Post-
Fukushima
accident

Peer review report

Stress tests performed on European nuclear power plants

ENSREG
European Nuclear Safety Regulators Group
Stress Test Peer Review Board

Executive Summary

General context

Following the severe accidents which started in the Fukushima Dai-ichi NPP on 11 March 2011, the European Council of 24/25 March 2011 requested that a comprehensive safety and risk assessment, in light of preliminary lessons learned, be performed on all EU nuclear plants. The request of the Council included "stress tests" performed at national level complemented by a European peer review. This was the first time that such a multilateral exercise covering over 140 reactors in all EU countries operating nuclear power plants was considered. The Council invited the European Nuclear Safety Regulators Group (ENSREG) and the European Commission to develop the scope and modalities for the stress tests with the support of the Western European Nuclear Regulators' Association (WENRA). WENRA drafted the preliminary stress tests specifications in April. Consensus on these specifications was achieved by ENSREG and the European Commission on 24 May 2011. The Commission and ENSREG agreed that the work on the stress tests should be carried along two parallel tracks; a safety track to assess how nuclear installations can withstand the consequences of various extreme external events and a security track to analyse security threats and incidents due to malevolent or terrorist acts. The work on security is carried out by an Ad hoc Group on Nuclear Security composed of Member States experts and is outside the scope of this report. The specifications of the peer review as well as a working paper on the transparency aspects of the EU stress tests were agreed upon at the 11 October 2011 ENSREG meeting.

Stress tests and peer review organisation

The safety track of the stress tests and peer review focus on three topics which are directly derived from the preliminary lessons learned from the Fukushima disaster and confirmed by the IAEA missions following the accident and reports from the Japanese Government. Natural initiating events, 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 for safety improvements, 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 European 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 specifications, to check that no important problem 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 disaster.

The 15 European Union countries with nuclear power plants as well as Switzerland and Ukraine performed the stress tests and were subjected to the peer review. The operators submitted their final assessments on 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 managed by a Board that consisted of seven senior regulators from EU countries and an EC senior manager. Each national regulator was invited to nominate one expert for each of the three topical areas. Most of the experts were experienced regulators. Knowledgeable scientists or consultants designated by regulators also participated. The European Commission also nominated experts. There were over 70 reviewers from 24 European countries participating in the peer review. Observers from several non-EU countries (Canada, Croatia, Japan, UAE and USA) as well as the IAEA also attended.

The peer review itself started with a desktop review of the national reports. Each reviewer had access to all the reports and could generate written questions to the national regulators. Over 2000 questions were generated. Following the desktop review, all peer reviewers met in Luxembourg on Sunday 5 February, for a full two week topical review. The review was structured by the 3 topics of the stress tests: natural hazards, loss of safety systems and severe accident management. The experts were grouped in 3 topical teams. Each topical team was composed of approximately 23 reviewers. Each of the 17 countries subjected to the peer review had to make a presentation to each of the three topical teams, to answer the written questions as well as additional questions asked during presentations. In-depth discussions on the results of the topical reviews were then performed within each of the teams until a consensus was reached. The findings of the review were shared between the 3 teams at the end of the process. Finally, the results of the review were grouped country by country in order to produce draft country reports.

In March 2012 a series of country reviews began. Each country subjected to the peer review was visited by a team of eight peer reviewers for three or four days. Complementary discussions were held in order to obtain appropriate answers to the questions left open after the topical review as well as clarification on important issues. A plant selected by the review team was also visited in each country. The reports drafted during the topical reviews were completed using additional information obtained during the visits. They were discussed within the teams in order to reach a consensus and finalised. The national regulator had the opportunity to make remarks but the final decision belonged to the review team. The 17 country reports are included as annexes to this report. They were used by the peer review Board to refine the preliminary conclusions drawn from the topical reviews and to write this report.

Transparency and an opportunity for public involvement have been objectives from the beginning. In pursuit of these objectives, the national reports have all been made public in English and most in the national language. The final peer review report with the country review annexes is also available publicly. The ENSREG and the peer review Board hosted a public meeting in January 2012 to inform the stakeholders and seek comments. Suggestions were collected on a public website in January 2012 and were later considered during the peer review process. Comments related to specific countries or reactors were forwarded to the responsible national regulators. Overall the public input has improved the stress test peer review process. Comments received in the public meeting influenced the structure of the final report. An additional public meeting is planned for 8 May 2012 in Brussels to present the results and answer questions.

Main results of the peer review

The peer review concluded that all countries have taken significant steps to improve the safety of their plants, with varying degrees of practical implementation. In spite of differences in the national approaches and degree of implementation, the peer review showed an overall consistency across Europe in the identification of strong features, weaknesses and possible ways to increase plant robustness in light of the preliminary lessons learned from the Fukushima disaster. As a result of the stress tests, significant measures to increase robustness of plants have already been decided or are considered. Such measures include provisions of additional mobile equipment to prevent or mitigate severe accidents, installation of hardened fixed equipment, and the improvement of severe accident management, together with appropriate staff training measures. In many cases, important modifications are being prepared for the near future. Details about national situations, as well as recommendations to national regulators, can be found in the attached country reports.

The peer review also identified four main areas of improvement to be considered at the European level, as presented in the following paragraphs.

European guidance on assessment of natural hazards and margins

Overall, the compliance with the ENSREG specification was good with regard to design basis for earthquake and flooding. However there was a lack of consistency identified with respect to natural hazards 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.

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.

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.

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.

Future actions

The peer review Board recognises that full understanding of the Fukushima accident will be a long-term process extending over several years, possibly a decade. The peer review has demonstrated the benefit of sharing between national regulators the results of the stress tests and ideas for strengthening safety and robustness of plants. In the spirit of continuous improvement for safety, the peer review Board considers that a follow-up of the actions resulting from the present stress tests as well as future assessments would be beneficial. Such a follow-up should be organised in the frame of the existing arrangements, rather than creating new ones.

One of the important results of the public interaction is a strong demand for a European initiative on off-site emergency preparedness. This subject was not part of the mandate of the peer review. However, the Board recognises importance of off-site emergency preparedness in Europe, as a follow-up of the Fukushima disaster.

Finally, it should be mentioned that performing such a peer review was a challenge and required very significant resources from the participating countries. In that sense, it should be considered as an exceptional exercise, which cannot be reproduced frequently. Notwithstanding, it was judged very positively by most of the participants and is expected to contribute to enhancing safety in Europe and in each European country.

1 INTRODUCTION

1.1 Mandate by the European Council and ENSREG specifications

The nuclear accident that occurred at the Fukushima Dai-ichi nuclear power plant in Japan, following the earthquake and tsunami of 11 March 2011, raised considerable attention on nuclear safety, worldwide.

While initiatives were taken in Member States by Governments and Safety Authorities, the European Commission and EU national nuclear safety regulators launched a process to carry out EU-wide risk and safety assessments of nuclear power plants ("stress tests"). The initiative was supported by the European Parliament and endorsed by the European Council (EU Council) at its meeting of 24 – 25 March 2011[1]. In its request the EU Council asked ENSREG and the Commission to carry out the assessment by *independent national authorities and peer review; their outcome and any subsequent measures that will be taken should be shared with the Commission and within ENSREG and should be made public.* The EU Council also stated that the *EU will request that similar "stress tests" be carried out in neighbouring countries and worldwide, regarding both existing and planned plants.*

The Commission and ENSREG agreed that the work on the stress tests should be conducted in two parallel tracks, as defined by the ENSREG and European Commission (EC) specifications[2]:

- A Safety Track to assess how nuclear installations can withstand the effects of extreme events. A detailed specification is annexed to the ENSREG declaration.
- A Security Track to analyse security threats and the prevention of, and response to, incidents due to malevolent or terrorist acts. The work on security is carried out by an Ad hoc Group on Nuclear Security composed of experts from the Member States, with the participation of the Commission and is outside the scope of this report.

1.2 Stress tests process and objectives

ENSREG initially defined a "stress test" as a targeted reassessment of the safety margins of nuclear power plants in the light of the events which occurred at Fukushima: extreme natural events challenging the plant safety functions and leading to a severe accident. As such, the main aim of stress tests is to assess the safety and robustness of nuclear power plants (NPPs) with regard to the preliminary lessons learned from Fukushima.

For this purpose, they go beyond the safety evaluations made during the licensing process and periodic safety reviews (PSRs).

Stress tests are conducted on a voluntary basis by the participating countries following a three-step process:

1. Assessment by the nuclear operators (licensees) during the period June – October 2011,
2. Review by national authorities (regulators) by end 2011, and
3. European peer reviews from January 2012 until April 2012.

In the first step, operators have analysed the robustness of their plants against the ENSREG specifications and proposed improvements. They reported mainly on the following topics:

- Topic 1: Initiating events: earthquakes, flooding and extreme weather conditions,

[1] EUCO 10/11 (paragraph 31)

[2] http://ec.europa.eu/energy/nuclear/safety/doc/20110525_eu_stress_tests_specifications.pdf (Declaration of ENSREG, 13 May 2011).

