presented above. In case of risk of brittle failure or in case the plastic energy dissipation is limited with respect to the accumulated dynamic energy in the structure (i.e. support with little deformation capacity) the application of a reduction factor is not recommended unless properly justified.

8.3.4.6 Qualification

The tritium plants actuated valves and REMS panels/skids, which are classified as HCC, will be subject to qualification by testing. If the selected components do not have yet this qualification, specific qualification test (shaking table and fire) will have to be carried out.

By analysis the structural integrity and stability of the valve body can be verified, but for operability, it is required to submit the assembly valve + actuator to shaking table to make sure that the stem can close after SL-3 event.

The fire scenario might require qualification of the valve to a certain internal temperature and/or external temperature that still needs to be determined.

8.3.5 HVAC, Fire Suppression Systems, Air Mixing System, Compressed Air, Demineralized Water, Breathing Air (TB04 Systems, PBS 65)

In the following the guidelines and criteria to perform the stress test for different types of Hard Core Components (HCCs) as follows:

- Piping and active components (isolation valves) and associated supports
- HVAC ducts and active components (fire dampers, isolation valves), and associated supports
- Fire Water ceiling sprinkler Pumps, Fire Water Tanks in Pump Houses
- Electrical and I&C components

The inputs, methodology, acceptance criteria, qualification and preliminary margin assessment are presented hereafter. It is considered that all TB04 components are “existing components”. See also ref. [R46].

8.3.5.1 Codes and Standards

In the Tokamak Complex, the approach is to prevent any excessive deformation of all piping (including Fire Water Sprinkler Systems and HVAC Duct to be considered for this HCC report) material and supports, for all the loads to be considered according to [R17], and considering the most stringent stresses limitations.

The HCC components are defined as SC1-SF.

For the loading condition inside the design basis this can be translated by the application of the following RCC-M criteria:

- **RCC-M Criteria 0** for all piping materials and supports for the reference situations (“*situations de calcul*” as per RCC-M C3132).
  For Criteria 0, stresses are limited to 1.0 S_h (equation 6).
  Note: for the Fire Water sprinkler System, conditions associated to the Fire loading have to be considered as “normal” conditions for the system.

- **RCC-M Criteria B** for all piping materials and supports and for accidental loading combinations defined in [R18], [R17] (including the {SL2 + CAT.IV}).
  For Criteria B, stresses are limited to 1.2 S_h

8.3.5.2 Load Combinations

The load combinations for the Beyond Design Basis Accident applied to the defined hard core components fall into two groups:

- SL-3 seismic event in the Tokamak Complex and,
- Multiples fire events in the Tritium Building.

In the load case of SL-3, the SL3 earthquake loading is only combined with Normal Operation, where the Normal Operation Loads correspond to operational mode 0 (plasma operation).

In the load case of Multiples fire event, the Normal Operation Loads correspond to the three operational modes (mode 0, mode 1 and mode 2).
The seismic load SL-3 and the multiple fire loads are not considered to be concomitant. SL-3 can cause a fire, but the temperature effects of the fire develop as the seismic event is finished.

For post-SL3 condition, the load combinations to be taken into account are the following:

- Combination 34 "Internal fire" [R17] (scenario 12 – Tritium building)
- Combination 35 "Helium leak in Galleries" [R17] (scenario 11 – Tokamak building)

8.3.5.3 Requirements, Acceptance Criteria and Seismic Classification

The requirements for the stress test assessment are the following:

TB04 Component	Earthquake Reference	CAT Load Combinations*	RCC-M Criteria
HCC	SL3	BDBA	C
Supports of HCC	SL3	BDBA	D
HCC Supporting Services	SL3	BDBA	C
Supports of HCC Supporting Services	SL3	BDBA	D
HCC Aggressors	SL3	BDBA	D
Supports of HCC Aggressors	SL3	BDBA	D

Table 8.24: Requirement and Service Levels for the HCC of TB04

* The SL3 earthquake loading is only combined with Normal Operations loads

Post-SL3, the loads to take into account, are defined in documents [R17] and [R1] according to:

- Combination 34 "Internal fire" (scenario 12 – Tritium building)
- Combination 35 "Helium leak in Galleries" (scenario 11 – Tokamak building)

For HCC and HCC Supporting Services, the target is to justify the absence of any excessive deformation to be compliant with functional capacity requirements defined.

- RCC-M Criteria C is considered.

For HCC aggressors, the target is to avoid any damage to HCC. Stability and integrity is then required.

- RCC-M Criteria D is considered.

Under a SL3 earthquake, only stability is required for supports of HCC and supports of HCC Supporting Services. Therefore, Criteria D is considered.

Note: a proposal is to consider that all “non-HCC” should be considered as potential HCC aggressors and therefore respect the above mentioned criteria.

If the verification of the above mentioned criteria cannot be achieved, a so-called “realistic” approach can be envisaged (“considering an elastic behaviour with consideration of a reduction factor” as explained in chapter 6.3.4).

In order to demonstrate the robustness of TB04 HCC design against a SL3 earthquake, the following has been proposed:

1. to identify (and quantify as far as possible) the potential margins inherent to the design process

   - refer to 8.3.5.5 “Preliminary Margin Assessment”

2. to identify the type of components for which the identified margins allow to justify *a priori* that the current envisaged design will not be impacted by the new requirements related to the SL3 earthquake

   - refer to 8.3.5.6 “HCC *a priori* justified against SL3”

For the type of components that cannot be justified *a priori,* a “realistic” approach can be envisaged. However, considering that the design is not yet finalized, could be considered more relevant to envisage if necessary, a new “reinforced” design introducing sufficient margins.

In the following, the evaluation of the margin is proposed by considering RCC-M 2012.

This methodology will be applied to the TB04 different types of “HCC”, as indicated below:

- Piping and active components (isolation valves) and associated supports
- HVAC ducts and active components (fire dampers, isolation valves), and associated supports
- Fire Water ceiling sprinkler Pumps, Fire Water Tanks in Pump Houses
- Electrical and I&C components

8.3.5.4 Seismic Input

It is considered that SL3 ground response spectrum is assumed as the envelope of Paleo + "1.5 x SMS".
Without any further information, it is also assumed that the building behaviour is not affected or modified by the magnitude of the SL3 soil spectra, and that the same linear approach can be applied. As a consequence, and as a first approach, "SL3 FRS" will be derived from "SL2 FRS" with a 1.5 coefficient.

In case the realistic approach will be selected, the following coefficients will be used:

- Damping factors coming from proven literature and EPRI code (see [R7],[R15]) for SL3 (5% for piping and supports, 7% for HVAC ducts and supports, 3% for pumps, 5% for electrical cabinets) see Table 1
- Stress limitation higher than Level D for HCC aggressors. For instance, it could be considered a limit of 3 S_h (instead of 2.4 S_h in level D), which correspond to an actual limitation of min{2 Sy; 0.85 Su}. This will give an additional margin of 1.25.

For more information on damping and reduction factor see chapter 6.3.4.

