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**Technical Requirements Specification**

# ITER Seismic Nuclear Safety Approach

The scope of this document is to define:safety objectives in case of an earthquake; preliminary assessment of the expected or desired response of ITER to earthquakes;overall seismic requirements for seismically classified components and structures.

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| **ITER Seismic Nuclear Safety Approach (2DRVPE)** | | | |
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| v1.0 | In Work | 22 Jul 2008 | |
| v1.1 | Approved | 18 Sep 2008 | |
| v1.2 | Approved | 22 Oct 2010 | Corrections and updates for consistency with safety importance classification documents. |
| v1.3 | Signed | 17 Jan 2011 | Clarification of requirement of no damage to SIC components, even for NSC items.<br>Some PBS34 cryodistribution components re-classified as SC2. |
| v1.4 | Approved | 08 Feb 2011 | For PBS34, mechanical barriers added to SC1 components in addition to isolation valves. |
| v1.5 | Signed | 26 May 2011 | Updated earthquake description and reference document, no technical content change.<br>Minor editing for clarification. |
| v1.6 | Approved | 23 Jun 2011 | This version addresses comments on version 1.5 as follows:<br>Page: 15, 24 Cryostat: added:<br>- Cryostat columns<br>- Pedestal Ring - bioshield supports<br>Page: 26, Buildings 46 and 47 were changed to SC2 as they shall not be/generate missiles on the adjacent buildings 42 and 43. |

# ITER Seismic Nuclear Safety Approach

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# 1 Scope

The scope of this document is to define:

- safety objectives in case of an earthquake,
- preliminary assessment of the expected or desired response of ITER to earthquakes,
- overall seismic requirements for seismically classified components and structures.

# 2 Seismic hazard characterization

The seismic assessment level considered corresponds to reference earthquake spectra in compliance with Basic safety rule RFS 2001-01 **<1>**. For the ITER Cadarache site, the analysis is performed using two spectra <2>:

– a spectrum derived from a review of historical seismicity over a period of approximately 1000 years (i.e. magnitude: 5.8, epicentre distance: 7.1 km, maximum ground acceleration: 0.315 g for rock soil), so called Séisme Majoré de Sécurité (SMS),

– characteristic paleoseismic spectrum, based on the analysis of geological faults over a period of tens of thousands of years (magnitude: 7, epicentre distance: 18.5 km, maximum ground acceleration: 0.281 g). This last earthquake gives higher values of acceleration than SMS for frequencies lower than 3 Hz.

The load specification and spectra for seismic events are given in Reference **<3>**. These spectra are calculated in the frequency range from 0.1 to 34 Hz, for different damping values. Rock and soft soil conditions are considered where appropriate.

The reference earthquake for the design, called Safe Shutdown Earthquake (SSE), is the envelope of the SMS and the paleoseismic spectrum. When more appropriate, both spectra (SMS+paleo) may be used instead of the SSE. This reference earthquake is also called the SL-2 earthquake.

SSE is a load case defined according to regulator deterministic rules. If an order of magnitude of occurrence is to be defined, SSE is classified as a Category IV event – Extremely Unlikely loading condition.

According to the fundamental safety rule RFS 2001-01 <1> the vertical ground pseudo-acceleration spectra are 2/3 of the horizontal one.

Less intense earthquakes (SL-1) are addressed in the facility design for investment protection. This level earthquake is considered to be a Likely Loading Condition. SL-1 level earthquake is not considered here.

# 3 Objectives for seismic safety

With respect to the radiological risks, the following two safety functions have been identified for ITER:

- confinement of radioactive material,
- limitation of external exposure to ionizing radiation.

Systems, structures and components implementing a safety function have been identified through reviews of safety design analyses undertaken during the ITER design phase. The Safety Importance Class components are associated with safety functions and their support functions as follows:

| **Safety Function** | | **Detailed Safety Functions** | |
|---|---|---|---|
| 1 | Confinement of radioactivity | 1a) | Process confinement barriers |
| | | 1b) | Building confinement barriers including systems for maintaining depression and filtering/detritiating effluents |
| 2 | Limitation of exposure | 2a) | Shielding to limit exposure and ALARA principle |
| | | 2b) | Access control |

| **Supporting Functions** | | **Detailed Supporting Functions** | |
|---|---|---|---|
| 3 | Protection of systems for confinement and limiting exposure | 3a) | Management of pressure |
| | | 3b) | Management of chemical energy |
| | | 3c) | Management of magnetic energy |
| | | 3d) | Management of heat removal and long term temperatures |
| | | 3e) | Fire detection/mitigation |
| | | 3f) | Mechanical impact (including seismic, dropped load, etc.) |
| | | 3g) | Management of mobilizable radioactive inventory |
| | | 3h) | Management of activated and contaminated material |
| | | 3i) | Control of safety protection and mitigation systems |
| 4 | Supporting functions | 4a) | Providing auxiliaries essential for implementing safety functions (electrical power supply, I&C, compressed air, etc…) |
| | | 4b) | Monitoring plant status: safety functions, radiation monitoring, etc… |
| | | 4c) | Providing protection of important to safety systems (e.g. earthing, lightning, etc…) |
| | | 4d) | Provide transport/lifting of radioactive components/materials |
| | | 4e) | Providing support to operator intervention (lighting, communications, etc..) |

These functions are described in the Safety Important Functions and Components classification – Criteria and methodology **<4>**.

