Post-
Fukushima
accident

Compilation of recommendations and suggestions

Peer review of stress tests performed on European nuclear power plants

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Compilation of Recommendations and Suggestions from the Review of the European Stress Tests

1. Introduction

Following the severe accidents which started in the Fukushima Dai-ichi nuclear power plant, the European Council of 24/25 March 2011 requested that stress tests be performed on all European nuclear power plants. The Council invited the European Nuclear Safety Regulators Group (ENSREG), the European Commission, and the Western European Nuclear Regulators' Association (WENRA) to develop the scope and modalities for the stress tests. WENRA drafted the preliminary stress test specifications in April. On 24 May 2011 full consensus of ENSREG and the European Commission was achieved. The stress tests and peer review focus on three topics which are directly derived from the preliminary lessons learned from the Fukushima disaster as highlighted by the IAEA missions following the accident and reports from the Japanese Government. Natural hazards, including earthquake, tsunami and extreme weather, the loss of safety systems and severe accident management are the main topics for review.

The stress tests and peer review assess these topics in a three step process. The first step requires the operators to perform an assessment and make proposals following the ENSREG specifications. The second step is for the national regulators to perform an independent review of the operators' assessments and issue requirements, whenever appropriate. The last step is a peer review of the national reports submitted by regulators. The objectives of the peer review were to assess the compliance of the stress tests with the ENSREG specification, to check that no important issue has been overlooked and to identify strong features, weaknesses and relevant proposals to increase plant robustness in light of the preliminary lessons learned from the Fukushima catastrophe. The 15 European Union countries with nuclear reactors as well as Ukraine and Switzerland performed the stress tests and were subjected to the peer review. The operators submitted their final assessments by 31 October 2011 and the regulators submitted their final national reports on 31 December 2011. The peer review started on 1 January 2012.

The peer review was completed with a main report that includes final conclusions and recommendations at European level and 17 country reports that include country-specific conclusions and recommendations. The report was approved by ENSREG and the EC on 26 April 2012. In a joint ENSREG/EC statement the stress test report was accepted and it was agreed that an ENSREG action plan would be developed to track implementation of the recommendations. As part of the ENSREG action plan each national regulator will generate a country-specific action plan. ENSREG decided that a consistent compilation of peer review recommendations and suggestions will be prepared, to assist the preparation or review of national action plans by national regulators.

The compilation of recommendations addressed to national regulators is made up of the main recommendations found in the conclusion of the stress test report (Chapter 8) as well as the items to be considered that are found in the other parts of the report. Each of the topical chapters (Chapter 5 addressing natural hazards, Chapter 6 addressing loss of safety systems and Chapter 7 addressing severe accident management) include numbered recommendations and there are additional recommendations in the body of the report. This compilation was developed by listing all the recommendations and suggestions, then removing duplication and grouping (for example, there were similar recommendations regarding the spent fuel pool in each of the three topics and these were grouped into a single recommendation under topic 2). After the four European-level recommendations, the remainder of the recommendations and suggestions are grouped according to the most applicable peer review topic (natural hazards, loss of safety systems and severe accident management).

2. European Level Recommendations

2.1. European guidance on assessment of natural hazards and margins

Overall, the compliance of the European stress tests with the ENSREG specification was good with regard to compliance of the installations with their design basis for earthquake and flooding. However there was a lack of consistency identified with respect to natural hazards assessments where significant differences exist in national approaches and where difficulties were encountered with beyond design margins and cliff-edge effects assessments. Therefore:

The peer review Board recommends that WENRA, involving the best available expertise from Europe, develop guidance on natural hazards assessments, including earthquake, flooding and extreme weather conditions, as well as corresponding guidance on the assessment of margins beyond the design basis and cliff-edge effects.

2.2. Periodic Safety Review

The peer review demonstrated the positive contribution of periodic safety reviews as an efficient tool to maintain and improve the safety and robustness of plants. In the context of the peer review, this finding is especially relevant for the protection of installations against natural hazards. Therefore:

The peer review Board recommends that ENSREG underline the importance of periodic safety review. In particular, ENSREG should highlight the necessity to re-evaluate natural hazards and relevant plant provisions as often as appropriate but at least every 10 years.

2.3. Containment integrity

The Fukushima disaster highlighted once again the importance of the containment function, which is critical, as the last barrier to protect the people and the environment against radioactive releases resulting from a nuclear accident. This issue was already extensively considered, as a follow-up of previous accidents, and possible improvements were identified. Their expeditious implementation appears to be a crucial issue in light of Fukushima accident. Therefore:

Urgent implementation of the recognised measures to protect containment integrity is a finding of the peer review that national regulators should consider.