8.3.5.5 Preliminary Margin Assessment

In this paragraph, the new requirements for the consideration of a SL3 earthquake for HCC, HCC Supporting services, and HCC aggressors will be compared with the initial design with regards to the consideration of the SL2 earthquake (and related combinations).
In this frame, the principle of the margin evaluation developed in this paragraph is, for a given type of component, to:

- Identify potential sources of margins (margins related to the stress criteria from code allowable, margins related to design solution, margins related to the load combinations).
- Quantify these margins (as far as possible),
- Pile these margins.

Finally, an assessment of the adequacy of these margins with respect to the expected loads induced by a SL3 earthquake is presented.

8.3.5.5.1 Piping

- Margin related to Code Criteria

For Criteria B, stresses are limited to 1.2 Sh (RCC-M C3654, equation 10):

$$S_a = \frac{P_{max}\ D_o}{4\ t_n} + 0,75\ i\ \frac{M_A + M_B}{Z} \leq 1,2\ S_h \qquad (10)$$

Analysis of requirements for HCC (and supporting services) / HCC aggressors (see8.3.5.1):
For Criteria C, stresses in equation 10 are limited to 1.8 Sh (RCC-M C3655).
For Criteria D, stresses in equation 10 are limited to 2.4 Sh (RCC-M C3656).
Note: S_h is the allowable stress defined in RCC-M Z III 310.

There is thus essentially a **margin coefficient (related to the criteria) of 1.5** between Criteria B and Criteria C (to be considered for HCC and HCC supporting services), and a **margin coefficient (related to the criteria) of 2** between Criteria B and Criteria D (to be considered for HCC aggressors).

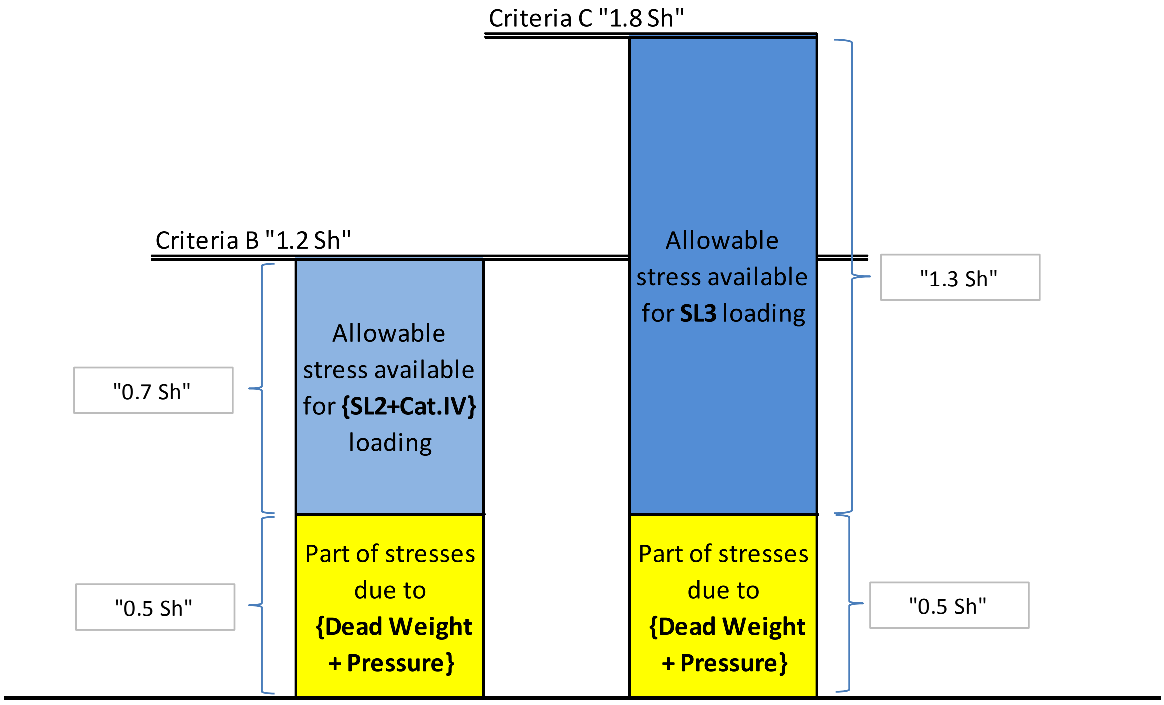
- Margin related to Design Solution

During supporting spacing pre-sizing, and based on the return of experience from other projects, the support spans with a target value for RCC-M C3552 equation 6 (limitation of stresses due to the dead weight and internal pressure) of 0.5 S_h, has been selected.

For a Criteria B, this leads to an actual limitation of the occasional/exceptional loads term in RCC-M equation 10 of 0.7 S_h (0.5+0.7=1.2).
For a Criteria C, this leads to an actual limitation of the occasional/exceptional loads term in RCC-M equation 10 of 1.3 S_h (0.5+1.3=1.8).

For criteria B, in the worst case if Cat IV is null then SL2 represent 0.7 S_h, the ratio between SL3 and SL2 for criteria C would be SL3 = (1.3/0.7) SL2 = 1.85 SL2

There is thus essentially a **margin coefficient of 1.85** (1.3/0.7) between occasional/exceptional loads considered with Criteria B (i.e. SL2+Cat.IV) and occasional/exceptional loads considered with Criteria C (i.e. SL3).



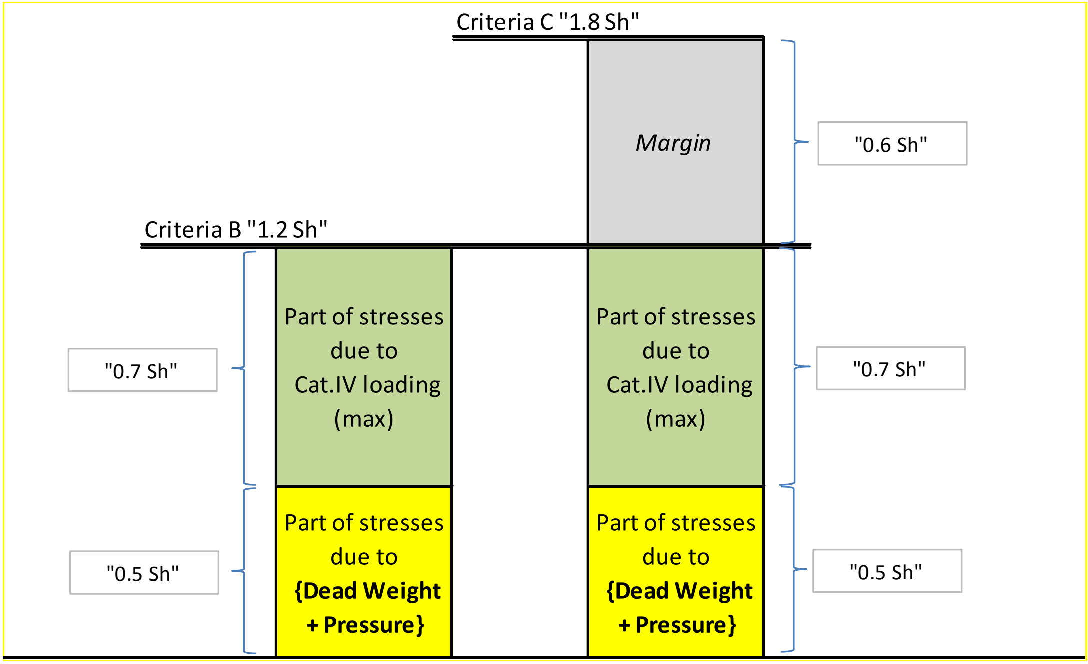
Applying the same approach for potential HCC aggressors, it could be identified a **margin coefficient of 2.7** ([2.4-0.5]/0.7) between occasional/exceptional loads considered with Criteria B (i.e. SL2+Cat.IV) and occasional/exceptional loads considered with Criteria D (i.e. SL3).