With respect to seismic safety and design, the safety objective is to ensure that safety functions are maintained in order to prevent releases to the environment or exposures in the event of an earthquake that would exceed the General Safety Objectives for ITER for accident situations.

| | General safety objectives | |
|---|---|---|
| | **For personnel** | **For the public and environment** |
| **Situations in design basis** | | |
| Normal situations | **As low as reasonably achievable, and in any case less than :**<br>**Maximum individual dose**<br>≤10 mSv/year<br>**Average individual dose for workers classified for radiation exposure**<br>≤2.5 mSv/year | **Releases less than the limits authorized for the installation,**<br>**Impact as low as reasonably achievable, and in any case less than :**<br>≤0.1 mSv/year |
| Incident situations | **As low as reasonably achievable and in any case less than :**<br>10 mSv **per incident** | **Release per incident less than the annual limits authorised for the installation.**<br>≤0.1 mSv |
| Accident situations | **Take into account the constraints related to the management of the accident and post-accident situation** | **No immediate or deferred counter-measures (confinement, evacuation)**<br>< 10 mSv<br>**No restriction of consumption of animal or vegetable products** |
| **Situations beyond design basis** | | |
| Hypothetical accidents | No cliff-edge effect ; possible counter-measures limited in time and space | |

In order to ensure safety in the event of an earthquake and comply with the safety objective, confinement and shielding shall be maintained, and the seismic design principle adopted is that at least one confinement system remains operational and adequate shielding remains in place after an earthquake, These systems have to be operational only for the significant inventories of active materials that could lead to higher doses than the ones mentioned above. A seismic defence-in-depth approach is also considered.

# 4 Post-earthquake safe state

The post-earthquake safe state is as follows:

- confinement of radioactive materials in the vacuum vessel and its extensions,
- confinement of radioactive materials in the heat transfer systems,
- confinement of radioactive materials in the fuelling and vacuum systems,
- confinement of radioactive materials in tritium plant processes,
- confinement of radioactive materials in Hot Cell processing areas,
- confinement of radioactive materials in the low-level radwaste processes
- prevention of personnel external over-exposure,
- stability of building and structures such that necessary safety important functions remain available,
- prevention of accident transients with risk of damage to confinement or release of radioactive materials.

In addition, as part of a seismic defence-in-depth approach, mitigating systems such as VVPSS and detritiation should be available following an earthquake.

# 5 Preliminary Assessment of SSE Consequences

The following is a general description of the expected response of ITER following an SSE level earthquake in order to identify specific requirements or further assessments.

Following a deterministic approach, if a system is not designed for earthquake conditions, damage may or may not be induced by an earthquake so that after an earthquake, other additional conditions may occur. These scenarios lead to designing the involved systems for seismic conditions, and lead to defining appropriate requirements (given in tables in annex 1).

## 5.1 Structures

The Tokamak complex (Tokamak, Tritium and Diagnostic buildings) rests on a common foundation raft supported by seismic isolation bearing pads. As a result of this, the horizontal component of the SSE spectra is filtered and horizontal accelerations on Tokamak complex equipment are limited. For other structures housing SIC components outside the Tokamak complex (e.g. Hot Cell, Low-level Radwaste building, etc.), no seismic isolation bearing devices are foreseen.

Structures housing SIC components are seismically designed to protect enclosed SIC components required following an earthquake.

Tokamak complex civil structures:

- rooms containing radioactive materials maintain their stability to prevent impairment of safety important components located inside the building, in particular structures providing shielding for accessible areas,
- rooms containing radioactive materials that contribute to a confinement function suffer limited concrete cracking such that Detritiation System can maintain some depression / in-flow, if required, to avoid uncontrolled releases;
- the building and crane structures maintain their stability after an earthquake to prevent impairment of safety important components located inside the building;
- radiation protection and adequate shielding.

Hot Cell Building civil structures:

- rooms containing radioactive materials and processing areas that contribute to a confinement function suffer limited concrete cracking such that there is no significant leakage of activity from processing areas to other rooms, and such that the Hot Cell Detritiation System can maintain some depression / in-flow to avoid uncontrolled releases;
- the building and crane structures maintain their stability to prevent impairment of safety important components located inside the building,
- the building does not interact with the Tokamak complex due to the presence of decoupling systems (for example, distance between buildings, flexibility of connections between them),
- radiation protection equipment and structures maintain adequate shielding capacity.

Main Control building, back-up control room, Low-Level Radwaste and Emergency Power Supply and their handling/crane system structures maintain their stability to prevent impairment of seismic safety important components.

Other structures comply with the requirement of not posing a threat to structures housing SIC components required following an earthquake either by physical separation or seismic design (e.g. for Diagnostic, Assembly, Personnel Access Control, NB High Voltage Power Supply and RF heating buildings). The control building design is such that the termination of the plasma is possible after an earthquake, and all functionality are available in the back-up control room.

## 5.2 Plasma Operation, Short-Term Standby and Test & Conditioning States

During a seismic event, although the plasma may terminate due to impurity ingress, loss of electrical power, loss of control, termination of fuelling or other damages to sub-systems, the ITER facility is equipped with a seismic detection system that automatically triggers safety actions, in particular the termination of the plasma.

The system terminating the plasma is a part of the Central Safety System (CSS see Preliminary Safety Report Volume I -7); it is qualified under seismic conditions.

Furthermore, the alarm transmitted in the main control room located in the control building and in the back-up control room allows the operators to manually activate this system.
The control CODAC and interlock systems, which are non-SIC, may fail.

For the plasma, a Type I Disruption may occur (cf. <6>), and the combined disruption and seismic load (SSE) is considered in the design. The vacuum vessel and its extensions shall remain stable without any significant releases of radioactivity. In-vessel components (blanket modules, divertor cassettes, etc.) may suffer local deformation, but not structural failures.