The measures to be taken can vary depending on the design of the plants. For water cooled reactors, they include equipment, procedures and accident management guidelines to:

− depressurize the primary circuit in order to prevent high-pressure core melt;
− prevent hydrogen explosions;
− prevent containment overpressure.

2.4. Prevention of accidents resulting from natural hazards and limiting their consequences

The Fukushima disaster has also shown that defence-in-depth should be strengthened by taking into account severe accidents resulting from extreme natural hazards exceeding the levels taken into account by the design basis and current safety requirements applicable to the plants. Such situations can result in devastation and isolation of the site, an event of long duration, unavailability of numerous safety systems, simultaneous accidents of several plants including their spent fuel pools, and the presence of radioactive releases. Therefore:

Necessary implementation of measures allowing prevention of accidents and limitation of their consequences in case of extreme natural hazards is a finding of the peer review that national regulators should consider.

Typical measures which can be considered are bunkered equipment to prevent and manage severe accident including instrumentation and communication means, mobile equipment protected against extreme natural hazards, emergency response centres protected against extreme natural hazards and contamination, rescue teams and equipment rapidly available to support local operators in long duration events. Such possible measures as identified by the peer review, are detailed in the report.

3. Other topics to be considered

The peer review report dealt with many topics in addition to the four previous ones. These topics should be considered by regulators in preparing or reviewing the national action plans. These include recommendations and suggestions, measures to increase robustness and measures already decided or implemented by some countries.

3.1 Topic I items (natural hazards) to be considered

3.1.1 Hazard Frequency

The use a return frequency of 10-4 per annum (0.1g minimum peak ground acceleration for earthquakes) for plant reviews/back-fitting with respect to external hazards safety cases.

3.1.2 Secondary Effects of Earthquakes

The possible secondary effects of seismic events, such as flood or fire arising as a result of the event, in future assessments.

3.1.3 Protected Volume Approach

The use a protected volume approach to demonstrate flood protection for identified rooms or spaces.

3.1.4 Early Warning Notifications

The implementation of advanced warning systems for deteriorating weather, as well as the provision of appropriate procedures to be followed by operators when warnings are made.

3.1.5 Seismic Monitoring

The installation of seismic monitoring systems with related procedures and training.

3.1.6 Qualified Walkdowns

The development of standards to address qualified plant walkdowns with regard to earthquake, flooding and extreme weather – to provide a more systematic search for non-conformities and correct them (e.g. appropriate storage of equipment, particularly for temporary and mobile plant and tools used to mitigate beyond design basis (BDB) external events).

3.1.7 Flooding Margin Assessments

The analysis of incrementally increased flood levels beyond the design basis and identification of potential improvements, as required by the initial ENSREG specification for the stress tests.

3.1.8 External Hazard Margins

In conjunction with recommendation 2.1 and 3.1.7, the formal assessment of margins for all external hazards including, seismic, flooding and severe weather, and identification of potential improvements.

3.2 Topic 2 items (loss of safety systems) to be considered

3.2.1 Alternate Cooling and Heat Sink

The provision of alternative means of cooling including alternate heat sinks. Examples include steam generator (SG) gravity alternative feeding, alternate tanks or wells on the site, air-cooled cooling towers or water sources in the vicinity (reservoir, lakes, etc) as an additional way of enabling core cooling.

3.2.2 AC Power Supplies

The enhancement of the on-site and off-site power supplies. Examples include adding layers of emergency power, adding independent and dedicated backup sources, the enhancement of the grid through agreements with the grid operator on rapid restoration of off-site power, additional and/or reinforced off-site power connections, arrangements for black start of co-located or nearby gas or hydro plants, replacing standard ceramic based items with plastic or other material that are more resistant to a seismic event. Another example is the possible utilisation of generator load shedding and house load operation for increased robustness, however, before introducing such arrangements the risks need to be properly understood.

3.2.3 DC Power Supplies

The enhancement of the DC power supply. Examples include improving the battery discharge time by upgrading the existing battery, changing/diversifying battery type (increasing resistance to common-mode failures), providing spare/replacement batteries, implementing well-prepared load-shedding/staggering strategies, performing real load testing and on-line monitoring of the status of the batteries and preparing dedicated recharging options (e. g. using portable generators).

3.2.4 Operational and Preparatory Actions

Implementation of operational or preparatory actions with respect to the availability of operational consumables. Examples include, ensuring the supply of consumables such as fuel, lubrication oil, and water and ensuring adequate equipment, procedures, surveillance, drills and arrangements for the resupply from off-site are in place.