- Margin related to Load Combinations

According to [R18], SL2 loadings have to combine with other Category IV accidents.
For the stress test assessment, SL3 loadings have to combine only with Normal Operation conditions.

This means that the "CAT. IV" part of the stresses generated by the {SL2+CAT.IV} loading will not be present when considering the SL3 loading.
This leads to an **additional margin** (to be considered in addition to the margins exhibited in the previous bullets), which cannot be currently quantified.
Since the "Post SL3" environmental conditions are not known to date, then "the environmental conditions will be the same used in the baseline for the SL-2 seismic event in CAT IV, when verifying HCC for Operability, Integrity such as tightness/confinement and Functional Capacity."

Using the same approach than above, but considering a minimum part for SL2 = 0 S_h, this leads to:



If it happens that "Post SL3" environmental conditions are more severe than the one currently defined, the figure above shows that there is a margin coefficient of 1.85 ((0.6+0.7)/0.7) with regards to stresses associated to the environmental conditions).

Note 1:

The way to quantify this margin (related to the load combinations) would be to identify, for the "worst" configuration (configuration for which the seismic loads are dominating), the ratio X (SL2/(SL2+Cat IV) of stresses induced by the SL2 loading compared to those induced by "CAT.IV" conditions loading. The total margin would then be 1.3/X (with X<0.7), meaning that the margin would be greater than 1.85.

- Conclusion for Piping

It has been identified that:

- There is a margin greater than 1.8 for HCC and HCC supporting services
- There is a margin greater than 2.7 for potential HCC aggressors.

These margins should be sufficient to cover the increase of stresses induced by a SL3 loading combined with Normal Operating conditions.

8.3.5.5.2 Piping Supports

- Margin related to Code Criteria

Analysis of requirements for HCC (and HCC Supporting Services) / HCC aggressors (see 8.3.5.1):

In RCC-M, design rules for supports are defined in volume H or volume Z.

To summarize, RCC-M defines:

- a coefficient 4/3 (=1.3) between stresses limitations for Criteria C and Criteria O/A/B (§ Z VI 2120)
- a coefficient 1.66 between stresses limitations for Criteria D and Criteria O/A/B (§ Z F 1370)

For supports (of HCC, of HCC Supporting Services and of HCC aggressors), Criteria D is to be considered. There is therefore a **margin (related to the criteria) coefficient of 1.25** (1.66/1.33).

- Margin related to Design Solution

Design of piping supports is based on frequency criteria. The supports are designed so that the first natural frequency of the support is greater than the cut-off frequency. Supports are then considered as rigid.

This design based on frequency criteria and not on resistance criteria, guarantees margins regarding the stress analysis. Based on other projects' feedbacks, the design ratio (ratio between the calculated stresses and the allowable stresses) of supports designed according to frequency/rigidity criteria should not exceed 50%/60%.

There is a very good confidence of having **a margin not less than 2 for HCC supports, HCC aggressor's supports and HCC Supporting Services supports.**

- Margin related to Load Combinations

The same approach than for piping load combinations can be applied for supports. This will lead to additional margin but not yet quantifiable.

- Conclusion for Piping Supports

Margins for piping supports have been identified and have been quantified as greater than 2 for HCC supports, HCC aggressor's supports and HCC Supporting Services supports.

These margins should be sufficient to cover the increase of stresses induced by a SL3 loading combined with Normal Operating conditions.

8.3.5.5.3 Piping Active Components

HCC Piping active components (isolation valves) will be subject to test-based qualification (shaking table) to demonstrate operability after a SL3 earthquake (refer to 8.3.5.7 Qualification).

8.3.5.5.4 HVAC Ducts and Supports

HVAC ducts and supports currently identified as HCC are designed with the same rules and criteria than the one for piping. Therefore the analysis for Piping and Piping supports apply to "HCC" HVAC ducts and supports. Therefore, by analogy with Piping and supports analysis, for HCC HVAC ducts and supports, the margins should be sufficient to cover the increase of stresses induced by a SL3 loading with Normal Operating conditions.

8.3.5.5.5 HVAC Active Components

HCC HVAC active components (fire dampers, isolation valves) will be subject to test-based qualification (shaking table) to demonstrate operability after a SL3 earthquake (refer to 8.3.5.7 Qualification).

8.3.5.5.6 Fire Water Sprinkler Pumps and Fire Water Tanks

The fire water sprinkler pumps will be subject to test-based qualification (shaking table) to demonstrate operability after a SL3 earthquake (refer to 8.3.5.7 Qualification).

<u>Case of Fire Water tanks</u>

In case of Fire Water tanks (steel tank) it is suggested to use the same approach of the design developed in the previous section and to apply the relevant codes and criteria (RCC-M J3000).

8.3.5.5.7 Electrical and I&C Components

HCC Electrical and I&C cabinets will be subject to test-based qualification (shaking table) to demonstrate operability after a SL3 earthquake (refer to 8.3.5.7 Qualification).

8.3.5.5.8 Anchorage

In the Tokamak Complex, the HCC will be anchored to fastening systems.
Two technologies are possible:

- Embedded plates (cast in place fastening system)
- Post-installed plates (post-installed fastening system)

Both of them are extracted from Design Catalogue of Cast-in-Place and Post-installed Fastening Systems ref [R34]
If the reaction forces are calculated with SL3 instead of SL2, the impact of SL3 depends of the margins available in design basis.

The currently available Catalogue of Standard Cast in Place Fastening Systems is still applicable and the embedded plates, previously selected to withstand loads from SL2 (and relevant combinations), will withstand loads from SL3 thanks to the margin evaluation.

In the Pump Houses, the same catalogue of Cast in Place Fastening Systems provided for Tokamak Complex buildings will be used.

A potential margin can be exhibited in the calculation methodology of the reaction forces on the plate. Currently, one envelope tensor (reaction forces Fx, Fy, Fz and moments Mx, My, Mz) is calculated and used for the interface with the plate.

Usually this tensor is based on the maximum values of forces in each direction and maximum values of all moments. This tensor is then envelope but it is not realistic (not representative of a real load case). The consideration of more realistic tensors will lead to margins in the design of the plate. See also section 8.2.4.