In-vessel water leaks are not foreseen, but the VVPSS is available as part of the seismic defence-in-depth approach.

The relative displacement between magnets and vacuum vessel and its extensions is limited to prevent damage to the vacuum vessel. The cryostat remains structurally intact so that there is no damage to the VV and its extensions. Into the cryostat, very limited air and He in-leakage are possible, but are limited such that the VV confinement function is not compromised. Nevertheless, the cryostat over-pressure protection is seismically qualified as part of seismic defence-in-depth design.

Loss of cryogenic cooling (or loads, displacements, damage to feeders, or leakage of cryogenic coolant) may lead to an eventual TF quench, and the TF fast discharge system is seismically qualified as part of the seismic defence-in-depth approach and will function to prevent structural failure or damage to confinement boundaries. While, arcs leading to confinement damage are not foreseen to develop in PF coils, the PF power cut-off remains available and is seismically qualified as part of the seismic defence-in-depth approach and will function to prevent structural failure or damage to confinement boundaries.

Additional heating systems, diagnostics, fuelling and vacuum systems connected to the vacuum vessel are designed to accommodate movements due to thermal expansion/contraction and from plasma event loads, and are designed for earthquake induced vibration and relative displacements or by means of isolation valves which close on loss of power or other process signals without significant releases of radioactivity from the system. The design of the fuelling system prevents significant releases from the fuelling system. Similarly, the use of adequate design margins supported by seismic qualification of components prevents significant releases from the vacuum pumping system. Some minor releases may occur from non-seismically qualified subsystems with small inventories.

The tritium plant systems are seismically qualified to prevent significant releases of tritium from the system either by design of the confinement barriers to withstand the vibration/displacement (flexibility in piping, clamping heavy components, etc.) or by means of isolation valves which close on loss of power or other process signals. The pressure relief system for the ISS separation columns, coldbox and rigid enclosure is available to ensure confinement integrity upon warm-up of cryogens. The design also prevents releases of hydrogen in the tritium building that could lead to explosive mixtures that could damage confinement systems. Post-earthquake, operating personnel can remotely shut down and secure tritium plant systems (no personnel are required locally inside tritiated atmosphere sectors). As much as possible, safety systems (e.g. Ubeds) would be available to allow placing tritium in safe storage.

Leakage of tritium is prevented to the maximum extent possible by the design. But, in the event of an unexpected leakage, the Detritiation function is available as part of the seismic defence-in-depth approach. The tritium detection function is maintained and detritiation remains capable of providing filtration and detritiation in case of contamination.

For the Tritium building, a fire due to a seismic event does not lead to a release of tritium through the detritiation system. However, in the event of a release (beyond design basis), the detritiation system is seismically qualified as part of seismic defence-in-depth design. The release path through the detritiation system takes into account that efficiency of the detritiation system is reduced to 90% with fire conditions inside the sector, instead of 99%. Releases of tritium at the exhaust point of the Tokamak Complex, would be within the OGS.

Residual heat radiated from in-vessel components is safely removed by the vacuum vessel cooling loop operating on its low-flow pump powered by an emergency diesel generator in case of loss of off-site power. Other heat transport systems are qualified to the SSE level to preclude ruptures; however limited leakages may occur, e.g. at fittings, without any leakage in the VV and in the cryostat.

As a defence-in-depth approach, the TCWS vault cooler remains available and ensures that there is no pressurization of the TCWS vault from TCWS leaks, so that impairment of systems providing required seismic safety functions (confinement, heat removal, etc.) is avoided.

Off-site power may be lost, but emergency power will be available and can be maintained indefinitely with additional fuel. The seismically qualified chilled water systems provide chilled water to SIC loads (e.g. detritiation systems, TCWS cooler). The compressed air supply in reservoirs feeding their SIC loads remains available to operate the safety important valves.

Hot Cell processing areas remain intact such that there is no significant release of radioactivity from processing areas to other rooms. Tritium recovery processes remain intact such that there is no significant release of tritium and can be shutdown and secured by operating personnel. Handling equipment is qualified such that there are no structural failures and loads are not dropped damaging SIC components. The Hot Cell detritiation (filtration and detritiation) function continues operation maintaining some level of depression in the processing areas.

The Low-level Radwaste building remains stable and processing systems with significant tritium inventories are seismically qualified such that there is no significant release of radioactivity. If there is a tritium recovery system in the building, the detritiation systems continue to be available (filtration and detritiation) in case of contamination. Some minor releases of radioactivity may occur from low-level waste processing systems with small inventories not qualified to the SSE level.

Local, manual fire-fighting devices are available, and dry risers are seismically designed and equipped with external couplings allowing their connection to a mobile system (fire truck) to supply the internal network if necessary. Rooms potentially affected by a fire after an earthquake remain accessible so as to facilitate the use of available systems where possible. Consequential fire damage to SIC components providing post-earthquake safety functions is limited and required safety functions are ensured through adequate separation and redundancy.

Failures of non-qualified systems and components may lead to local personnel hazards including cryogen leaks, electrical hazards, fire, asphyxiation hazards (e.g., $SF_6$), etc. The design incorporates sufficient features to prevent consequential fire, flooding, etc. from impairing safety functions and OGS limits are not exceeded.

## 5.3 Short-term and Long-term Maintenance States

The main difference from the above assessment is the potential for in-vessel remote handling operations to be underway at the time of the earthquake.