- Topic 2: Loss of safety systems: issues related to loss of power or ultimate heat sink; or a combination of both, as a consequence of any event, and

- Topic 3: Severe accident management (SAM)

In the second step, national regulators evaluated the work of the operators and eventually imposed additional requirements on them. The regulators summarised the situation in national final reports. These reports were submitted to the EC by 31 December 2011.

In the third step, a team of peer reviewers have reviewed the national reports and presented a set of conclusions and recommendations. This report summarises and provides an overview of the whole process.

1.3 Peer review objectives

The ENSREG requirements [2] noted that a transparent EU-wide review was needed in order to enhance credibility and accountability in the national stress tests performed by the 17 participating countries[3] and summarised in their national reports.

The peers reviewed the comprehensiveness and the consistency with standards of the approaches taken by the operators and the national regulators in their work.

1.4 Purpose of the present report

The results of the peer reviews are summarised in this report. The purpose of this report – as prepared by the peer review Board is threefold:

a) To describe the peer review process,
b) To provide ENSREG with the outcome of the peer review process,
c) To present the main results in terms of strong features, weak points, identified measures already taken at national level as well as indicating areas to be considered for possible further improvements.

2 DESCRIPTION OF THE PEER REVIEW PROCESS

2.1 General approach

The main purpose of the final national reports is to evaluate the safety assessments performed by the operators as well as proposed measures for possible improvement and if necessary identify additional needed improvements.

The peer review teams reviewed the 17 final national reports according to the following methodology:

- First, the peer reviews were conducted on a topical basis, assessing the national reports in the three topical areas (extreme natural hazards, loss of safety systems, and severe accident management issues). In the course of these topical reviews, three expert teams analysed the contributions from all countries on the particular topic.

- Next, the results for each of the topical reviews were incorporated into draft country reports for each country. These draft country reports, including lists of complementary questions to be clarified, were then finalised during specific country visits by dedicated country review teams.

[3] **15 EU Member States** (Belgium, Bulgaria, Czech Rep., Finland, France, Germany, Hungary, Lithuania, Netherlands, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom) and **2 Neighbouring Countries** (Switzerland, Ukraine).

ENSREG and the EC agreed on the composition of the peer review teams, consisting of experts from nuclear and non-nuclear Member States and participating neighbouring countries, as well as from the EC (Directorate-General for Energy and the Commission's Joint Research Centre (JRC)):

- Each of the three topical review teams comprised 20-30 experts, with a team leader, a deputy team leader and two rapporteurs. Members of the team whose national facilities were under review were not part of that specific review. Observers from Canada, Croatia, Japan, the UAE, the USA and the International Atomic Energy Agency (IAEA) also participated.

- The six country review teams, visiting 17 countries, each comprised eight experts, including a team leader and a rapporteur. The EC provided the rapporteur and one member in each review team.

A peer review secretariat was also created with the support of the JRC of the EC.

2.2 Project organisation

2.2.1 Board

ENSREG and the EC decided to establish a peer review Board to provide adequate supervision, ensure consistency and provide a report to ENSREG on the peer review process. The Board comprises:

- A Chairperson (Ph. Jamet – France),
- A Deputy Chairperson (A. Gurgui – Spain),
- A project manager with the task of ensuring overall coordination of the activities (P. Krs – Czech Republic),
- Three team leaders of the topical reviews (D. Shepherd (UK) for Topic 1, E. Liszka (Sweden) for Topic 2 and J. Misak (Slovak Republic) for Topic 3,
- A representative of non-nuclear Member States (A. Molin – Austria), and
- A representative of the European Commission (M. Garribba – Directorate-General for Energy).

2.2.2 Review teams

The peer review experts proposed for participation in topical and country reviews were nominated by the participating countries and the EC, and communicated to the peer review secretariat:

- Each Member State, each fully participating neighbouring country[4] and the European Commission, had the right to nominate one expert for each of the three topical review teams.

- The qualifications of the experts were decided by the nominating parties; information on the experts background was provided to facilitate the composition of balanced country review teams.

- In nominating their participants for the topical review teams, countries also indicated whether their nominees could serve as team leaders or deputy team leaders.

- The appointment of topical review team leaders and deputy team leaders was agreed by ENSREG and the EC.

The country review teams were assembled by the peer review secretariat on the basis of the persons suggested and the countries to be visited by each team. The composition of each team was then confirmed by the peer review Board and the respective country.

In the appointment of the country review teams, the principle followed was that each team has two reviewers for each topic of the topical review. This ensures consistency and continuity from the topical to the national parts of the review.

[4] i.e. Switzerland and Ukraine.

The list of reviewers is included in appendix 2.

2.2.3 EC support

Facilities, organisational and financial support was provided by the EC for the peer reviews and the Board meetings in Brussels and Luxembourg. Thirteen experts from the EC (Directorate-General for Energy and JRC) participated in the topical and the country reviews. The EC JRC provided the peer review secretariat.

2.3 Project implementation and schedule

2.3.1 Pilot phase

A peer review pilot exercise was performed on 7 and 8 December 2011 at the EC Directorate-General for Energy premises in Luxembourg. This exercise comprised the review of one example national report, covering the three above topics. UK, Germany and Finland volunteered to submit a draft national report each on one topic for the pilot review.

Given the complexity and the time scale of the peer review phase, the pilot phase was designed to test all the subsequent phases of the peer review process and allow their smooth management. The pilot phase identified a number of adjustments needed in the process while concluding that the process is realistic and the given time schedule, although very ambitious, is achievable.

2.3.2 Desktop review

A desktop review was performed by each participating expert on all national reports or a subset of them (each national report was reviewed by at least 3 experts) during the period 1 – 20 January 2012.

Written questions were sent by each expert to the secretariat and to the respective country. The secretariat then compiled and grouped questions and sent them to all reviewers of the respective topic and to the respective countries, with the aim of facilitating the discussion during the topical review meetings in February. **In total, more than 2000 questions were received from reviewers in preparation of the topical reviews[5].** Individuals responsible for drafting the country report prepared the first version of the country report.

2.3.3 Topical reviews

Over the period 5-17 February 2012, the topical reviews were performed at the EC premises in Luxembourg. Three national reports were presented each day (in parallel for the three topical review groups), followed by question and answer sessions.

Groups of experts from the national regulators of the 17 participating countries presented their respective national reports for each specific topic and answered the questions sent in advance (originating from the desktop review) and those raised spontaneously during the meeting.

On the basis of these discussions, topical country summaries were improved and agreed upon within the respective groups.

Next, topical country summaries were assembled and harmonised across countries and topics in order to produce one draft topical review report for each of the three topics. These documents included not only a summary of the respective issues per country, but also highlighted corresponding strengths and weaknesses identified by the national regulators or the peer review teams.

Similarly, the topical country reviews were used to develop draft country-specific reports, including lists of complementary questions and issues to be clarified during the country reviews.

2.3.4 Country reviews

Six teams of varying composition were set up to visit each of the 17 participating countries during March 2012 and perform a more detailed review of the country report. In order to maintain a clear link

[5] See Annex.

with the topical reviews, teams included two reviewers who attended the topical review for each topic, a team leader and a rapporteur. To prevent any conflict of interest, the reviewers were not allowed to originate from a country which the team would be reviewing. Teams have been constructed also taking into account the preferences of each Member State in peer reviewing the report of other Member States.

Draft country reports were sent to each country at the end of the topical review phase. E-mail or phone discussions on the reports started before the country review took place in order to prepare the country visit and ensure full mutual understanding of the issues to be reviewed.

Country reviews focused on questions, comments, and recommendations identified during the topical review. The purpose of the visit was to examine and resolve issues identified during the earlier stages of the process. In order to guarantee rigor and objectivity, the national regulator under review was asked to allow access to all necessary information by the peer review team, subject to the required security clearance procedures. Staff and facilities were also made available to the visiting team to discuss the open issues. A visit to a NPP selected by the review team was organised in each country in order to provide complementary information on some aspects of the implementation and results of the stress tests.

2.3.5 Identification of final conclusions

The peer review process led to final conclusions being reached concerning the consistency of the exercise, the common issues identified through the topical reviews as well as country-specific issues that are detailed in the country reports attached to this report. The last chapter of this report contains the conclusions reached by the peer review Board.

The present report summarises the results and conclusions of the peer review. It includes 17 country reports as annexes.

3 TRANSPARENCY AND PUBLIC INVOLVEMENT

3.1 Background and framework

The EU Council of March 2011 requested that all necessary information be provided to the public and that the outcome of the stress tests and any necessary subsequent measures to be taken should be made public.

Being aware that full transparency, combined with this opportunity for public involvement, would contribute to the stress tests being recognised by European citizens, ENSREG decided that national regulatory authorities should be guided by the "principles for openness and transparency"[6] as adopted by ENSREG in February 2011 and that these principles should also apply to the stress tests (Annex I to the Declaration of ENSREG of May 2011[7]).

The means of ensuring full transparency and also providing an opportunity for public involvement were finalised in October 2011 and have subsequently been published[8].

3.2 Information on the ENSREG web site

ENSREG decided that information about the stress tests would be made available on a dedicated location on its website. The site includes information about the background and specifications, the stress test process, the timetable as well as the composition of peer review teams. In addition, information on peer review progress has been provided by two monthly updates for February and March 2012.