8.3.5.5.9 Margin due to Design Practice

According to industrial practices and as already applied on other projects, the objective is to preserve as much as possible margins during design phase. For instance, for piping (or support) stress analysis, a target of 75% design ratio (ratio between the calculated stresses and the allowable stresses) is envisaged (i.e. design margin of 25%).

This margin in the design may be used to accommodate slight adaptations during construction.

8.3.5.6 HCC "a priori" justified

As a conclusion of the margin evaluation presented in the previous paragraphs, and based on the data know to date, the margins identified for all "static" components identified as "HCC" are sufficient to cover the increase of stresses induced by a SL3 loading combined with Normal Operating conditions.

Meanwhile, HCC Active components (such as fire dampers, isolation valves, pumps) will be subject to test-based qualification (shaking table) to demonstrate operability after a SL3 earthquake (refer to 8.3.5.7 Qualification).

8.3.5.7 Qualification

The HCC (and services supporting HCC) with an operability requirement after a SL3 earthquake will require a specific test-based qualification against SL3 (qualification according to RCCM recommendations).

Currently, the qualification of these components is limited to SL2.
The requirement of a qualification to SL3 may have an impact on the qualification process:

- possible reconsideration in the choice of the qualification laboratory as the shaking-tables of laboratories currently retained may not be adapted to such acceleration,

- as the qualification to SL2 can already be challenging, possible impact on the design of these HCC active components (up to a change of component and manufacturer)

- to isolate the component in the vertical direction (not efficient in the horizontal directions regarding the already seismic pads action) and to impose force in the horizontal direction.

- to relax the current design requirements in terms of leak tightness (Isolation Valve) or Fire effect (Fire Damper)

8.4 Electrical and I&C Systems

8.4.1 Coil Power Supply (PBS 41)

This section provides detailed technical guidelines to perform the stress test for Hard Core Components (HCCs) of coil power supply and distribution (PBS 41). The inputs, methodology acceptance criteria and margin of the testing actions have been presented hereafter.

This section also comprises a compilation of technical guidelines that provide acceptable methods to comply with the stress test approach.

For more information see ref [R47].

8.4.1.1 Codes and Standards

For the coil power supply, the codes and standards used in design are:

- ISO 6258–Nuclear power plants – Design against seismic hazards
- ASME 2007 Section III, Division 1 –Appendix N - Dynamic Analysis Methods.
- RCC-MR: Design and construction rules for mechanical components of nuclear installations
- ASCE 4-98 - Seismic Analysis of Safety-Related Nuclear Structures and Commentary.
- Codes for strength analysis of equipment and pipelines of nuclear power plants/ Rules and regulations in nuclear power engineering (ПНАЭ) Г-7-002-86, Moscow, Energoatomizdat, 1989 (in Russian).
- ASN Guide 2-01 - Taking seismic risk into consideration for nuclear facility civil work design

8.4.1.2 Load Combinations

Until when the extreme earthquake spectra will not be available, the extreme earthquake SL-3 will be assumed as the envelope of Paleo + 1.5×SMS. For the scenario 11, the seismic earthquake loading are only combined with normal operating loads (corresponding to the operational mode 0). For scenario 12, since the HCCs of PBS 41 are mainly penetrated busbars in building 11, and they are not required to resists to events as scenario 12 specified, the multiple fire load combination are not applicable to HCCs of PBS 41.

All the HCCs of PBS 41 are one kind of components, DC busbars and their supports.

The seismic load combination of these busbars and supports is:

$1.0\ DW + 1.0\ LL + (E_{SL\text{-}3}^2 + SAM^2)^{1/2}/F$

Where:

DW= Dead Load;

LL= Operating live load during normal operation;

F= Reduction factor;

$E_{SL\text{-}3}$= Extreme Seismic Loads;

SAM= Seismic Anchor Motion

SAM stresses due to the SL-3 should be included whenever they are judged to be significant.

Fire load combinations are not applicable to HCCs of PBS 41.

8.4.1.3 Type of Analysis

The DC busbars of PBS 41 have been modelled and analysed during the design phase using Finite Element Method (FEM) (modal analysis and linear response spectrum method).

In the validation of their performance and functions in extreme earthquake situation, the DC busbars will be divided into several segments, and principal frequencies will be calculated with model analysis. The FRS of SL-2 will be used as seismic spectra input of the linear response spectrum analysis, and then the deformation/displacement and stress distribution of the busbars and supports will be worked out. The results of SL-1 and SL-3 will be calculated respectively by multiplying factors of 1/3 and 1.5. [R35].

For the stress test in addition to the response spectrum analysis, other type of analyses such as time – history linear analyses can be used for a more realistic approach.

8.4.1.4 Requirement, Acceptance Criteria and Seismic Classification

Most of the requirements, acceptance criteria and associated seismic classification for the stress test scenarios for the PBS 41 HCCs are kept equal to those of the design basis. The HCCs of PBS 41 are DC busbars penetrating from building to building 11, and those penetrating from L4 to L3 in building 11. Their function for the stress test scenarios is to keep confinement.

The leakage rate, acceptance criteria and seismic classification are shown in table 8.25.

The busbars and associated supports must ensure the structure stability requirement with limited movement in order to guarantee the confinement function of the busbar penetrations

HCCs of PBS 41	Leakage rate	Acceptance Criteria	Seismic Classification
DC busbars for Magnets	<100 volume %/day @300 Pa pressure differential; <820 volume %/day at 0.02 MPa pressure differential	D	SC-2
DC busbars for in vessel coils	<100 volume %/day at 0.1 MPa pressure differential <5.5 volume %/day at 300 Pa pressure differential	D	SC-2

Table 8.25: Requirements for HCCs of PBS 41

Note: the leak rate is designated to the room in B11, not the single penetration

8.4.1.5 Seismic Input

At present, the official seismic input is unavailable. The extreme seismic input has been assumed the envelope of Paleo + 1.5 SMS.

For the definition of the FRS in the Tokamak complex, the FRS calculated for SL-2 shall be increased by a factor 1.5 (SL-3 FRS = 1.5 x SL-2 FRS).

The HCCs of PBS 41 are DC busbars (aluminium) and their supports (steel). The supports are bolted steel structural supports and the DC busbars are clamped and bolted by their supports. According to the Percent Critical Damping of the EPRI NP-6041, these DC busbars and their supports can be classified as welded or pre-stressed bolted steel structures. The damping value used in the stress test scenario will be 5% (see paragraph 6.3.4) (the damping is 4% in the design basis, see reference [R35]). For the detailed information HCCs of PBS 41, see document *Detailed list of HCCs PBS 41(IDM_D_JE43GH v1.4)*.

The following reduction factors will be used for the SL-3 seismic load combinations:

F_D=1.5 for DC busbars of magnets,

F_D =1.5 for DC busbars of in VV coils.

For the busbar supports the reduction factors will be equal to:

F_D =1.5[1] for busbar support inside the Tokamak

F_D =2.0[1] for busbar support outside the Tokamak

in agreement with paragraph 6.3.4.