For transport casks containing in-vessel components in transit, stability is maintained with no significant release of radioactivity into/from casks etc. For casks docked to the VV or Hot Cell ports, some leakage from the docking seal may occur and the detritiation function is available.

For in-vessel maintenance including blanket module, port plugs and divertor cassettes, loads are not dropped and there is no impact leading to damage to confinement barriers.

## 5.4 Other States

An earthquake may occur at some time when the plant is in another state or following an accident (this is more likely in the long-term recovery state).

During recovery from an in-vessel water leak, the VVPSS water may be contaminated and the Suppression Tank Venting System in operation. The VVPSS remains intact and leakage is within assumptions used for safety analyses. The detritiation function (DS) continues to function.

Following events leading to rooms that are contaminated and are being detritiated at the time of the earthquake, the detritiation function continues operation maintaining some level of depression in the affected areas.

# 6 Seismic design and classification

The seismic design of equipment is based on functional safety requirements in the event of an earthquake for operational or maintenance states, conditions following an accident or other abnormal facility states. These requirements concern the following points:

- maximum displacement (e.g. interaction between vacuum vessel and toroidal field coils, ...),
- integrity of geometric characteristics and degree of permanent deformation,
- leakage,
- operating capability of mechanical or electrical equipment (valves, pumps, circuits, etc.) of systems to perform a safety function,
- adequacy of shielding.

Components and structures are classified to facilitate the design process. The seismic classification principle is based on the safety objective and functional requirements in the event of an earthquake. The seismic classes defined are as follows:

- SC1 (SF) - Seismic class one-SF: Structural stability and required functional seismic safety performance maintained in the event of an earthquake, The respect of this level of requirement guarantees the level of safety as throughout the normal operation of the equipment. Nevertheless, taking into account seismic load characteristics, fatigue is not taken into account.

- SC1 (S) - Seismic class one-S: Structural stability maintained in the event of an earthquake, i.e. no rupture of piping, no collapse of structures or equipment, limited plastic strain, limited concrete cracking, structural support functions maintained. With this level of requirement, it is possible that a small level of deformation could occur. Consequently, it could be necessary to inspect equipment before re-using it.

- SC2 – Seismic class two: Non-damage to SC1 equipment; absence of damage to SC1 equipment for buildings and structures housing and protecting safety important components, or to buildings that can potentially damage such structures in the event of collapse, no other requirements regarding structural or functional performance in the event of an earthquake,

- NSC – Non-seismic category. No seismic requirements for safety. However, *all* systems, structures and components must respect the requirement that there must be no failure that would prevent a SIC-1 or SIC-2 component from performing its safety function.

# 7 Seismic Requirements

Based on the above expected or desired plant response, seismic requirements are established and presented in the Annex 1 to this Abstract. Those SIC components that are required to perform safety functions during or after an SSE earthquake are identified and requirements set such that the required objectives are met.

The collapse, falling, dislodgement or any other spatial response of a SIC or non-SIC component as a result of an earthquake shall not jeopardize the functioning of other SIC components providing a safety function. Damage to components that are not SIC should not lead to failure of SIC components or prevent SIC components from performing their safety functions.

The combinations of loads from earthquakes with other loading events are considered in the design of components and structures.

Mechanical equipment seismically designed for a SSE could have to face foreshocks or aftershocks, which are about the level of a so-called SMHV (Séisme Maximum Historiquement Vraisemblable: Maximum conceivable historic earthquake), defined following the Fundamental Safety rule <1>.

The SMHV spectra for the Cadarache site is reported in Reference <2>. For SMHV the envelope of SMHV “Proche” and “Lontain” should be take into account. The SMHV pseudo-acceleration is roughly half of the SMS for frequencies up to 0.4Hz and 0.7 of the SMS for frequencies above 2Hz.

Generally, systems that are qualified for the main shock (level of a SSE), are thus automatically qualified for the level of the foreshock or the aftershock.
The only need to proceed to a specific demonstration to take into account these foreshocks and aftershocks are, for mechanical equipment, when operating conditions or loading conditions are significantly modified after the first shock.

For example, a tank, empty in normal situations, which after the main shock could collect spilled water coming from a non-seismically designed circuit, would be re-analysed to ensure it could withstand the aftershocks with this additional load.

In other cases, including reinforced concrete buildings, a demonstration for a foreshock or an aftershock is covered by the main shock.

Diesel generators providing safety load supply are qualified for SMHV (running) and SSE on stand-by, since it is postulated that the redundant diesel generators can be started in case of a first earthquake from level SMHV with start of one diesel generator.

Generally, seismic technical requirement can be verified by:
- calculation,
- test results,
- other appropriate and justified methods.

Technical requirement calculations could be used to verify the designs according to criteria specified in the appropriate codes or standards.

# 8 References

<1> Basic safety rule RFS 2001-01: Determination of earthquake risk for surface nuclear facilities

**<2>** 620000-CCS-SAB-02 Données Sismiques pour les INB de Surface du Site de Cadarache (2EPRCQ)
<3> Load specification for building with safety requirements (2ERTXQ)
<4> Safety Important Functions and Components classification – Criteria and methodology (347SF3)

<5> Accident Analysis Report Volume II (2DJFX3)

<6> Load Specification (222QGL)