National reports (both progress reports and final reports) have been made available in a timely manner as was the report to the EU Council by the EC.

[6] HLG_p(2011-14)_57 – 'Principles for Openness and Transparency'.
[7] HLG_p(2011-15)_66 – 'Scope and modalities for comprehensive risk and safety assessments'
[8] HLG_p(2011-16)_80 – 'Transparency aspects in the implementation, reporting and follow-up of the stress tests'

This report, including the country-specific peer review reports, will also be available on the ENSREG website.

ENSREG also recommended that the operator reports be published, provided that this does not jeopardize other interests, for example security, recognised in national legislations or international obligations, in line with Annex I of the "Declaration of ENSREG". Many operators followed this recommendation.

Furthermore, comprehensive information relevant for public involvement is presented and regularly updated, including presentations, the summary and conclusion of the January public event.

3.3 Participation of Board members in national and other meetings

ENSREG stated that, at the national level, regulators should consider how to engage the public by organising a structured and comprehensive information process. During the January public event, members of the public noted that local events would be more effective than a large public event in Brussels. As such, in the view of the peer review Board, organisation of local public events sponsored by the national regulatory authorities was a good idea. Such events took place in a number of countries. Members of the peer review Board offered to take part and were therefore invited to some of the public events.

In addition, members of the peer review Board made a number of presentations at various other meetings at national, European and international levels.

3.4 Suggestions raised by the public on the Web site, answers and contributions to the peer reviews

A number of questions and suggestions were posted on a public website in the period 1 - 20 January 2012. They were published on the ENSREG website and far more questions and suggestions were raised during the public event held on 17 January 2012, in Brussels.

A summary of these questions and suggestions as well as pertinent answers was compiled by the end of January and published on the ENSREG website. The main issues were:

- public involvement;
- off-site emergency preparedness;
- security issues, airplane crash in particular; and
- the stress test peer review process.

The ENSREG website will be open again from 25 April to 6 May to collect comments on this report.

3.5 Main output and conclusions of the interactions of the European stakeholders at the beginning of the process, contribution to the peer reviews

The January public event associated with the stress tests peer review was well attended. There was sufficient time for question and answer sessions which permitted an open and constructive discussion. Participants used the opportunity to express their views on the process, to share comments, to express their expectations of the ongoing process. They also extensively discussed with representatives of the organisations that played a role in developing and organising the stress tests and peer reviews, including the EC, ENSREG, WENRA and the peer review Board.

The chairman of the public event summarized the main conclusions which were also published on the ENSREG website. He highlighted the unique character of the stress tests. The decision to conduct European stress tests in a coordinated way has generally been appreciated. Topics addressed in the scope of the stress tests and stress test specifications were generally well received, however, he noted scepticism remaining regarding topics not included in the stress tests and its specifications. The stress tests execution has been globally welcomed. It was recognised that operators and regulators have provided extensive analyses. They have respected the given deadlines and published their respective reports, providing comprehensive information to all interested parties, including means for public participation. He also noted that the independence of the review process was questioned. Many participants expressed high expectations with regard to the outcome of the peer review. In particular the peer review Board and ENSREG were expected to establish a common and consistent European dimension in the evaluation of the stress tests results. It was expected that the outcome of the stress tests would be validated against existing international standards for nuclear safety and the WENRA reference levels, where applicable. Finally, a need for continuous improvement beyond the stress tests was unanimously recognised, while views differed on the pertinent priorities.

The present report contains a number of recommendations for future actions to address major issues in this regard. It also takes into account suggestions and comments provided by European stakeholders.

3.6 Presentation of final conclusions to European stakeholders

This report and its findings in particular, will be presented at a second public event to be held in the first half of May 2012. This period was selected late enough to enable members of the public to review this report before the public event and early enough for the outcome of this second public event to be reflected in the European Commission's final report to the European Council.

4 GENERAL QUALITY OF NATIONAL REPORTS AND NATIONAL ASSESSMENTS

4.1 Compliance of the national reports with the topics defined in the ENSREG stress tests specifications

In general terms, all the national reports addressed the three topics defined in the ENSREG stress tests specifications.

For topic one, natural external hazards, ENSREG identified three areas of investigation - earthquake, flooding and extreme weather. Although most national reports address the design basis for earthquake (DBE) and flooding (DBF) reasonably well, very few assess cliff-edge situations in the manner requested by ENSREG. This is possibly because of the short timeframe of the stress tests exercise. Many countries indicated that future work in this respect is either ongoing or is planned in the near future. Several national reports noted that addressing cliff-edge effects for flooding is not necessary. This was accepted by the peer review for external flooding if it can be demonstrated that such flooding is practically impossible due to local geography. The peer review identified that a systematic assessments along the lines proposed by ENSREG is worthwhile. 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.

For the topic two, the reports covered all areas prescribed by the ENSREG specifications - loss of offsite power (LOOP), station blackout (SBO) and loss of ultimate heat sink (UHS), plus combinations thereof. In all cases, national reports extensively assessed the plant responses to specific events, also indicating the margins (time) available until specific remedial measures need to be undertaken. The stress tests confirmed that all the countries rely on well developed regulatory requirements, in line with IAEA standards and guidance. Nevertheless, differences in plant design bases lead to particular differences in response to events evaluated. The peer review process offered a good opportunity for experts from participating countries to understand such differences and utilise lessons learned for identification of further improvements.

The information provided in the national reports on topic three, severe accident management, addressed the topics of the ENSREG specifications in full. National reports describe existing accident management and on-site emergency arrangements, as well as measures for further enhancement of the provisions. However, their presentation and level of detail does not always follow the format proposed by ENSREG.

4.2 Adequacy of the information supplied, consistency with the guidance provided by ENSREG

All participating countries submitted reports on the conduct and regulatory assessment of their respective national stress tests on time. As mentioned above, there were differences in approach, both in the methodology of various investigations and in the form of reporting. Nevertheless, this is to be expected since the ENSREG stress tests exercise is novel and was conducted over a deliberately compressed timescale. Taking account of the circumstances, these variations were considered acceptable, and did not impact the outcome of the stress tests. The main constraint was the time available for each phase of the stress tests process and the regulatory review of its results. All countries reported that a number of activities were still ongoing or are to be launched in the very near future.

The information provided was, in general, very good. In some cases, in particular for countries with numerous plants and different designs, summary information was provided in the national report, with detailed, plant level information usually being available in the operator reports. Nevertheless, it could be concluded that the information provided fulfilled the guidance established by ENSREG and allowed for a comprehensive peer review.

Participating countries fully cooperated with the European peer review process during the topical peer reviews and country visits. Peer review experts made very effective use of the topical discussions organised in Luxemburg from 5 to 17 February and the seventeen country visits that took place from 11 to 31 March, to complete the reviews and obtain the information and evidence needed for drawing concise conclusions from the Fukushima event at the European level.

4.3 Adequacy of the assessment of compliance of the plants with their current licensing/safety case basis for the events within the scope of the stress tests

Plant compliance with their current licensing bases was reviewed both by the operators and the regulatory bodies during the national phase of the stress tests, drawing in part on their regular safety assessment activities. The stress test peer review process demonstrated that although countries used different approaches, all the national reports provided evidence of compliance of the plants with their current licensing/safety case basis. Development of updated IAEA safety standards and WENRA reference levels (RLs) over the last decade also promoted a significant shift towards greater consistency between the European countries in terms of general acceptance criteria. Nevertheless, areas for modification of existing RLs or the development of enhanced RLs were identified.

As a general conclusion, there was no indication that any of the plants reviewed within the stress tests did not comply with its licensing basis. , Concerning minor deviations from regulatory requirements that were found, in particular when performing regulatory inspections, standard regulatory procedures were applied in line with legislative framework.

Stress test peer review process results clearly indicate that particular attention needs to be paid to periodic safety reviews as an important and powerful tool for regular reassessment of plant safety status.

Many national reports identify explicit work to demonstrate ongoing compliance with reviewed nuclear installation safety cases. In such a compressed timescale, it is difficult for the peer reviewers to obtain a sense of compliance or otherwise. It was only possible to obtain a snapshot from the peer review country visits and it is therefore recommended that national regulators consider how best to ensure that specific requirements (e.g. IAEA safety standards and WENRA reference levels) for all three topical areas under investigation are adequately maintained. Specific proposals are given in Chapters 5, 6 and 7 and summarised in the final conclusions of this report. The lessons learned, to date, from the Fukushima event (the analysis of the event continues) have in all countries led to modified or additional safety requirements on specific issues. This process is currently ongoing and in most cases is included in the normal process between regulator and licensee.