Note 1: these factors are valid for components designed to AISC allowable, which are typically limited to 0.8 to 1.0 Sy. In case of different codes with respect AISC, the use of reduction factors have to be properly justified.

8.4.1.6 Qualification

For the DC busbars penetrated through Building 11 and their supports, the stability of their structure and the margin of their design can be demonstrated by analysis. Therefore, no testing is required for the qualification of these PBS41 HCCs. For the detailed information HCCs of PBS 41, see document *Detailed list of HCCs PBS 41(IDM_D_JE43GH v1.4)*.

8.4.2 Electrical Power Distribution (PBS43 and PBS 44)

This section comprises a compilation of technical guidelines that provide acceptable methods to comply with the stress test approach.

This section covers, loading, method of analysis and acceptance criteria for:

1. **Cable trays. Including cable trays supports, cable loads and cable trays connections, for HCC cables.**
2. **Ultimate Power Supply. Including Ultimate Generators, UPS, DC chargers, batteries, Distribution Boards and Trenches.**

Cable Trays and Ultimate Power Supply are part of the proposed Hard Core Components for PBS 44 and PBS43.

For more information see ref [R48].

8.4.2.1 Cable Trays (PBS 44)

8.4.2.1.1 Codes and Standards

The adopted design code for Cable Tray Supports is the 1994 edition of ANS/AISC N690, Supplement 2 (2004) [R36].

AISC N690 covers two different design concepts; one is Allowable Stress design (ASD) concept using safety factor and the other is a Load Resistant Factored Design (LRFD) concept using a load factor for applied loads and the resistance factor for material capacities. **The 1994 edition of ASIC N690 has adopted the ASD. This is the edition that has been officially approved by United States Nuclear Regulatory Committee (USNRC), including Supplement 2 (2004).**

8.4.2.1.2 Load Combinations

Here below it is reported the load combinations used in the design basis and the load combination for the stress test assessment.

- <u>Existing Load Combinations for Trays Structure in the Design Basis</u>

- Dead Loads (DL)
  - Self-weight of the structural members
  - Mass of cable trays including covers and cables
- Construction Live Loads (LL)
  - Mass of 100 kg for the construction and inspection personal standing.
- Seismic Load (Es)

  SIC & Non-SIC cable tray system components in Tokamak Complex are classified SC-1 or SC-2.
  Seismic Load is based on the SL-2 seismic level.
  Floor Response Spectra (FRS) for SL-2
  7 % Damping Ratio for SL-2.

- Load Combinations:

Load Conditions	Dead Load (D.L.)	Live Load (L.L.)	Seismic Load (E_s)
Construction/ Normal	1	1	-
Abnormal/Extreme Environmental	1	-	1

Table 8.26: Seismic Load Combinations for the Design Basis

- Load Combinations for SL-3 Event

For the earthquake scenario (Earthquake Tokamak Building) the SL-3 is combined with normal operation conditions, corresponding to operational mode 0.

- Dead Loads (DL)
  - Self-weight of the structural members
  - Mass of cable trays including covers and cables
- Seismic Load (Es)
  - Seismic Load is based on the SL-3 seismic level
  - Floor Response Spectra (FRS) for SL-3
  - Damping Ratio for SL-3.

Load Condition	Dead Load (DL)	Live Load (LL)	Seismic Load (Es)
SL-3	1.000	0	1.000/F

Table 8.27: Seismic Load Combinations for the Stress Test

1.0 DL + SL-3/F

F= Reduction factor (see 6.3.4)

- Load Combinations Fire Scenario in Tritium Building

For the fire scenario (Multiples fire in Tritium Building) the seismic load SL-3 and the fire loads are not considered concomitant.

- Fire Protection in Design Basis

The fire protection design follows the ITER Safety Requirement Room book [R37].

The cable trays in critical areas (see table below) shall be covered by fire protection envelope, to extract the cable fire load in that area.

B2	B1	L1	L2	L3	L4*	L5	Shafts
14-B2-20	14-B1-20	14-L1-20	14-L2-20	14-L3-20	14-L4-20	14-L5-20	V1
14-B2-21	14-B1-21	14-L1-21	14-L2-21	14-L3-21	14-L4-21	14-L5-21	V4
14-B2-22	14-B1-22	14-L1-22	14-L2-22	14-L3-22	14-L4-22		All levels
14-B2-24	14-B1-22a	14-L1-23	14-L2-23		14-L4-23		
14-B2-25	14-B1-23	14-L1-23A	14-L2-24				
	14-B1-24	14-L1-23B					
	14-B1-25	14-L1-23C					
	14-B1-26	14-L1-24					
	14-B1-27						
	14-B1-28						
	14-B1-28a						
	14-B1-29						

Table 8.28: Cables Trays in the Critical Area

In addition, when two redundant safety trains are in the same fire sector, the intrusive train has also a fire-wrapping around the cable tray to guarantee the functionality of the cable under a fire condition according to the ISO-834 exposure curve.

8.4.2.1.3 Type of Analysis

The recommended dynamic analysis to be used is **Response Spectrum Analysis** (RSA).

The procedure of response spectrum analysis is based on the following main steps:

1. Generate a FE model of the structure with all supports included
2. Extract the natural vibration modes
3. Select a damping value (see point 8.4.2.1.5)
4. Choose the FRS curve corresponding to the position and damping in the Tokamak Complex.
5. Perform 3 Response Spectrum analysis for the envelope for all the points in one level on each direction x, y, and z.
6. Combine the results from the 3 separate excitations by the Square Root of the Sum of the Square (SRSS) rule.

Finally, the results in previous point will be combined with those obtained from the application of the component weight.

Other types of analyses are also allowed to be performed for the Stress Test assessment:

- Linear elastic Time History analysis.
- Non-linear static analysis
- Non-linear Time History analysis.

8.4.2.1.4 Requirement, Acceptance Criteria and Seismic Classification

The Standard Review Plan Section 3.8.3 (NRC NUREG-0800) of U.S. Nuclear Regulatory Commission, ''Concrete and Steel Internal Structures of Steel or Concrete Containments'' shows the acceptance criteria of design codes, standards, and specifications for steel internal structures and Other Seismic Category I Structures.

The use of a realistic approach is foreseen for the seismic qualification by analysis of the cable trays and supports in order to verify **Stability requirements**. The qualification by analysis has to clearly demonstrate that the capacity exceeds the total demand.
According with AISC-N690-94, the Allowable Stress Design considers that the allowable stress of material F_a for each structural component shall be equal or less than the yield stress of material F_y, multiplied by a factor *alpha* that decreases the yield stress.