3.2.5 Instrumentation and Monitoring

The enhancement of instrumentation and monitoring. Examples include separate instrumentation and/or power sources to enable monitoring of essential parameters under any circumstances for accident management and the ability to measure specific important parameters based on passive and simple principles.

3.2.6 Shutdown Improvements

The enhancement of safety in shutdown states and mid-loop operation. Examples of improvements include, reducing or prohibiting mid-loop operation, adding dedicated hardware, procedures and drills, the use of other available water sources (e. g. from hydro-accumulators), requiring the availability of SGs during shutdown operations and the availability of feedwater in all modes.

3.2.7 Reactor Coolant Pump Seals

The use of temperature-resistant (leak-proof) primary pump seals.

3.2.8 Ventilation

The enhancement of ventilation capacity during SBO to ensure equipment operability.

3.2.9 Main and Emergency Control Rooms

The enhancement of the main control room (MCR), the emergency control room (ECR) and emergency control centre (ECC) to ensure continued operability and adequate habitability conditions in the event of a station black-out (SBO) and in the event of the loss of DC (this also applies to Topic 3 recommendations).

3.2.10 Spent Fuel Pool

The improvement of the robustness of the spent fuel pool (SFP). Examples include reassessment/upgrading SFP structural integrity, installation of qualified and power-independent monitoring, provisions for redundant and diverse sources of additional coolant resistant to external hazards (with procedures and drills), design of pools that prevents drainage, the use of racks made of borated steel to enable cooling with fresh (unborated) water without having to worry about possible recriticality, redundant and independent SFP cooling systems, provision for additional heat exchangers (e. g. submerged in the SFP), an external connection for refilling of the SFP (to reduce the need for an approach linked to high doses in the event of the water falling to a very low level) and the possibility of venting steam in a case of boiling in the SFP.

3.2.11 Separation and Independence

The enhancement of the functional separation and independence of safety systems. Examples include the elimination of full dependence of important safety functions on auxiliary systems such as service water and the introduction of an alternate source of cooling.

3.2.12 Flow Path and Access Availability

The verification of assured flow paths and access under SBO conditions. Ensure that the state in which isolation valves fail and remain, when motive and control power is lost, is carefully considered to maximise safety. Enhance and extend the availability of DC power and instrument air (e. g. by installing additional or larger accumulators on the valves). Ensure access to critical equipment in all circumstances, specifically when electrically operated turnstiles are interlocked.

3.2.13 Mobile Devices

The provision of mobile pumps, power supplies and air compressors with prepared quick connections, procedures, and staff training with drills. Mobile devices are intended to enable the use of existing safety equipment, enable direct feeding of the primary or secondary side, allow extended use of instrumentation and operation of controls, allow effective fire-fighting, and ensure continued emergency lighting. The equipment should be stored in locations that are safe and secure even in the event of general devastation caused by events significantly beyond the design basis (this also applies to Topic 3 recommendations).

3.2.14 Bunkered/Hardened Systems

The provision for a bunkered or “hardened” system to provide an additional level of protection with trained staff and procedures designed to cope with a wide variety of extreme events including those beyond the design basis (this also applies to Topic 3 recommendations).

3.2.15 Multiple Accidents

The enhancement of the capability for addressing accidents occurring simultaneously on all plants of the site. Examples include assuring preparedness and sufficient supplies, adding mobile devices and fire trucks and increasing the number of trained and qualified staff (this also applies to Topic 3 recommendations).

3.2.16 Equipment Inspection and Training Programs

The establishment of regular programs for inspections to ensure that a variety of additional equipment and mobile devices are properly installed and maintained, particularly for temporary and mobile equipment and tools used for mitigation of BDB external events. Development of relevant staff training programmes for deployment of such devices.

3.2.17 Further Studies to Address Uncertainties

The performance of further studies in areas were there are uncertainties. Uncertainties may exist in the following areas:

- The integrity of the SFP and its liner in the event of boiling or external impact.
- The functionality of control equipment (feedwater control valves and SG relief valves, main steam safety valves, isolation condenser flow path, containment isolation valves as well as depressurisation valves) during the SBO to ensure that cooling using natural circulation would not be interrupted in a SBO (this is partially addressed in recommendation 3.2.10).
- The performance of additional studies to assess operation in the event of widespread damage, for example, the need different equipment (e.g. bulldozers) to clear the route to the most critical locations or equipment. This includes the logistics of the external support and related arrangements (storage of equipment, use of national defence resources, etc.).