4.4 Adequacy of approaches used to evaluate margins and robustness of plants

For topic one, natural external hazards, the peer review process noted the generally sound approach to demonstrating an appropriate design basis but identified that the evaluation of margins beyond design basis (BDB) is not consistent in participating countries. A few countries have adopted established approaches for seismic margins and have quantified the inherent robustness of the plant beyond the design basis. However, the majority have made only a general claim that margins exist and therefore there is no information on the basis of which to consider effective potential improvements. ENSREG was clear regarding the approach proposed for flooding, where incremental increases and associated assessments of acceptability and improvements were detailed. Only a small number of countries have done this. The approach to margins for extreme weather demonstrated even more variability, probably because the existing guidance is less well developed. Despite these uncertainties, the majority of national reports identified significant and worthwhile improvements from the approaches adopted.

In topic two, loss of electrical power and loss of the ultimate heat sink and the combination thereof, scenarios were assessed in the topical review regardless of their cause or frequency. In practically all cases, the plant response assessment was properly undertaken for all situations required by ENSREG specifications. In most instances, the loss of UHS (as well as the combination of the SBO and loss of UHS) was enveloped by the SBO event. This leads to some aggravating situations for plants in which the design concept relies on multiple layers of AC power or multiple sources of water. For those, plants selected to define a SBO for two cases, partial and full loss of alternating current (AC) power. This was found to be a correct way of following the ENSREG specifications. The lack of a clear and unambiguous common terminology (such as definition of ultimate as opposed to alternate heat sink) was an issue related with the assessment of the heat sink. Some countries considered additional sources of water (like dedicated wells, or nearby lakes), others considered a possibility of residual heat transfer to the atmosphere as an alternative heat sink.

Discussions during the topical reviews allowed for clarification of differences in the assumptions, methodologies and presentation of results. It was then concluded that the safety margins and cliff-edge effect determination for losses of safety systems were generally in line with ENSREG specifications.

Robustness for Topic 3, severe accident management, can mainly be thought of in terms of the sufficient time available before the occurrence of important events which escalate the severity of the accident (e.g., core damage, vessel and containment failure). Another measure of robustness is the level of the redundancy, diversity and independence of provisions in place to prevent or limit radioactive releases to the environment. The national reports address in a fairly uniform way the hardware, procedural and human provisions available, their extent, the level of preparedness including, verification and validation of SAMGs, strategies for implementing specific accident mitigation measures, etc. Nevertheless, the SAM provisions differ, as those are closely related with the plant type and design, but also with the historical developments in specific countries. In practically all the national reports the need for further analysis is identified as necessary prerequisite for incorporating all lessons learned from the Fukushima event in the severe accident management area.

4.5 Regulatory treatment applied to the actions and conclusions presented in the national reports

National reports include specific information with regard to the involvement of individual regulators in the process, in particular on the actions of the authorities related to the stress tests and on their conclusions. In all cases, the national regulatory authorities, sometimes supported by their technical support organisations (TSOs), reviewed the assessments undertaken by the licensees. The regulatory actions included dedicated inspections, decisions/orders given, assessments of and in some cases regulatory approval, necessary improvement/remediation measures and their planned schedules. In addition to the actions of the operators, regulatory organisations launched their own investigations related to the Fukushima event. Furthermore, all regulatory authorities may refocus their activities, for example, to include specialised inspections. Long-term changes may be needed depending on the findings from the final assessment of the accident and the lessons learned from it.

The national regulators screened information coming from Japan and international organisations such as the IAEA. In many countries, immediate national checks were performed even before the ENSREG stress tests specifications were developed and were agreed on. Some of the governments demanded reports on the results of such quick checks before summer 2011. On the other hand, there are countries which decided for a more gradual approach where the final decisions on programs and measures to be implemented in response to the Fukushima event will be made after comparison with the EU stress test peer review results.

All regulatory bodies have taken very seriously the stress tests process at the national level, and in certain cases have already assessed specific new proposals presented by the operators. A large number of previously scheduled activities have been accelerated and decisions have been issued by the regulatory authorities identifying further safety improvements resulting from the stress tests process. According to the national reports, national regulators have been highly pro-active in identifying improvements and areas for further analyses.

5 EUROPEAN PLANTS ASSESSMENT RELATIVE TO EARTHQUAKES, FLOODING AND OTHER EXTREME WEATHER CONDITIONS

5.1 Description of the present situation of plants at the European level

5.1.1 Regulatory basis for safety assessment and regulatory oversight

A variety of regulatory approaches are adopted for protection against external events. Most countries adopt a prescriptive approach, in which regulations specify details of how safety cases are to be produced and detailing hazard parameters resulting in a DBE or similar. Other countries adopt a high-level, goal-setting approach, in which more discretion is left to the operator, provided that they justify the approach adopted. Either approach can lead to a satisfactory safety case but demonstration is only adequate if the national regulator and/or operator determine that external events are assessed with the appropriate level of conservatism.

IAEA guidance suggests that a minimum 0.1g horizontal peak ground acceleration should be adopted for seismic loading, where a detailed hazard assessment may indicate a lower level for design or re-assessment. This default level has not yet been fully adopted in a small number of instances. However where this is the case there are local plans to address the deficiency. It is recommended that this be taken into consideration by regulators when reviewing seismic hazards for future PSRs.

Most countries have demonstrated an adequate approach to seismic and flooding design bases, given that regulators consistently require this. However the assessment of margins beyond the design basis (BDB) is far more variable since this is not generally a regulatory requirement. Very few countries have determined cliff-edge effects and the associated protection improvements in the manner envisaged by ENSREG. The situation with regard to extreme weather is even less satisfactory. Some countries demonstrated a capability based on recent historic data, which is less demanding than good practice would dictate. In general there was little evidence of assessing margins BDB.

5.1.2 Main requirements applied to this specific area

A good practice adopted by IAEA member states and used by the peer review is that external events should be addressed by designing to the hazard level consistent with a 10,000 year return period, i.e. a frequency equivalent to 10^{-4} per annum. Many countries adopt this level for new designs, while a large number of countries adopt it for re-evaluation of older designs. However a small number have not adopted this level for re-evaluation/back-fitting, in some cases since they judge that it is not feasible to define the characteristics of the earthquake at such remote frequencies. It is recommended that regulators consider how to determine consistency in ensuring that all plant reviews/back-fitting with regard to external hazards safety cases, achieve this level of demonstration.

The main issue of hazard reassessments is to identify the need for appropriate modifications to NPPs. Either deterministic or probabilistic methods can be used, but should be consistent with IAEA guidance.

Towards the end of the peer review process, IAEA issued guidance on meteorological design basis parameters which will be expected to form a focus for development of extreme weather assessments in the near future[9].

5.1.3 Technical background for requirement, safety assessment and regulatory oversight

External events safety cases ideally should have elements of both deterministic and probabilistic approaches. The deterministic approach requires definition of a review level loading analogous to a design basis loading. The national reports indicate that there is a significant level of agreement, underpinned by IAEA and other guidance, for this level to be consistent with a frequency of 10^{-4} per annum. A small number of countries adopt a more conservative approach using a frequency of 10^{-5}.

Because of the high level of uncertainty regarding natural events, it is helpful and logical to complement the deterministic assessment with probabilistic safety analysis (PSA). Although seismic PSA is a well-developed technique it was apparent from the peer review that it is not universally implemented for older plants and it is recommended that national regulators should consider ensuring that seismic PSAs are included in the PSR process. For natural hazards other than seismic and flood the PSA process is not as well-developed and alternative approaches to determining margins and identifying potential plant improvements may be more appropriate, although at least one country appears to successfully include extreme weather in its PSA. The requirements for potential plant improvements derived from either the deterministic or probabilistic methods should be consistent. In both cases the objective should be to determine opportunities for plant improvement.

The stress tests specifications did not consistently result in relevant information in the national reports concerning regulatory oversight. However it can be reliably inferred that hazard safety cases are appropriately regulated, although it was difficult to determine how oversight is continued into plant operation. From the national reports that did address this aspect it is apparent that effective inspections can be undertaken to ensure that equipment is properly installed and maintained and it is recommended that all national regulators should consider establishing programmes for such inspections, particularly for temporary and mobile equipment and tools used for mitigation of BDB external events.

5.1.4 Periodic safety reviews

It was clear from the national reports that PSRs are well-established throughout the participating countries and they have formed the basis for continuous plant improvements, as well as for regular re-assessment of the licensing basis. In most cases, a reassessment of the external hazard is part of the PSR process. PSRs including re-assessment of the seismic hazard were found to be particularly strong safety features since such repeated periodic updates make it possible to take advantage of advances in science and technology. It is recommended that regulators should consider how to strengthen the PSR process by developing a more consistent approach to the determination of hazard levels and margins for external events, at least every 10 years and whenever necessary.

5.1.5 Plant compliance with current requirements

All national reports provided good evidence of compliance with design-basis requirements for earthquake and flooding. BDB is less clear, partially because methods are not as mature and readily

[9] Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations - IAEA Safety Standards Series No. SSG-18;Published Thursday, December 01, 2011.

available, and partially because the regulatory requirements are less clear, as discussed above. For extreme weather even the design-basis is not clear, however new IAEA guidance9 was issued near the end of the stress test process and this may provide the initiative for more consistency to be developed within the participating countries.