Description	**Design Concept**	**Designation**
ASD (Allowable ***Stress*** Design)	$F_a \leq \alpha F_y$	AISC N690 1994

Table 8.29: Allowable Limit in N690-94

For each category (from Normal up to Extreme and Abnormal) it is associated the load combinations and the Stress Limit Coefficient. Generally, depending on the category, the stress limit coefficient increases the allowable as follows

Load Combinations And Applicable Stress Limit Coefficients

Category	Load Combination[f]	Stress Limit Coefficient[b,h]
Normal	1. $D+L$ 2. $D+L+R_o+T_o$	1.0[c]
Severe[i]	3. $D+L+W$ 4. $D+L+E_o$ 5. $D+L+W+R_o+T_o$ 6. $D+L+R_o+T_o+E_o$	1.0[c]
Extreme	7. $D+L+R_o+T_o+W_t$ 8. $D+L+R_o+T_o+E_{ss}$	1.6[g]
Abnormal[d]	9. $D+L+R_a+T_a+P_a$	1.6[g]
Abnormal[d,e] Severe	10. $D+L+R_a+T_a+Y_r+Y_j+Y_m+E_o+P_a$	1.6[g]
Abnormal[d,e] Extreme	11. $D+L+R_a+T_a+Y_r+Y_j+Y_m+E_s+P_a$	1.7[g]

[a]Coefficients are applicable to primary stress limits given in Sections Q1.5.1, Q1.5.2, Q1.5.3, Q1.5.4, Q1.5.5, Q1.6, Q1.10, and Q1.11.

[b]In no instance shall the allowable stress exceed $0.7F_u$ in axial tension nor $0.7F_u$ times the ratio Z/S for tension plus bending.

[c]For primary plus secondary stress, the allowable limits are increased by a factor of 1.5.

[d]The maximum values of P_a, T_a, R_a, Y_j, Y_r, and Y_m, including an appropriate dynamic load factor, shall be used in load combinations 9 through 11, unless an appropriate time history analysis is performed to justify otherwise.

[e]In combining loads from a loss of coolant accident (LOCA) and a seismic event the SRSS (square root of the sum of the squares) may be used, provided that the responses are calculated on a linear basis.

[f]All load combinations shall be checked for a no-live-load condition.

[g]In load combinations 7 through 11, the stress limit coefficient in shear shall not exceed 1.4 in members and bolts.

[h]Secondary stresses which are used to limit primary stresses shall be treated as primary stresses

[i]Consideration shall also be given to snow and other loads as defined in ASCE 7.

Table 8.30: Load Combinations and Associated Stress Limit Coefficients, extracted from N690

According with the above table and the design values for normal conditions, the alpha values are classified in the next table

Description	Load Conditions		Ratio ③ (=② / ①)	Load Factor (=1 / ③)
	Normal ①	Abnormal ②		
Tensile	0.6 x F_y	0.95 x F_y	1.6	0.625
Bending	0.6 x F_y	1.6 x 0.6 x F_y	1.6	0.625
Shear	0.4 x F_y	0.95 x $F_y/\sqrt{3}$	1.4	0.715

Table 8.31: Alfa Coefficients

8.4.2.1.5 Seismic Input

Earthquake ground motion of SL-3 has been assumed as the envelope of Paleo + 1.5 × SMS.

For the definition of the FRS, it has been considered in the present methodology the provisional use of 1.5xSL2FRS.

The damping values are intended for elastic seismic analysis where energy dissipation is approximated by viscous damping. The proposed damping value for cables trays are show in the Load Specifications ref [R28] in case of a SL1 and SL2 event.

System		SL-1	SMHV and SL-2
General	Welded steel or bolted steel with friction connection	3%	4%
	Bolted steel with bearing connection	5%	7%
Piping	Piping System	3%	4%
Electrical distribution	Cable tray System - Maximum Cable loading	7%	10%
	Cable tray System - Empty	5%	7%
	Conduit System - Maximum Fill	5%	7%
	Conduit System - Empty	3%	7%

Table 8.32: Damping values in the Design Basis

The selected dumping factor used in the calculation of the cable trays in case of SL1 event is 5% and in case of SL2 event is 7%, whatever the percentage of cable filling. This is used because of conservative analysis and design for cable tray supports. **A damping factor of 15% for cable trays and 7% for electrical conduits is proposed in case of a SL3 event, according with proven literature such as EPRI NP-6041-SLR1 standard, see chapter 6.3.4.**

Distribution Systems	
Piping System	5.0
Conduit	7
Instrument tubing	7
Cable tray	15.0
HVAC Duct	7.0

Table 8.33: Damping Values in the Stress Test Assessment

According with ASC/SEI 43-05, ''Seismic Design Criteria for Structures, System and Components in Nuclear Facilities'', 2005 (table 8.1), the following reduction factors have been proposed for cable trays and electrical conduits, see also chapter 6.3.4.

Distribution Systems	
Piping System	
- Butt joined groove welded pipe	1.75(1)
- Socked welded pipe	1.5
Conduit	1.5
Instrument tubing	1.5
Cable tray	1.5
HVAC Duct	1.5

Table 8.34: Reduction Factor in the Stress Test Assessment

For the mechanical equipment and distribution system located inside the Tokamak complex, the values have to be limited to 1.5.

The use of reduction factor is justified by the ductility in material and the capacity to redistribute stress and loads when stress yield point is reached. In case of dynamic load, this also results in energy dissipation by the structure. These properties are taken into account by the implementation of the reduction factors presented above. In case of risk of brittle failure or in case the plastic energy dissipation is limited with respect to the accumulated dynamic energy in the structure (i.e. support with little deformation capacity) the application of a reduction factor is not recommended unless properly justified.

8.4.2.1.6 Margin in the Design Basis

The existing Cable Tray Support Design (based on ANSI/ASIC N690-94) and performed by KEPCO E&C takes into account the following basic criteria for each member:

- **For design loads: SIR ≤ 0.8 (Stress interaction Ratio):** The applied stress IR (Interaction Ratio) as 0.8 is the design stress limitation per designer engineering practice based on engineering judgement. That is embedded 20% safety margin in cable tray design calculation and 25% in the loads.

8.4.2.2 Ultimate Emergency Power Supply (PBS43)

The Ultimate Emergency Power Supply (hereafter described as UEPS) System shall be designed to feed all Hard Components loads as consequence of the two envelop scenarios that can cause a ''Total loss of power supplies'' :

- Scenario 11: Cumulative accident situations in the Tokamak Building
- Scenario 12: Cumulative fire outbreaks in tritium facility process rooms

According with ref [R38], the list of HCC that integrate the UEPS is:

- Ultimate Generators: To provide electrical power to interruptible 400 Vac and 230 Vac HCC loads.
- Ultimate Fuel Transfer System: To provide a certain level of autonomy to the Ultimate Generators.
- Ultimate UPS: To provide electrical power to uninterruptible 400 Vac and 230 Vac HCC loads.
- Ultimate DC charger and batteries: To provide electrical power to uninterruptible 110 Vdc and 48 Vd HCC loads.
- Ultimate Distribution Boards: To distribute the energy between the loads. In all rages of voltages and types AC-DC.

Also the trenches between the building in which diesel will be located and the HCC to be supplied have to be considered a HCC. See also reference [R38].

Could be the case that one or more of the UEPS components will not be needed because of the non-using of one or more type of voltage. This must be decided during the design phase and once the voltage of the instruments is set.