## 8.1 ANNEX 1

<table>
<tr><th>PBS</th><th>System</th><th>Preliminary assessment of consequences</th><th>Sub-systems/components</th><th>SC1</th><th>SC2</th><th>NSC</th><th>Comments and additional indication about Safety Requirements during and following SSE Earthquake</th></tr>
<tr><td rowspan="7">11</td><td rowspan="7">Magnet Systems</td><td rowspan="7">• No damage to vacuum vessel or other confinement barriers.<br>• Detection and fast discharge system is available to discharge energy stored in TF coils and disconnect power supplies to PF coils. (WBS 4.2)<br>• Loss of cryogenic cooling of magnets may occur - coils warm and evaporating helium is relieved into expansion tanks or to environment if these or outside pipes have been damaged<br>• No arcs causing coil damage, and VV confinement barrier intact.<br>• Limited Helium leakage from cryogenic lines into cryostat</td><td>• TF and PF coils & supports.<br>• ELM coils and support (according to their final design)</td><td></td><td>Structural stability + limited displace-ment</td><td></td><td>• Structural stability maintained with loads and displacements within limits to prevent damage to VV.</td></tr>
<tr><td>• Feeders & instrumentation.<br>• I&C for detection of TF coil quench</td><td>Function</td><td></td><td></td><td>• available</td></tr>
<tr><td>• Feeders & instrumentation<br>• TF Discharge system</td><td>Function</td><td></td><td></td><td>• available</td></tr>
<tr><td>• Feeders & instrumentation<br>• Feeders</td><td>Function</td><td></td><td></td><td>• Feeders in state able to prevent arcs</td></tr>
<tr><td>• Pf coils cut off system</td><td>Function</td><td></td><td></td><td></td></tr>
<tr><td>• Cryogenic lines<br>• Function required : leaktightness</td><td>Limited He leakage</td><td></td><td></td><td>• He leakage into cryostat must be sufficiently low that the VV confinement is not compromised.</td></tr>
<tr><td>• Central solenoid.<br>• Conductors.<br>• Correction coils.</td><td></td><td></td><td>X</td><td>• No requirements</td></tr>
</table>