3.3 Topic 3 items (severe accident management) to consider

3.3.1 WENRA Reference Levels

The incorporation of the WENRA reference levels related to severe accident management (SAM) into their national legal frameworks, and ensure their implementation in the installations as soon as possible. This would include:

- Hydrogen mitigation in the containment - Demonstration of the feasibility and implementation of mitigation measures to prevent massive explosions in case of severe accidents.
- Hydrogen monitoring system - Installation of qualified monitoring of the hydrogen concentration in order to avoid dangerous actions when concentrations that allow an explosion exist.
- Reliable depressurization of the reactor coolant system - Hardware provisions with sufficient capacity and reliability to allow reactor coolant system depressurization to prevent high-pressure melt ejection and early containment failure, as well as to allow injection of coolant from low pressure sources.
- Containment overpressure protection - Containment venting via the filters designed for severe accident conditions.

- Molten corium stabilization - Analysis and selection of feasible strategies and implementation of provisions against containment degradation by molten corium.

3.3.2 SAM Hardware Provisions

Adequate hardware provisions that will survive external hazards (e.g. by means of qualification against extreme external hazards, storage in a safe location) and the severe accident environment (e.g. engineering substantiation and/or qualification against high pressures, temperatures, radiation levels, etc), in place, to perform the selected strategies.

3.3.3 Review of SAM Provisions Following Severe External Events

The systematic review of SAM provisions focusing on the availability and appropriate operation of plant equipment in the relevant circumstances, taking account of accident initiating events, in particular extreme external hazards and the potential harsh working environment.

3.3.4 Enhancement of Severe Accident Management Guidelines (SAMG)

In conjunction with the recommendation 2.4, the enhancement of SAMGs taking into account additional scenarios, including, a significantly damaged infrastructure, including the disruption of plant level, corporate-level and national-level communication, long-duration accidents (several days) and accidents affecting multiple units and nearby industrial facilities at the same time.

3.3.5 SAMG Validation

The validation of the enhanced SAMGs.

3.3.6 SAM Exercises

Exercises aimed at checking the adequacy of SAM procedures and organisational measures, including extended aspects such as the need for corporate and nation level coordinated arrangements and long-duration events.

3.3.7 SAM Training

Regular and realistic SAM training exercises aimed at training staff. Training exercises should include the use of equipment and the consideration of multi-unit accidents and long-duration events. The use of the existing NPP simulators is considered as being a useful tool but needs to be enhanced to cover all possible accident scenarios.

3.3.8 Extension of SAMGs to All Plant States

The extension of existing SAMGs to all plant states (full and low-power, shutdown), including accidents initiated in SFPs.

3.3.9 Improved Communications

The improvement of communication systems, both internal and external, including transfer of severe accident related plant parameters and radiological data to all emergency and technical support centre and regulatory premises.

3.3.10 Presence of Hydrogen in Unexpected Places

The preparation for the potential for migration of hydrogen, with adequate countermeasures, into spaces beyond where it is produced in the primary containment, as well as hydrogen production in SFPs.

3.3.11 Large Volumes of Contaminated Water

The conceptual preparations of solutions for post-accident contamination and the treatment of potentially large volumes of contaminated water.

3.3.12 Radiation Protection

The provision for radiation protection of operators and all other staff involved in the SAM and emergency arrangements.

3.3.13 On Site Emergency Center

The provision of an on-site emergency center protected against severe natural hazards and radioactive releases, allowing operators to stay onsite to manage a severe accident.

3.3.14 Support to Local Operators

Rescue teams and adequate equipment to be quickly brought on site in order to provide support to local operators in case of a severe situation.

3.3.15 Level 2 Probabilistic Safety Assessments (PSAs)

A comprehensive Level 2 PSA as a tool for the identification of plant vulnerabilities, quantification of potential releases, determination of candidate high-level actions and their effects and prioritizing the order of proposed safety improvements. Although PSA is an essential tool for screening and prioritising improvements and for assessing the completeness of SAM implementation, low numerical risk estimates should not be used as the basis for excluding scenarios from consideration of SAM especially if the consequences are very high.

3.3.16 Severe Accident Studies

The performance of further studies to improve SAMGs. Examples of areas that could be improved with further studies include:

- The availability of safety functions required for SAM under different circumstances.
- Accident timing, including core melt, reactor pressure vessel (RPV) failure, basemat melt-through, SFP fuel uncovery, etc.
- PSA analysis, including all plant states and external events for PSA levels 1 and 2.
- Radiological conditions on the site and associated provisions necessary to ensure MCR and ECR habitability as well as the feasibility of AM measures in severe accident conditions, multi-unit accidents, containment venting, etc.
- Core cooling modes prior to RPV failure and of re-criticality issues for partly damaged cores, with un-borated water supply.
- Phenomena associated with cavity flooding and related steam explosion risks.
- Engineered solutions regarding molten corium cooling and prevention of basemat melt-through.
- Severe accident simulators appropriate for NPP staff training.