It is also considered valuable for the ongoing compliance of plants to be rigorously validated by regulators and it is recommended that regulators, together with operators, should consider how to develop standards to address qualified plant walkdowns with regards to earthquake, flooding and extreme weather – to provide a more systematic search for non-conformities and correct them (e.g. appropriate storage of equipment). This plant-based activity would benefit from clear labelling of qualified equipment.

5.2 Assessment of robustness of plants at the European level

5.2.1 Approach used for safety margins assessment

There are well-established practices for assessing seismic margins BDB, referred to as seismic margin assessment. This appears similar to a deterministic method although the acceptance criteria are derived from probabilistic fragility assessments. Alternatively, similar fragilities can be implemented in a seismic PSA. Many countries have adopted one of these approaches and used them to determine potential improvements. However, nearly half the countries participating in the stress tests did neither and cited generic potential margins in response to the ENSREG specifications.

Assessment was made more complicated by different nomenclature used in international guidance, such as SL1, SL2, DBE, etc. Whatever approach is adopted it is clear that the primary objective should be to determine potential plant improvements and this should be the focus of the work.

For flooding, ENSREG was very explicit about the approach to be adopted to assess margins – presume increases in flood level BDB and determine cliff-edge responses and potential improvements to address them. Only a small number of countries have done this. In many cases the national report argues that the possibility of a significant flood BDB is very remote and can be discounted. Nevertheless many of these countries still identify possible improvements. It is accepted that at some sites, due to the inherent physical geography, any cliff-edge effect resulting from an external flooding, caused by rising water level, can be practically eliminated. However it is recommended that national regulators in all countries that have not considered incrementally increased flood levels and associated potential improvements consider requesting the operators to do so.

As mentioned above, it is recommended that WENRA, involving the best available expertise from Europe, should consider how to determine a consistent approach to margin assessments for external events – probably best done through the provision of more advice regarding the scope of periodic reviews and/or in conjunction with the work of agencies such as IAEA. It would, in particular, be appropriate to encourage further development of consistent approaches to extreme weather.

Where BDB studies have been carried out effectively, relevant improvements have been identified and it is important that the regulators in those countries that did not comply fully with the ENSREG specifications should consider how to complete such an assessment.

5.2.2 Main results on safety margins and cliff-edge effects

In general, the seismic design basis is satisfactorily determined on the basis of events consistent with a 10^{-4} per annum return frequency. This is consistent with good practice and international guidance. However there are some countries where the acceleration levels consistent with the perceived 10^{-4} per annum return frequency are very low. In these circumstances, IAEA guidance suggests that a minimum 0.1g horizontal peak ground acceleration (PGA) should be adopted. This has not been the case in a small number of instances.

The science of seismic hazard assessment and the availability of relevant knowledge continues to improve and it is important that the loading be determined realistically. It is therefore recommended that regulators should consider how to encourage wider discussion regarding good practice for determining the seismic hazard design basis, in order to ensure that the design level and any indicated margin is meaningful in all cases.

Where BDB studies have been carried out effectively relevant improvements have been identified and it is important that the regulators in those countries that did not comply should consider how to complete such an assessment.

The safety margin evaluations that have been reported demonstrated that the evaluation of margins can be effective in identifying plant improvements for increased robustness. The reports also identified significant improvements implemented following PSRs.

For a number of plants, some of the extreme weather loadings are claimed to be encompassed by different events that are judged to require higher levels of plant or structural resistance. On a case-by-case basis this may be judged to be an acceptable approach but the equivalence of the loading has to be demonstrated.

All European countries have determined that a tsunami is either not a realistic threat for the existing plant sites or is encompassed by other flood initiators. Generally, the DBF has been addressed effectively and demonstrated to be adequate. However only a small number of countries have assessed flood margins in the manner that ENSREG specified, i.e. assuming incremental increases in flood level and seeking cliff-edge effects and potential improvements. Many countries have made cases that BDB flooding is an extremely low frequency event and therefore did not evaluate the condition. Even so, many of these countries identified some improvements after subjective consideration. Examples include increased height of openings into protected rooms, provision of additional temporary flood protection dams or volumetric protection of safety-related rooms. The peer review concluded that a systematic assessment of margins along the lines proposed by ENSREG is worthwhile unless there is overwhelming evidence that BDB flooding is an extremely infrequent event. It is recommended that regulators consider pursuing an assessment in-line with the ENSREG specifications where this has not yet been done.

5.2.3 Strong safety features and areas for safety improvement identified in the process

In general the requirements of the DBE and DBF are satisfied appropriately by qualified structures, systems and components (SSCs) and topological arrangements. Many SSCs are either demonstrated to have margins beyond DBE or are claimed to have moderate margins by virtue of robust DBE design. Such approaches are augmented by the adoption of separation and redundancy with regards to BDB hazards.

Over one third of the European plants have adopted a "hardened core" philosophy to provide an additional independent sub-set of safety related SSCs capable of withstanding earthquake and flooding events significantly BDB.

The protected volume approach is noted as an effective way of demonstrating flood protection for identified rooms or spaces.

Where an adequate case has not been demonstrated, the majority of countries have identified future work either to assess margins or establish them by means of modifications.

Most countries have plans to provide rugged mobile equipment to perform the necessary safety functions if the permanent systems were to be impaired. It is recommended that the design for storage of such equipment should take account of external events at the design and beyond design levels to ensure appropriate availability in the event of being required. Similar considerations apply for external hazard robustness of on-site centres for SAM.

The extent of work to assess hazard cases and improve plants arising from PSRs is noteworthy and many countries have demonstrated adequate robustness on the basis of earlier work done to satisfy the PSR process. It is recommended that regulators should encourage consolidation of the PSR process to include assessment of margins against external events, including regular reviews of the design and beyond design hazards.

With regard to hazards, particularly seismic, it would appear that techniques and available data are still developing. It is recommended that regulators should consider co-operation with other agencies in order to develop a consistent approach across Europe, taking account of updates in methodology, new findings and any relevant information from continuous research on active and capable faults in the vicinity of NPPs.

Many, but not all NPPs have permanently installed seismic monitoring and alarm systems. Information from such systems enables operators to make informed judgements regarding whether or not to continue operation following a seismic event. Clearly such decisions should be based on appropriate procedures and training. It is recommended, where they do not currently exist, that regulators consider requiring seismic monitoring systems and appropriate procedures and training,

It was evident that the approach to secondary effects of seismic events, such as flood or fire arising as a result of the event, is not always addressed consistently. It is recommended that the national regulators should clarify such requirements for future assessments.

Some countries refer to weather alert systems. Advance warning of deteriorating weather is often available in sufficient time to provide the operators with useful advice and it is recommended that national regulators should seek to ensure that appropriate communications and procedures are developed by all operators.

5.2.4 Possible measures to increase robustness

Most countries have not completed a formal margins assessment or PSA for the seismic hazard. The peer review concludes that the potential benefit is substantial and recommends that national regulators should consider requiring such analyses where they have not been completed.

In some countries the original seismic design was based on very low accelerations. All countries accept that modern standards require a design level based on a 10^{-4} per annum frequency of occurrence. However the hazard determination is not always consistent with modern standards and understanding and it is recommended that national regulators consider requesting a re-appraisal of hazards against modern standards, as part of the PSR process.

For flood the peer review concluded that a systematic assessment of margins along the lines proposed by ENSREG is worthwhile, unless there is overwhelming evidence that BDB flooding is not feasible. It is recommended that regulators consider pursuing such assessments where they have not yet been completed.

There is substantial variability regarding approaches to extreme weather, partly arising from a lack of clarity with respect to regulatory requirements, but also a lack of available established methods. It is recommended that regulators consider promoting a European-wide debate on the benefits of a more systematic approach to extreme weather challenges and a more consistent understanding of the possible design mitigation measures.

5.2.5 Measures already decided or implemented by operators and/or required for follow-up by regulators

For external event safety cases it is difficult to identify generic physical mitigation measures, since the approach to improve margins is plant-dependent. However, all countries have identified further work in response to the stress tests, or associated work arising from the Fukushima event and it is recommended that ENSREG continues to promote discussions within the community to ensure maximum benefit within Europe. Concerning extreme weather, application of the latest IAEA guidance [10] (issued in 2011) is likely to assist in this respect.

5.3 Peer review conclusions and recommendations specific to this area

All national reports have identified significant and worthwhile potential improvements with programmes extending over several years. It is recommended that national regulators consider the following:

1) Driving all plant reviews/back-fitting with respect to external hazards safety cases to the 10^{-4} per annum/0.1g minimum peak ground acceleration.

2) That in all countries that have not considered incrementally increased flood levels and associated potential improvements they should consider requiring the operators to do so. When carried out at the right level, the exercise is practicable and can easily provide valuable insight into effective and realistic improvements.

3) Strengthening the PSR process by encouraging a more consistent approach to the determination of margins for external events, including external event PSAs (including seismic) and regular reviews of the design and beyond design hazards.

4) That with regard to hazard definition, techniques and data are still developing. WENRA, involving the best available expertise from Europe, should 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.

5) Clarifying requirements for the approach to the secondary effects of seismic events, such as flood or fire arising as a result of the event, in future assessments.

6) That the protected volume approach is an effective way of demonstrating flood protection for identified rooms or spaces.