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| 15 | Vacuum Vessel | • Vacuum vessel remains intact.<br>• Cooling of vacuum vessel sectors by natural convection with VV PHTS.<br>• Small air in-leakage may occur. | • Main vessel and shielding.<br>• Vessel ports. | Structural stability | | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV or deformation of cooling passages.<br>• Loads, strains, deformation below limits to ensure leakage from vacuum vessel no greater than that assumed in safety analysis. |
| 16<br>17 | Blanket<br>Divertor | • No damage to VV or other confinement barriers.<br>• Interruption of cooling, but heat removal by radiation to vacuum vessel.<br>• No In-vessel coolant leakage from in-vessel component damage, no structural failures. | • Blanket first wall, shield, diagnostic FW.<br>• Port limiters.<br>• Blanket module connections.<br>• Divertor.<br>• Cassette integration.<br>• Targets, dome, PFC tests. | | Structural stability + limited displace-ment | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |
| 18 | Fuelling and Wall Conditioning | • Systems designed such that there are no significant releases to rooms.<br>• Fuelling terminated e.g. on loss of off-site power. | • Pellet injection system.<br>• Gas injection system.<br>• Glow discharge conditioning system. | Structural stability | | | • Structural stability of process components maintained with loads and displacements within limits to prevent significant leakage of activity from system to rooms. |
| | | | • Fusion power termination system | Function | | | • Function required only the necessary time to terminate the plasma |
| 23 | Remote Handling & Machine Maintenance | • Integrity maintained with no significant leakage into/from casks etc.<br>• Loads are not dropped; no impact leading to damage to confinement barriers.<br>• Leakage from casks docked on VV | • Transfer cask system. | Structural stability + confinement function | | | • Cask in transit stopped/ movement limited to prevent impact that may cause damage to cask.<br>• Structural stability of casks in transit maintained with loads and displacements within limits to prevent significant leakage of activity from system to rooms. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | or Hot Cell may occur. | • Blanket remote handling.<br>• Divertor remote handling.<br>• Neutral Beam remote handling. | | Structural stability + limited displace-ment | | • Loads secured for seismic loadings; displacements limited to prevent damage to confinement barriers. |
| | | | • Viewing/Metrology system. | | | X | • No requirements |
| | Hot cell maintenance process and equipment | • No structural failures.<br>• No significant leakage of activity from processing areas to other rooms.<br>• Loads are not dropped damaging SIC components. | • Hot cell maintenance process and equipment. | Structural stability + confinement function | | | • Structural integrity of processing areas and components with loads and displacements within limits to prevent significant leakage of activity to surrounding rooms. |
| | | | • loads | | Structural stability + limited displace-ment | | • Loads secured for seismic loadings; displacements limited to prevent damage to confinement barriers. |
| | Low-level radwaste Waste Processing | • No structural failures.<br>• No significant leakage of activity from processing areas to other rooms.<br>• Loads are not dropped damaging SIC components. | • Low-level radwaste Waste Processing. | Structural stability + limited displacement | | | • Structural stability of processing areas and process components with loads and displacements within limits to prevent significant leakage of activity to surrounding rooms. |
| | | | | | Structural stability + limited displace-ment | | • Loads secured for seismic loadings; displacements limited to prevent damage to confinement barriers. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| 24 | Cryostat | • Structural integrity maintained; no damage to VV or other confinement barriers.<br>• Air leakage into cryostat is acceptable.<br>• No Leakage of helium into cryostat, or does not lead to damage of VV or other confinement barriers. | • Cryostat Main Chamber.<br>• Cryostat Penetrations.<br>• Cryostat columns.<br>• Pedestal Ring - bioshield supports. | | X | | • Structural stability of cryostat chamber and penetrations maintained with loads and displacements within limits to prevent damage to VV or other confinement barriers. |
| | | | • Cryostat Venting & Overpressure Protection System. | | Structural stability + limited displace-ment | | • Loads and displacements within limits to allow functioning as needed to prevent damage to VV or other confinement barriers from cryogen leaks.<br>• I&C if needed for detection and operation functional. |
| | Vacuum Vessel Pressure Suppression System | • Pressure suppression available. | • Vacuum Vessel Pressure Suppression System | Function | | | • Loads and displacements within limits to allow functioning of rupture discs.<br>• Loads and displacements within limits to prevent damage to VVPSS tank and internals |
| 26 | Tokamak cooling water system | • Piping remains intact | • VV PHTS | Confinement<br><br>Structural stability + limited displacement | | | • Structural stability maintained with loads and displacements within limits to prevent damage or deformation of cooling passages that could lead to a flow blockage.<br>• Loads, strains, deformation below limits to ensure no rupture. |
| | | • Piping remains intact<br>• Plasma/NB heat load terminated.<br>• Interruption of coolant circulation circuit may occur due to loss of off-site power. Coolant discharge into Relief Tank if any short-time | • FW/BLKT PHTS<br>• DIV/LIM PHTS<br>• NB PHTS | No leakage<br><br>Structural stability + limited displacement | | | • Loads, strains, deformation below limits to ensure no rupture. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | pressure rise.<br>• Minor increase in leakage may occur, e.g. from fittings, – no TCWS vault pressure increase. | • Coolant discharge system into Relief Tank | Function | | | • Loads, strains, deformation below limits to ensure no rupture<br>• I&C for detection and operation functional. |
| | | • Piping remains intact<br>• Minor increase in leakage may occur, e.g. from fittings | • CVCS.<br>• Draining & Refilling System.<br>• Drying System. | No leakage | | | • Loads, strains, deformation below limits to ensure no rupture. |
| | | • Failures may occur, but no flooding leading to damage to SIC components | • Component cooling water.<br>• Chilled water system (non-SIC).<br>• Heat rejection system | | | X | • Assess consequential damage (pipewhip, flooding etc.) and design to prevent damage to SIC components. |
| | | • Chilled water to SIC loads continues; interruption during earthquake acceptable; able to be restarted.<br>• TCWS vault coolers available.<br>• DS available | • Chilled water system (SIC). | Function | | | • Loads, strains, deformation below limits to ensure Chilled water to SIC loads continues; interruption during earthquake acceptable; able to be restarted.<br>• Loads, strains, deformation below limits to ensure TCWS vault coolers available.<br>• I&C for detection and operation functional. |
| 27 | Thermal shields | • No Helium leakage from cryogenic lines into cryostat or leakage is limited such that the there is no damage to the VV or other confinement barriers. | • VV Thermal shield.<br>• Cryostat thermal shield. | No leakage or limited leakage | | | • Loads, strains, deformation below limits to ensure limited He release and no damage to VV or other confinement barriers. (see `PBS 2.4 Cryostat) |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| 31 | Vacuum Pumping and Leak Detection | • Systems designed such that no significant releases to rooms.<br>• Operation terminated e.g. on loss of off-site power. | • Cryopumps.<br>• Rouging pumps.<br>• Leak detection. | Structural stability | | | • Structural stability of process components maintained with loads and displacements within limits to prevent significant leakage of activity from system to rooms or cryogens into the VV. |
| | | | • Isolation valves<br>• Associated I&C | Function | | | • Loads, strains, deformation below limits to ensure isolation valves function/fail-safe if required for confinement.<br>• I&C for detection and operation functional. |
| 32 | Tritium Plant | • Systems designed such that no significant releases to rooms.<br>• Systems designed such that no significant releases to sectors.<br>• Hard shell coldbox and expansion tank seismically qualified.<br>• Fail-closed isolation valves on ISS process loops operable.<br>• Warming up of the distillation columns may occur; columns pressure will rise up to the set point of overpressure protection system and tritium will be relieved into the external expansion tank. | • Tokamak Exhaust Processing system. | Structural stability + limited displacement | | | • Structural stability of process components maintained with loads and displacements within limits to prevent significant leakage of activity from system to confinement sectors |
| | | | • Storage and Delivery System | Structural stability Confinement function Storage function | | | • Structural stability process components maintained with loads and displacements within limits to prevent significant leakage of activity from system to confinement sectors. |
| | | | Isotope Separation Systems<br>• Process components | Confinement | | | • Structural stability process components maintained with loads and displacements within limits to prevent significant leakage of activity from system to sectors. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | | Isotope Separation Systems<br>• Overpressure protection | Function | | | • Loads, strains, deformation below limits to ensure overpressure protection function/fail-safe if required to protect confinement.<br>• I&C for detection and operation functional. |