The UEPS system will feed the HCCs loads only when the Emergency Power Supply (EPS) (*) components cannot provide the operability function to these loads in case of an extreme event. In this case, the power supply will be transferred through an automatic transfer device from the EPS components to the UEPS components. The signal that will trigger this transfer switch could be a local signal (for example an under-voltage relay), a remote signal (for example a detection signal for high level earthquake) or the combination of both. As back up, also manual starting is considered.

* The Emergency Power Supply (EPS) System feed all emergency loads, which are important to safety, classified into PIC. Even in the event of LOOP (loss of off-site power), the EPS system shall provide the emergency loads with reliable electricity with sufficient capacity and duration for their due performance. The two trains of EPS serve as a full-capacity independent on-site standby power source, satisfying the single failure criteria. EPS components are classified as SC-1-SF so they must comply with the safety requirements (Single Failure

Criterion, Independency, redundancy) in case of a SL2 event. In normal operation EPS trains A and B is connected with the ITER SSEN network and feed SIC loads. It is proposed that it feeds the HCCs loads in design basis events.

The design for the UEPS components is proposed to be the same that for the EPS components. The main difference is that not all the safety requirements must be applied to the UEPS components. In particular the requirements related with the own definition of Ultimate Power system that consist on a dedicated single network. So the following safety requirements are not applicable: Single Failure Criterion; Redundancy; Independence.

The seismic requirement will be increased to an SL3 event.

For the extreme situation, as SL-3, the UEPS must remain in operation. Level B criteria shall be maintained.

In addition, UEPS shall be designed with the requirement that any aggravated accident (BDBA) cannot constitute Common Cause Failure (CCF) of both EPS and UEPS.

8.4.2.2.1 Codes and Standards

The selected Standards and Codes that the UEPS components need to be followed are the same that the EPS components need to comply with. In particular for the design and qualifications for seismic events are:

- RCC-E (2012), Design and construction rules for electrical equipment of nuclear islands.
- IEC 60780, Nuclear Power Plants – Electrical Equipment of Safety System – Qualification.
- IEC 60980, Recommended Practices for Seismic Qualification of Electrical Equipment of Safety System for Nuclear Power Plants.

8.4.2.2.2 Load Combinations

Detailed load combinations for each electrical and mechanical component shall be developed by the Manufacturer.

Design Loads of the Emergency Diesel Generator and its ancillary components comprises:

(1) Seismic load for SL2 event,

(2) Design pressure

(3) Nozzle load,

(4) Thermal (expansion) load

(5) Dead weight.

Allowable values and limits in service level C and D for mechanical components (ref [R19]) shall be respected as requirements of Integrity and Stability for Category III and IV.

Design Loads of the Ultimate Emergency Diesel Generator and its ancillary components will be properly defined by the manufacturer. The UEPS is classified as new HCC, and then the SL-3 seismic event will be combined with Normal operation loads. The requirement for a new HCC is the operability. Service level B criteria (according to ASME section III or RCC-M or equivalent) for Operability will be required for UEPS components.

8.4.2.2.3 Requirements

According with IEC 60980, the seismic qualification shall demonstrate the safety system equipment's ability to perform its required function during and/or after the time it is subjected to the forces resulting from one S2 earthquake. In addition the equipment should withstand the effects of a number of S1 earthquakes prior to the application of an S2 earthquake.

For seismic levels, The ITER Project uses similar definition for seismic levels (SL-1 and SL-2). These definitions are given in Load Specifications (LS) [R28] and are consistent with IAEA Safety Guide 50-SG-S1. In the case of a Ground motion level 2 (S2), *the ground motion is considered to be the* ***maximum earthquake potential at the site area.***

IEC 60980 defines the S2 earthquake as *the earthquake that produces the* ***maximum vibratory ground motion*** *for which certain structures, systems and components are designed to remain functional. Those are essential to assure proper function, integrity and safety of the total system which is to be qualified.*

So, it is proposed to follow the seismic qualification requirements defined in IEC 60980 for a S2 earthquake with the **maximum vibratory ground motion calculated as consequence of a SL-3 event.**

The seismic requirements shall specify: time duration, frequency range, acceleration values.

Information which provides these data may be: vibratory motion; strong motion time duration; RRS (Required Response Spectrum) for the fixing points on which the equipment will be mounted. The RRS shall include data for the principal axis (horizontal) and the vertical axis, and should be specified for 2%, 5% and 7% damping ratio.

Standard IEC 60980 gives the option to the manufacturer to choose between two test sequences: Five S1 (SL-1) and one S2 (SL-2) earthquakes; or, two S2 earthquakes. This is generally assumed, unless a different number can be justified. In our case, **for a SL3 qualification**, for each HCC must be agreed the test sequence to be implemented and specified. One proposal is to perform **one SL-2 earthquake and two SL-3 earthquakes.**

8.4.2.2.4 Qualification

Some of general methods to achieve this qualification are described in IEC 60980. Every one of the Ultimate Emergency Power Supply must follow one of these three methods.

- Qualification by analysis (Seismic qualification analysis SQA); or combination of test an analysis in which the performance of the equipment is predicted without physical test or on the basis of existing data.

  SQA includes four successive steps: Equipment review; Sub-assembly review; Qualification operation, computations; Synthesis and margin evaluation.

- Qualification by testing in which a typical example of the equipment is tested.

  This method is recommended for complex assemblies where SQA is not possible. Seismic Test Qualification test program include seismic loads, test sequence, operational loads, functional performance and demonstration of operability.
- Qualification by experience.

Qualification of the equipment may be achieved by justifying their similarity with previously qualified equipment. Similarity of the excitation environment shall be established by techniques that can be technically justified.

8.4.2.2.5 Testing Waveforms

Definitions:

- RRS (Required Response Spectrum): Response spectrum issued by the user as part of the specifications for proof testing. The RRS constitutes a requirement to be met. **RRS is coincident with the expected FRS in case of SL3 event.**
- TRS (Test Response Spectrum): Response spectrum that is obtained from the actual motion of the shake table by analytical techniques of by spectrum analysis equipment
- ZPA (Zero period acceleration): Acceleration level of the high frequency portion of the response spectrum.

Test waveform used in the qualification tests:

TRS must envelop the RRS over the test frequency range. TRS and RRS shall be compared to the same damping value or with a dumping value of TRS greater that of the RRS.

The waveforms must include a peak acceleration value equal or greater than the ZPA of the RRS. Ideally must not include any frequency greater than the maximum specified by the RRS.