7) How best to ensure that specific operational requirements of external events safety cases are adequately maintained. Regulators and operators should consider developing standards to address qualified plant walkdowns with regards 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 BDB external events). This plant-based activity would benefit from clear labelling of qualified equipment.

8) That some countries have proposed to develop a “hardened core” of selected safety systems protected against extreme hazards.

9) That the design for storage of mobile equipment to perform necessary safety functions should take account of external events at the design and beyond design levels, to ensure appropriate availability in the event of being required following a significant external event. Similar considerations apply for external hazards robustness of on-site centres for SAM.

10) Installation of seismic monitoring systems and development of associated procedures and training for those NPPs that currently do not have such systems.

11) That some countries refer to weather alert systems. Advance warning of deteriorating weather is often available in sufficient time to provide the operators with useful advice and national regulators should ensure that appropriate communications and procedures are developed by all operators.

6 EUROPEAN PLANTS ASSESSMENT RELATIVE TO LOSS OF ELECTRICAL POWER AND LOSS OF ULTIMATE HEAT SINK

6.1 Description of present situation of plants across Europe

6.1.1 Regulatory basis for safety assessment and regulatory oversight

The majority of countries recognise that the IAEA standards form a good general basis for continuous improvement with respect to the LOOP, SBO and loss of UHS. The national regulatory requirements for this area are generally in line with the IAEA safety standards. However, these national regulatory requirements and regulatory oversight are country-specific. Even so, the underlying safety principles are universal and consist of a comprehensive system of safety objectives with basic safety goals and safety requirements with respect to defence in depth principles and ensuring critical safety functions. Some countries are more specific or apply additional requirements to various levels of defence in depth and diversity for both electrical power supply and residual heat removal. There can also be slight differences in practical application in specific areas, such as systems safety classification, based on an internal logic according to the country-specific situation, or the historical development of the country's nuclear activities and of the country-specific plant design. In order to harmonise and apply good regulatory practices in European countries and in order to learn from each other, WENRA developed reference levels designed to further improve the level of nuclear safety and regulation in the member countries. Implementation of the WENRA reactor safety Reference Levels (RLs) began in 2007. It should be noted that these levels are relatively general and do not provide detailed requirements in the area of topic 2.

6.1.2 Main requirement applied to this specific area

In addition to the general safety requirements discussed above, specific requirements and regulatory guides are applied in different countries, covering the areas of electrical power system and UHS requirements. In particular, for electrical systems more detailed safety requirements are available and in some countries the guidelines are well developed, comprising a more detailed level of technical requirements. These provide the operator with more detailed specifications concerning the design basis and the safety requirements pertaining to electrical systems and components. In line with the principle of continuous improvement of nuclear safety, the most recent requirements are applied to existing plants insofar as is practicable.

Safety requirements regarding the UHS are more general and are addressed in terms of redundancy and diversity. It is difficult to identify specific requirements, such as for the provision of an alternate diverse UHS function, and there is no evidence of the existence of such detailed guidance with regard to this particular function.

6.1.3 Technical background for requirement, safety assessment and regulatory oversight

As defined in the ENSREG specifications, the deterministic approach has been applied as the main approach for the preparation of the national stress tests reports. Nevertheless, complementary information from both the deterministic and probabilistic assessments has been used in the national reports and in discussions, where relevant, as this is reflected in regulations and regulatory guidance in the majority of the countries. Operational experience feedback was also provided, as in some cases it is taken into account and required by the regulations. In addition, the safety impact of plant retro-fits, modernisation programs and accumulated improvements achieved over time, has been demonstrated with corresponding PSA results. The adoption of WENRA reactor safety RLs and the use of deterministic analysis together with level 1 PSA, and in many countries level 2 PSA, is also an important part of the position and requirements presented in the national reports.

6.1.4 Periodic safety reviews

The PSR as a tool for regulatory oversight appears to be universally accepted and applied in European countries with a basic period of 10 years for all operating plants. The scope and the frequency can vary slightly depending on a country's specific practice; however they are on the whole in line with IAEA guidance. In some cases, the regulatory body has adapted the PSR process in order to increase efficiency and to ensure adequate implementation times, as well as to ensure the safe long-term operation of plants.

6.1.5 Compliance of plants with current requirements

The national reports were not required to provide a particular or explicit statement related to conformity with the national requirements. However, it appears from the topical review that the majority of regulators carried out the necessary checks to ensure that the plants are in compliance with the national requirements, but the process has focused on the technical scope of the stress tests and the issues highlighted by the Fukushima accident. The lessons learned up to now from the accident (obviously without any in-depth analysis) have led in several countries to more stringent or additional safety requirements on specific issues. This process is currently ongoing and in most cases involves a dialogue between the regulator and the operator.

6.2 Assessment of robustness of plants at the European level

This chapter of the report addresses the response to the ENSREG specifications for LOOP and loss of the ultimate heat sink (UHS) and the combination thereof. These scenarios were assessed, regardless of their cause or frequency. The combination of these scenarios with additional failure assumptions is beyond the scope of the ENSREG specifications for Topic 2, although in the topical review, the possible impact was considered as part of the discussions.

6.2.1 Approach used for safety margins assessment

The aim of the EU stress tests as a targeted reassessment of the safety of nuclear installations was to evaluate the effects of extreme natural events included in the design basis and beyond.

<u>Issues recognised during the stress tests regarding terminology</u>

– ultimate heat sink (UHS) and alternate ultimate heat sink:

The term “alternate UHS” was interpreted differently in various countries. Most countries considered a diverse source of cooling medium (water from ponds, wells, etc.) as an alternate UHS, but some countries also considered secondary or primary feed-and-bleed into (ultimately) the atmosphere, or the use of emergency condensers, as an alternate UHS.

– loss of off-site power (LOOP) and station blackout (SBO):

The term ‘SBO’ was interpreted differently in several countries. Most countries considered SBO as “complete SBO”, but some countries considered “loss of the protection for design basis accidents”.

A clear and unambiguous common terminology in this regard would enhance transparency and comparability. However, the peer review ensured that the evaluation was performed on the substance of the underlying safety assessment rather than on the basis of terminology alone.

<u>Design safety margins</u>

Design provisions are among the cornerstones of safety analysis and a description of them was required in the national reports. As the ENSREG stress tests specifications define a deterministic approach, in which event sequences are postulated regardless of their plant-specific occurrence frequency, the robustness of the design provisions to prevent their occurrence is not easily estimated, rated or quantified.

Without embarking on a probabilistic approach, a qualitative means of indicating the level of robustness of specific design provisions to ensure safety functions can still lie in the definition of the level of robustness, as practiced in some countries. Examples are: level of redundancy (no redundancy, single failure criterion, n+2 criterion, or more), level of diversity, etc.

<u>Cliff-edge effects and coping times</u>

The main measures required by the ENSREG stress tests specifications are cliff-edge effects and their coping time determination. These cliff-edge effects were provided in the report in most cases, or were obtained during the peer review. In most cases, a conservative approach is applied to calculating the coping times associated with identified cliff-edge effects. This conservative approach sometimes results in relatively short coping times. However, the real coping times available might be longer (sometimes even considerably so). A direct and objective comparison of such values would require the adoption of the same level of conservatism for associated assumptions and calculations. Nevertheless, the basic safety criterion here is to identify cliff-edge effects and when they occur, but also to indicate provisions to prevent these cliff-edge effects or to increase plant robustness. Consequently, part of the stress tests results was a demonstration that adequate measures in the form of plant modifications can and will be taken within the coping time, regardless of the level of conservatism adopted.

<u>Comprehensiveness of safety assessment</u>

In general, it is recognised that the national reports and the country presentations made during the topical review tried to provide a comprehensive safety assessment. Where some (or parts) of the installed systems that are credited in a plant-specific safety case might not satisfy all state-of-the-art requirements (often for historical reasons), it is ensured that sufficient defence in depth is provided by other systems.

<u>Adequacy / level of detail in national reports</u>

Large nuclear countries and/or countries with many plants of different designs tend to report on the basis of a design type, rather than providing a full set of plant-specific data and analysis results. This generated requests for clarifications during the topical reviews and, if necessary, during country visits.

6.2.2 Main results on safety margins and cliff-edge effects

In the EU there are a number of reactor designs, each with certain specific design features. Their safety margins depend on redundancy and diversity of equipment and associated defence in depth. However, for the purposes of the stress tests, these safety margins were assessed, for example, the coping time during which the core may uncover if countermeasures are not adopted. In considering such margins it should be noted that the electrical power supply and UHS are ensured by a number of redundant and diverse systems. Furthermore, in some plants, an extra layer of defence is provided by either stationary systems or mobile equipment that is qualified to operate in the anticipated external conditions. These defence systems help to ensure the required safety functions even if all standby safety-related equipment is lost.

Due to specific design features, some reactor designs are found to have greater margins than the others. However, the important factor to be considered is whether effective countermeasures can be implemented within the coping time to prevent core damage. For some cases a cliff-edge effect is apparent in that it appears that there may be insufficient time to implement countermeasures taking into account the ENSREG stress tests conditions. However, this does not necessarily mean that the cliff-edge effect would automatically lead to core damage due to the conservative approach used. Furthermore, the measures identified are intended to improve this situation.