| | | | Isotope Separation Systems<br>• Isolation valves | Function | | | • Loads, strains, deformation below limits to ensure isolation valves function/fail-safe if required for confinement.<br>• I&C for detection and operation functional. |
| | | • Systems designed such that no significant releases to sectors.<br>• Fail-closed isolation valves operate to prevent significant releases.<br>• Operation may terminate e.g. on loss of off-site power. | Water Detritiation Systems<br>• Process components | Confinement | | | • Structural stability process components maintained with loads and displacements within limits to prevent significant leakage of activity from system to sectors |
| | | | Water Detritiation Systems<br>• Isolation valves | Function | | | • Loads, strains, deformation below limits to ensure isolation valves function/fail-safe if required for confinement.<br>• I&C for detection and operation functional |
| | | • Systems designed such that no significant releases to sectors.<br>• Detritiation system continues to operate | Detritiation Systems<br>• Tokamak Complex | Function | | | • Able to operate just after the earthquake |
| | | | Detritiation Systems<br>• Hot cell | Function | | | • Able to operate just after the earthquake |
| | | • Systems designed such that no significant releases to sectors | • Test blanket tritium recovery system<br>• Glovebox detritiation system | Confinement | X | | • Loads, strains, deformation below limits to prevent significant leakage of activity from system to sectors |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| 34 | Cryoplant and cryo-distribution | • No He leakage into VV<br>• He leakage into Cryostat is not sufficient to degrade the confinement function of the VV.<br>• Helium leakage from cryogenic lines to rooms and/or environment may occur.<br>• Potential impact on SIC components in some locations | Cryodistribution Components<br>• Lines connected to VV and Cryostat<br>• Cryogenic isolation valves and mechanical barriers | X | | | • Isolation valves in auxiliary coldboxes functional to limit non-condensable into VV and cryostat<br>• I&C for detection and operation functional. |
| | | | Cryodistribution Components<br>• Lines in the vicinity of SIC-1 and SIC-2 components | | X | | • To avoid damage to SIC systems. |
| | | | Cryodistribution Components<br>• Other systems | | | X | • No requirements. |
| 41 | Coil Power Supply & Distribution | • Arc protection to disconnect PF power supplies available.<br>• TF coil discharge available.<br>• Other failures may occur that lead to termination of plasma. | • Switch, discharge circuits, busbars | Function | | | • Loads, strains, deformation below limits to ensure ability to discharge TF coils remains functional.<br>• Loads, strains, deformation below limits to ensure ability to detect need for and switch off PF coil power supplies remains functional.<br>• I&C for detection and operation functional. |
| | | | • High voltage substation.<br>• AC/DC converters, Reactive Power compensators and filters. | | | X | • No requirements |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| 43 | Steady State Power Supplies | • Emergency power (Class I, II, III) available. | • Emergency power supply system (Class I, II, III) | Function just after the earthquake | | | • Loads, strains, deformation below limits to ensure ability to provide power to systems providing safety function; interruption during earthquake acceptable; able to be restarted.<br>• I&C for detection and operation functional. |
| | | • Off-site (Class IV) power may occur. | • Main transformers, switchgear, load centres, distribution boards.<br>• Tokamak grounding. | | | X | • No requirements |
| 45 | Command Control and Data Acquisition | • Loss of function may occur. | • Control, data acquisition & communication | | | X | • No requirements |
| 46 | Central Interlock System | • Loss of function may occur.<br>• Access control does not prevent safe exit of personnel. | • Central Interlock System | | | X | • No requirements |
| 48 | Central Safety System | • Functionality remains available. | • Central Safety System | Function | | | • Safety control remains operational from Back-up Control Room.<br>• I&C for detection and operation functional. |
| 51 | Ion Cyclotron H&CD | • Vacuum vessel penetrations remain intact and leak tight.<br>• Penetrations ensure room confinement requirements met. | Ion cyclotron antenna<br>• Components | Structural stability + limited displacement | | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |
| | | | Ion cyclotron antenna<br>• main transmission line, VV penetration | Confinement of VV | | | • Loads, strains, deformation below limits to ensure no significant leakage of activity from system into rooms. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | • Failures may occur that lead to termination of additional heating. | • IC radio frequency power sources.<br>• Ion cyclotron H&CD power supply. | | | X | • No requirements |
| 52 | Electron Cyclotron H&CD | • Vacuum vessel penetrations remain intact and leak tight. Isolation valves needed for confinement functional.<br>• Penetrations ensure room confinement requirements met. | • EC launchers (upper & equatorial) | | Structural stability + limited displace-ment | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |
| | | | • EC transmission line, VV penetration | Confinement of VV | | | • Loads, strains, deformation below limits to ensure isolation valves function as required.<br>• I&C for detection and operation functional |
| | | • Failures may occur that lead to termination of additional heating | • EC radio frequency power sources<br>• EC H&CD power supplies | | | X | • No requirements |
| 53 | Neutral Beam H&CD | • Vacuum vessel penetrations remain intact and leak tight. Isolation valves needed for confinement functional.<br>• Penetrations ensure room confinement requirements met. | • Beam source & HV bushing.<br>• Beam line components.<br>• Pressure vessel, magnetic shielding.<br>• Diagnostic neutral beam. | | Structural stability + limited displace-ment | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |
| | | | Other H&CD systems<br>• confinement of radioactivity | Function | | | • Loads, strains, deformation below limits to ensure no significant leakage of radioactivity from system into rooms. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | | Other H&CD systems<br>• Isolation valves | Function | | | • Loads, strains, deformation below limits to ensure isolation valves function as required to maintain confinement.<br>• I&C for detection and operation functional. |
| | | • Failures may occur that lead to termination of additional heating | • Active correction & compensation coils.<br>• Power supply for neutral heating beam. | | | X | • No requirements |
| 54 | Lower Hybrid H&CD | • Vacuum vessel penetrations remain intact and leak tight. Isolation valves needed for confinement functional.<br>• Penetrations ensure room confinement requirements met. | • LH launcher. | | Structural stability + limited displace-ment | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |
| | | | • LH Main transmission line. VV penetration | Function | | | • Loads, strains, deformation below limits to ensure no significant leakage of radioactivity from system into rooms. |
| | | • Failures may occur that lead to termination of additional heating | • LH radio frequency power source.<br>• LH H&CD power supply. | | | X | • No requirements |
| 55 | Diagnostics | • Vacuum vessel penetrations remain intact and leak tight. Isolation valves needed for confinement functional.<br>• Penetrations ensure room confinement requirements met. | • Upper port systems.<br>• Equatorial port systems.<br>• Lower port systems.<br>• In-vessel & distributed.<br>• Generic components. | Structural stability + limited displacement | | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | | Above mentioned Systems<br>• Radioactive components | No leakage | | | • Loads, strains, deformation below limits to ensure no significant leakage of activity from system into rooms. |
| | | | Above mentioned Systems<br>• Isolation valves | Function | | | • Loads, strains, deformation below limits to ensure isolation valves function as required to maintain confinement. |
| 56 | Test Blankets | • Systems designed to prevent significant releases of radioactive or reactive materials. | • In-vessel/in-port components | Structural stability + limited displacement | | | • Structural stability maintained with loads and displacements within limits to prevent damage to VV. |
| 62<br>63 | Buildings | See separate Table below | • Reinforced concrete buildings.<br>• Steel frame buildings. | | | | • See separate Table below |
| 64 | Radiological Protection | • Ability to monitor (estimate) releases from site retained.<br>• Radiation protection monitoring (portable) available. | • Radiological Protection | X | | | • Ability to monitor (estimate) releases from site retained.<br>• Radiation protection monitoring (portable) available. |
| 65 | Gas and Liquid Distribution | • Local, manual fire-fighting devices are available, and dry risers are seismically designed and equipped with external couplings<br>• Air receivers and supply to SIC loads available | Fire protection System<br>• Dry risers and valves | Function | | | • Loads, strains, deformation below limits to ensure dry risers and valves available for external water supply when needed. |
| | | | • Compressed air system for SIC components. | Function | | | • Loads, strains, deformation below limits to ensure compressed air from receivers able to supply SIC loads. |
| | | | • Potable water system.<br>• Hot water flow and return.<br>• Demineralized water system. | | | X | • Assess consequential damage (flooding etc.) and design to prevent damage to SIC components. |
| | | | • Breathing air system | | | X | • No requirements |