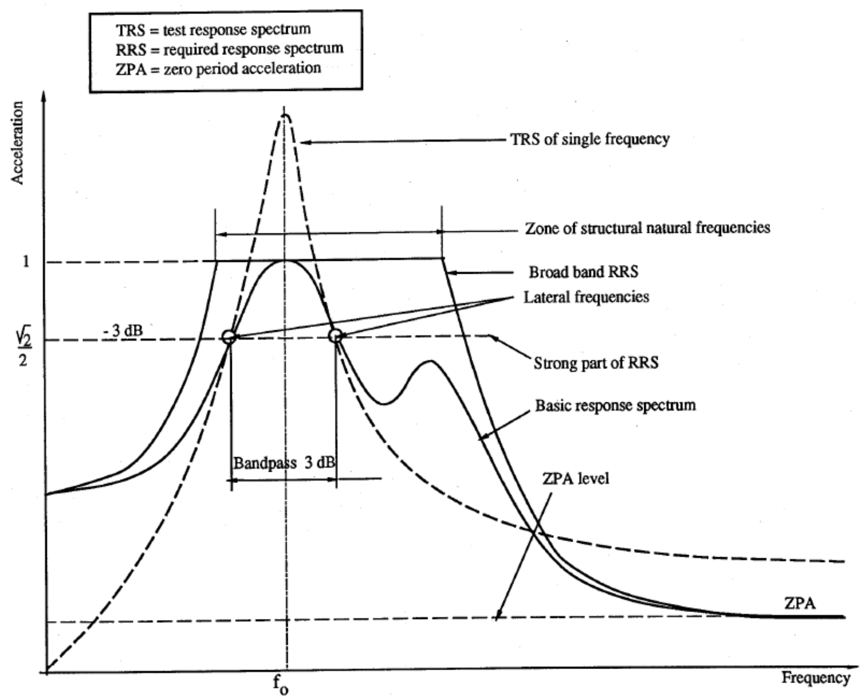


Figure 1 - Typical envelope response curve

Figure 8.1: Typical Envelope Response Curve

8.4.2.3 Cable Penetrations

8.4.2.3.1 Design Requirement Baseline for Electrical Penetrations

According with [R39], an electrical penetration is a safety barrier opening that allows passing one or more cables or cable trays, depending on the zoning requirements.

The typical weak points are represented in the following scheme:

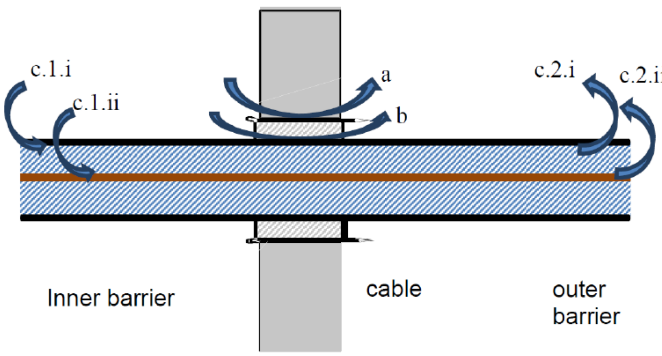


Figure 8.2: Typical Penetration Scheme

In order to seal the penetration, a metal edging is specified for all openings.

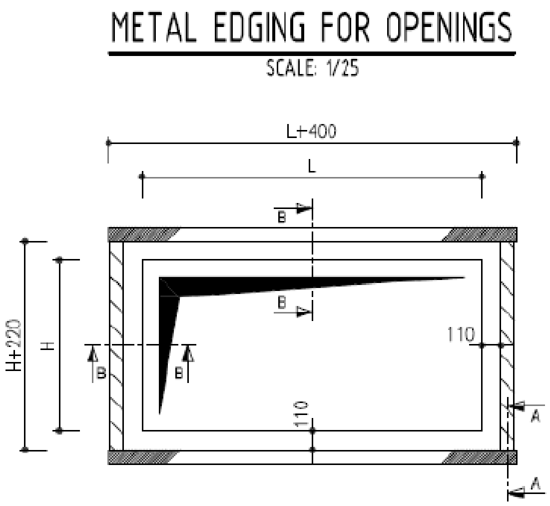


Figure 8.3: Typical Penetration with Metal Edging

The electrical penetration assembly crossing safety barrier walls shall be able to satisfy without loss of function, one or combinations of the following requirements:

- Seismic Requirements.
- Zoning Requirements: Confinement zoning, radiological zoning, explosion zoning, beryllium zoning, magnetic zoning, fire zoning (2h), and waste zoning.
- Flooding Requirements.
- Aircraft Crash

In the case of the **Seismic Requirements**, the penetration shall be able to sustain a seism event equal to the one surrounding wall is qualified for (confinement requirement has to be guaranteed), or the one imposed by the safety level of the passing cable/tray, whatever is higher.

The three commercially available solutions for electrical opening sealing, based on the above design requirements are based on:

- **Silicone foam**: which fill completely all the space between cables and cable trays.
- **Multilayer rubber** (multi cable transits), where each individual cable is sealed.
- **Non-continuous wall penetration**: EPA or Electrical Penetration Assembly.

After analysing all requirements, it is concluded that the main attributes that would influence the selected solution would be Gas Leak Tightness and Radiation Shielding properties.

Room Conditions	Pressure Variations				Radiation		Fire	Explosion
Proposed Solution	Cable w/ filler?*	< 0.05 bar	0.05 bar - 0.45 bar	> 0.45 bar	Resistance	Shielding	EI120	
Low Density Foam	Y	OK	N/A	N/A	Poor	Very poor	Y	Very poor
High Density Foam	Y	OK	OK	N/A	Good	Good	Y	Poor
Multilayer Rubber	Y	OK	OK	OK*	Good	Poor	Y	Good
EPA-Non-continuous	N	OK	OK	OK	Very Good	Very Good**	Y	Very Good

Table 8.35: Sealing Material for Penetration and Associated Characteristics

Following this approach, generic solutions for the Tokamak Complex were proposed depending on the level and wall.

EPA penetrations are only considered in Tritium building walls (Tokamak-Tritium; Tritium-exterior).

All commercial solutions are qualified for seismic requirement for SL2 events.

For a detailed list of electrical penetrations, refers to the following document ITER HARD CORE COMPONENTS - SUMMARY REPORT (PQR228), ref. [R51].

The cable penetrations considered as HCC must follow the same methodology that the Ultimate Emergency Power Supply:

- Standards and Codes: see paragraph 8.4.2.2.1
- Seismic qualification Requirements: see paragraph 8.4.2.2.3
- Qualification by Test or Analysis: see paragraph 8.4.2.2.4
- Load Combinations: see paragraph 8.4.2.2.2
- Seismic Analysis Method: see paragraph 8.4.2.2.5

8.4.3 I&C Systems

In general, the HCC I&C components such as relays, pressure/temp/radiation sensors must be qualified for a SL3 event. This qualification includes all the individual electrical, control and protection devices of the HCC as overall, and must follow the applicable Codes and Standards.

The qualification must follow the one of these three methods.

- Qualification by analysis (Seismic qualification analysis SQA); or combination of test an analysis in which the performance of the equipment is predicted without physical test or on the basis of existing data.

    SQA includes four successive steps: Equipment review; Sub-assembly review; Qualification operation, computations; Synthesis and margin evaluation.

- Qualification by testing in which a typical example of the equipment is tested.

    This method is recommended for complex assemblies where SQA is not possible. Seismic Test Qualification test program include seismic loads, test sequence, operational loads, functional performance and demonstration of operability.

- Qualification by experience.

Qualification of the equipment may be achieved by justifying their similarity with previously qualified equipment. Similarity of the excitation environment shall be established by techniques that can be technically justified.

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