The safety margins and cliff-edge effects have been calculated for various loss of safety function scenarios, as specified in the stress tests specifications. The LOOP, loss of all alternate-current power (SBO), loss of UHS, and SBO combined with loss of UHS have been analysed. The margins and cliff-edge effects arising from most critical situations are discussed below.

Reactor - LOOP

LOOP is considered to be within design basis for all plants and is managed through a range of redundant and diverse means. Typically, the power supply reaches the power plant via several independent power lines. In addition, in some plants, depending on their design and operational experience, there is a credible possibility of house load operation. If this fails, there are redundant standby emergency DGs, additional DGs, gas turbines, dedicated hydropower and other power plants which can power the electrical buses dedicated to plant safety. From the perspective of safety margins, the emergency power source (diesel/gas turbine generators) can typically provide power for about 72 hours (as per ENSREG stress tests specifications) to 8 days, and sometimes longer. This is based on the stocks of consumables (fuel, lubrication oil, gas etc.) available on-site. Beyond this, it is assumed that additional supplies would need to be brought in from off-site.

Reactor - SBO

The analysis has shown that in terms of safety margins, SBO is the limiting case for most of the reactor units. An isolated loss of UHS, which is typically water or the atmosphere, does not lead to fast reactor core heat-up, although it may be the limiting case in the longer term (availability of the cooling medium).

For a large pressurized water reactor (PWR) at power before the initiating event, SBO would typically lead to core heat-up after around 1-4 hours if no countermeasures were implemented. For a small PWR, core heat-up would take around 10 hours and for an advanced gas-cooled reactor (AGR) it would be greater than 10 hours, again assuming that no countermeasures were implemented. For some boiling water reactors (BWRs) designs SBO leads to core heat-up [10] within 30-40 minutes, if no countermeasures are adopted.

It was also observed that PWRs are susceptible to relatively fast core heat-up if the reactor is open a few days after shutdown (for refuelling). In this case core heat up is typically within the one to three hours range (without countermeasures). In particular coping times appear to be substantially reduced for mid-loop operation and it is recommended that regulators should encourage operators to find a way to minimise such operational conditions.

Spent fuel pools - SBO

The safety margins for spent fuel pools (SFPs), as well as spent fuel storage facilities (SFSFs) were also analysed. Generally, for SFPs the SBO is the most limiting scenario. Nevertheless, if water is available and it can be delivered to the SFP, evaporative cooling is effective and the condition is not critical.

For the worst case in which the entire core is unloaded into the SFP with no make-up, the fuel may uncover in about 7-9 hours. The analysis shows that for interim SFSFs that store fuel with low decay heat, the safety margins for both loss of UHS and SBO are in the range of several days, even if no countermeasures are adopted.

Batteries - SBO

Batteries play an important role in the SBO case because they ensure the minimum operability of some small equipment important to safety, the monitoring of plant parameters, and emergency lighting. It was observed that the typical battery design discharge time is in the range of 1-3 hours. However, through testing, some plants also confirmed that this discharge time is a conservative estimate and that realistically it is much longer, e.g. 6-9 hours.

[10] Core heat- up means that the temperature of the fuel exceeds the value given by safe operating limits and conditions. Consequently, at that point the first signs of fuel damage, such as loss of fuel rod cladding integrity, may be expected.

It is also noted that at some plants, direct current (DC) power can be ensured by recharging station batteries via small DGs, or even backup station batteries that can be connected to the DC bus via temporary cable connections.

Reactor coolant pump (RCP) seals - SBO

RCP seal integrity may be challenged in a SBO event during which cooling is lost. Typically, RCP seal integrity can be ensured for several hours without cooling. Some plants reported that RCP seals can retain their integrity for 24 hours. It was also reported that some RCP seal designs ensure integrity even without cooling.

Ventilation - SBO

It was also noted that loss of ventilation can be a limiting case in the longer term (several hours) because some equipment may suffer overheating and consequently fail.

Countermeasures

It should be emphasised that plants typically have countermeasures in place to cope with the above conditions, namely SBO and loss of UHS. The safety margins indicated above can be substantially increased, and cliff-edge effects may even be avoided. For example, using the diesel driven auxiliary/emergency feedwater pumps to feed the steam generators (feed & bleed), the total time before loss of fuel cladding integrity is more than 72 hours. This can be significantly increased with the systems already available on-site to about 8-10 days by using independent diesel driven pumps from the fire water system.

To cope with the SBO situation in BWRs (equipped with reactor core isolation cooling system (RCIC)), water availability for use in the RCIC systems is more than 20 hours. The steam is released into the wetwell and feeding can continue through the stationary or mobile diesel driven pumps. At some plants, the energy from the wetwell can be released via the containment filtered venting as the last resort scenario. However in this case it is necessary to verify (see 6.2.4) that valves fail in a position so that they are still operable in SBO conditions. This was not the case in the Fukushima accident.

Typically the demineralised water storage available on-site in condensate storage tanks is enough for 72 hours. The volume of cooling water available on-site is sufficient to ensure heat removal from essential consumers for more than 6-8 days.

6.2.3 Strong safety features

From the national reports and the peer review process, a number of strong safety features were identified in European NPPs. These are expected to be instrumental in preventing severe fuel damage in the reactor or spent fuel storage in the event of LOOP, SBO, loss of UHS or loss of UHS combined with SBO. These are available in some NPPs, but not necessarily all of them. Some of the safety features were due to the initial plant design, while in other cases, specific safety features were added through safety modernisation efforts over the years.

While strong safety features and their actual benefits are closely related to the design concept and/or particular solutions developed, many features might be of interest as add-on improvements. Nevertheless, some of the strong safety features in one of the designs may not be needed or even feasible in other designs, because similar functions are addressed in different ways. Still, plants that do not have specific features might consider adding them, as possible safety improvements, subject to specific needs and to compatibility with the original design.

The consideration of strong safety features is directly related to the specific event scenarios considered. In accordance with the concept of defence in depth, plants were originally designed with multi-layer protection. On some plants, safety features were later added to strengthen these multiple layers.

Safety features designed to minimise disruption following loss of power include the capability of the main generator to handle load shedding and house load stabilisation (which is regularly tested in some countries), multiple grid connections at different voltage levels including secure connections (e. g. underground cable) to a grid located at a certain distance. This is strengthened by arrangements (reported by some countries) in which the grid operator is contractually or otherwise obliged to ensure grid reliability as well as give power restoration priority to a NPP. Site-specific robust safety features include direct and/or dedicated connection (separate from the grid or the plant's own switchyard) to a nearby hydro or a gas power plant, having a black start capability.

For the scenarios with complete and unrecoverable LOOP, all designs rely on multiple redundancies of dedicated and qualified power sources, mainly DGs and gas turbines. Strong safety features include qualification of equipment and its housing for a range of events including beyond design basis seismic events and beyond design basis floods, but also guaranteed and periodically verified availability of fuel and lubrication oil. Some designs include further layers of totally independent power sources (DGs), though often dedicated to specific functions (like battery charging) and not having full capacity like primary sources.

In the SBO scenarios analysed within the stress tests (which seem to be very unlikely on all of the NPP sites), all of the dedicated and emergency AC power sources are lost. In such cases, all the plants rely on safety-related DC sources (batteries) to enable operation of the control equipment (e. g. valve actuators), safety instrumentation and emergency lighting. The strong safety features identified include the high capacity of these batteries (up to 12 hours), load shedding procedures (to extend battery life time; up to 20 hours was reported) as well as regular and dedicated testing of batteries, to ascertain their capacity under accident conditions. One strong safety feature is permanent monitoring of the battery status, thus assuring full capacity when the need arises.

For a situation in which both AC and DC power becomes unavailable, positive safety features were mainly add-ons. Many plants reported having a range of mobile power sources, from DGs dedicated to charging batteries or powering specific pumps (e. g. feedwater or service water), usually a few hundred kW and mounted on a transportable skid, to trailer-mounted high-power DGs. Strong safety features for example include fuel tanks and cable spools mounted on a skid/trailer with a DG, as well as pre-established connections points, procedures on how to connect (and power specific busbar, operating switches and breakers to disconnect less important loads) and drills that encompass full sequences (from bringing a DG trailer to a location, to connecting and powering dedicated consumers). An important and sometimes overlooked positive safety feature is the practice of storing mobile equipment in areas that are resistant to the devastation that could be caused by a seismic event, flood or other internal or external impact.

For the SBO scenarios caused by devastation that is (often) beyond the original design basis, numerous plants decided to install a "hardened core" of equipment and organisational measures or bunker-based systems having their own power sources with dedicated fuel reserve, dedicated pumps with independent sources of water, their own instrumentation and controls. The design of a dedicated bunkered system varies, reflecting the needs of the original plant design, specific identified threats, etc. Single or multiple redundancies are to be found in these bunkers. Some of the bunkers are fully resistant to a range of external threats, while others have dedicated water supplies offering long-term independence. In all cases, bunker-based systems are separate and independent from the plant's safety systems.