| PBS | System | Preliminary assessment of consequences | Sub-systems/components | SC1 | SC2 | NSC | Comments and additional indication about Safety Requirements during and following SSE Earthquake |
|---|---|---|---|---|---|---|---|
| | | | • Bottled gases | Confinement | | | • Loads, strains, deformation below limits to ensure no significant leakage of flammable gases from system into rooms with SIC components. |

Buildings containing SIC equipment potentially used in post-earthquake situations are seismically designed according to nuclear rules. Other buildings are either seismically designed not to interact with nuclear building for the same level of earthquake or located at sufficient distance to prevent damage to seismically designed buildings. The various buildings of the INB are listed below

Summary description and assessment of Safety Objectives:

- No structural failure and no damage to SIC components within buildings housing SIC-S: e.g. Tokamak Building, Tritium Building, Hot Cell Building, Low-level Radwaste Building, Diagnostic and TF Discharge Building, and Emergency Power Building.
- Rooms providing confinement function – limited loss of leak tightness (for concrete parts: limited cracking.)
- Other buildings can be damaged.
- HVAC in potentially contaminated areas shutdown and fire isolation valves isolate rooms to prevent spread of fire if needed (inlet when no tritium leakage, inlet and outlet when tritium leakage).

| Number | Building | SC1(s) | SC2 | NSC |
|---|---|---|---|---|
| 11 | Tokamak Building | X | | |
| 12 | Tokamak Complex Excavation Support Structure | X | | |
| 14 | Tritium Building | X | | |
| 19 | Seismic Isolation Basemat | X | | |
| 21 | Hot Cell Facility Building | X | | |
| 23 | Radwaste Facility Building | X | | |
| 24 | Personnel Access Control Building | X | | |
| 71 | Control Building | X | | |
| 74 | Diagnostic Building | X | | |
| 13 | Assembly Building | | X | |
| 15 | RF Heating Building | | X | |
| 32 | Magnetic Power Conversion Building 1 | | | X |
| 33 | Magnetic Power Conversion Building 2 | | | X |
| 34 | NB Power Supply Building | | | X |
| 36 | Main AC Distribution Building | | | X |
| 37 | NB HV Power Supply Building | | X | |
| 38 | Reactive Power Control Building | | | X |
| 42 | Fuel Storage Tanks (EPS Train A) | | X | |
| 43 | Fuel Storage Tanks (EPS Train B) | | X | |
| 44 | EPS Building Train A | | X | |
| 45 | EPS Building Train B | | X | |
| 46 | MV Distribution Building LC/1A | | X | |
| 47 | MV Distribution Building LC/2B | | X | |
| 51 | Cryo-plant Compressor Building | | | X |
| 52 | Cryo-plant Cold-box Building | | | X |
| 53 | Cryo-plant Infrastructure | | | X |
| 55 | PF Coil Building | | | X |
| 61 | Site Services Building | | | X |
| 67 | Cold Basin & Cooling Towers | | | X |
| 68 | Cooling Water Pump Station | | | X |
| 69 | Heat Exchangers | | | X |
| 75 | FD & SN Resistors Building | | X | |
| 61-00-ST | *Safety-related* Services Trenches | | X | |
| 61-00-ST | *Non-safety-related* Services Trenches | | | X |
| 61-00-PB | Plant Bridges | | X | |
| SF | Special Foundations | | | X |
| NF, CF | Fences | | | X |
| MV | Medium Voltage Switchgear | | | X |
| LC | Load Centre | | | X |