To cope with losses of the main UHS, a variety of design features are being used. Positive features include multiple (and large) reserves of water such as dedicated tanks (e. g. seismic proof), large capacity pools (e. g. with spray-based heat removal from essential service water system), dedicated wells (with their own, independently powered pumps) as well as arrangements to obtain water from nearby lakes (using tanker trucks or fire hoses). Specially designed main cooling discharge channels that will retain large amounts of water if the UHS is lost, is among one of these positive features. A strong safety feature is to use the atmosphere as the UHS, for example with dedicated (safety class) cooling towers or spray ponds.

For the LOOP/SBO but also for the loss of the UHS scenarios, maintaining water injection to reactors and/or steam generators (SGs)/isolation condensers offers an ultimate means of cooling the core.

Varied and diversified systems for performing this function have been identified, including electric power-independent turbine driven pumps, arrangements for gravity feed (coupled with opening of selected valves), dedicated diesel driven pumps as well as pre-installed connections for external feed, such as from the on-site fire trucks. For use of the fire trucks, positive safety features identified include the pre-arranged connections, arrangements and drills for actual establishment of the connection for feeding of SGs.

Positive safety features were identified in relation to the SFPs. These include pools containing large volumes of water, design of pools to prevent drainage, robust construction, use of racks made of borated steel to enable cooling with fresh (unborated) water without having to worry about possible re-criticality. Other robust safety features include redundant and independent SFP cooling systems, dedicated external connection to provide the SFP feed, power-independent monitoring instrumentation as well as procedures and drills to restore SFP cooling and/or inventory being included in the plant emergency procedures.

All in all, the peer review concluded that many of European NPPs possess numerous strong safety features that would prevent accidents from occurring, even those initiated by a low-probability hazards. The strong safety features and their objectives vary across the designs, and are often dependent on the age of the design and the specific threats they are designed to address. While some of the strong safety features are inherent in the design (e. g. some reactors have very large quantities of water; some designs rely on physically diverse equipment; others on multiple redundancy and physical separation; some designs feature the a leak-proof primary pump seal design, preventing losses of coolant), while others may, in certain circumstances, be replicated by the NPP operators elsewhere (something which, as discussed in following paragraphs, is already happening).

Thanks to prudent original designs and in particular to dedicated safety enhancements implemented over the years, European plants can as a whole be considered as having multiple strong safety features that would prevent deterioration, even in the very unlikely disaster scenarios such as those evaluated by the EU stress tests.

6.2.4 Areas for safety improvement and possible measures to increase robustness

As discussed in the preceding section, many positive safety features have been identified at plants throughout Europe. Some of those are inherent in the design (large volume of water in SGs, multiple layers of power sources, etc.), while others have been added as safety improvements over the years. These safety improvements might have been introduced to rectify the design deficiencies found, resolve the findings of the individual plant vulnerability analysis, or respond to new requirements that were issued while considering the “state of the art” requirements that are established within the PSR (which is mandatory for all NPPs in Europe).

Nevertheless, plant designers and operators had multiple choices and have chosen the solutions that are often specific to the design or specific site. Therefore different safety features are available to cope with similar scenarios. The strong safety features for one plant would not therefore necessarily be a similarly “strong” safety feature when transferred to another plant. The selection of features is ultimately specific to the plant/design and site and the advantages and drawbacks have to be carefully considered before any transfer.

Nevertheless, the review process identified the areas for safety improvements that are likely to be applicable to a wider range of plants operating in Europe. While some of them are already installed in plants, those plants on which they have not been implemented, subject to compatibility with the design concept and arrangements, should consider adding some. Such improvements and arrangements are expected to increase the robustness of the plants, even beyond the already high level of safety identified during the stress tests. It must be emphasised that the increased robustness might be achieved in a number of ways, so the safety improvements are not an all-inclusive list to be mandated for every plant. In fact, the safety improvements should most importantly complement the design features, support those that are strong and rectify any deficiencies identified.

Robustness of AC power supply

Enhancing the availability of both the on-site and off-site power supplies is an essential element of enhancing NPP robustness and its resistance to a variety of internal and external initiators. While many operators have already introduced specific arrangements, adding equipment and procedures to increase robustness, specific improvements might still be possible and in some cases justified. The safety improvements include enhancement of the grid, though agreement with the grid operator on rapid restoration of off-site power, but also through increasing and/or reinforcing off-site power connections or arranging for black start capability for co-located or nearby gas or hydro plants. This might include improved high-voltage insulators (in the switchyard or off-site) by replacing standard ceramic based items with plastic or other material that is resistant to a seismic event. Utilisation of generator load shedding to house load operation might increase robustness, but may also increase the specific risk of voltage regulation problems. Before introducing such arrangements the risks need to be properly understood. Further increases in robustness could be achieved by adding layers of emergency power (as some plants have done) but also by adding specific, independent, dedicated backup sources.

Availability of fuel and water stocks

The review during the stress tests revealed that many plants already possess stocks of fuel and water at the site that would ensure operation of safety systems (and mobile devices) for days without resupply. Nevertheless, in some plants, the fuel might be available but would require additional systems for transfer to the users (that might be unavailable, for example, due to a lack of power). A systematic review and, if necessary, improvements to the availability of fuel on-site and arrangements for resupply off-site will increase the robustness. Attention needs to be given to other consumables such as lubrication lube oil, which might be critical for large DGs. The same applies to the availability of water, firstly with regard to the physical availability in various man-made and natural storages, but equally important is to undertake a systematic assessment to ensure that equipment and means are available for providing water to locations and equipment where needed. The full chain considering equipment, procedures, surveillance and drills must be in place to ensure robustness.

Functional separation and independence

While in many cases identified and already rectified, the independence of important components from other systems (e. g. cooling water for pumps and DGs) is an important issue for increased robustness. Some plants introduced modifications (e. g. fire-water backup cooling for DGs), while others might consider safety improvements related to functional independence and separation. Another safety improvement is the provision of an alternate heat sink independent from the main AC power supply.

Provision of mobile devices for electrical power and water supply for makeup and cooling

Availability of mobile power sources or water supply means is a feature that will increase robustness, especially in situations that are (significantly) BDB, where plants' inherent robustness is challenged. Many plants already possess a variety of mobile devices including skid/trailer based DGs and pumps, dedicated fire trucks, etc., including the connection points and procedures on how to engage mobile units. Nevertheless, a systematic selection and acquisition of the equipment that would provide a variety of power and pressure levels and that is safely stored on-site and/or off-site will enhance robustness. The transportation and simple and fast connection of the mobile equipment, including its proper operation (considering fuel supply, independence but also organisation and procedures) shall be ensured by appropriate plant and site centric design and regular testing after installation. Considering the inclusion of mobile devices in a plant's safety-related surveillance might enhance the standby capability and thus increase robustness. It is essential that connection points for DGs, batteries, water injection points/piping (e. g. for SFP) are pre-established and have clear access.

Robustness of DC power supply (Batteries)

The DC power supply is, in almost all designs, an essential power source for monitoring and controls. Plant robustness, depending on the specifics of the design and arrangements, could be increased by improving the battery discharge time. Battery discharge time can be increased by upgrading the existing battery or changing its type (an additional benefit of which could be increased resistance to common-mode failures), by providing spare/replacement batteries or by implementing well-prepared load-shedding/staggering strategies. Regular real load testing and on-line monitoring of the status of the batteries might also add to robustness. Some plants have already increased robustness through dedicated recharging options (e. g. using portable generators).

Instrumentation and monitoring

In most cases, the instrumentation (and control) systems require an uninterruptible power supply (either directly DC or AC backed-up by batteries). In the event of a SBO and following discharge of the batteries, the instrumentation and the monitoring systems thus might become inoperable. Some plants, when introducing SA measures, undertook to install separate instrumentation and/or power sources to enable monitoring of essential parameters under any circumstances. Starting with verification of the availability of instrumentation in specific SBO and loss of DC sequences, safety improvements could be achieved and robustness strengthened by installing additional power sources and / or additional instrumentation that is based on simple physical principles (e. g. passive temperature, pressure readers).

Capability/strategy for handling accidents occurring simultaneously on all plants of the site

In a case of an event caused by an external hazard, multi-unit sites are especially vulnerable, as resources need to be shared. In some cases, the assessment of internal initiators did not consider that there were sufficient equipment and staff to cope with challenges on multiple units. Assuring preparedness and sufficient supplies for coping with events affecting all the units on a site would enhance robustness. Some plants reported implementing improvements in this respect (like adding mobile devices and fire trucks) and increasing the number of trained and qualified staff. Others should consider taking another look at their level of preparedness and introducing safety improvements.

Assured flow paths and access under SBO conditions

Losses of AC power, but even more so, DC power and instrument air may lead to a situation in which the operation of critical equipment (mainly valves) is no longer possible. In some cases, the equipment might default to a predetermined “safe state”, but this safe state is not necessarily that required to ensure safety in a particular condition (e. g. containment isolation by fail-safe closure of feedwater valves will prevent secondary feed and bleed that use feedwater lines). Increased robustness may be achieved by enhancing and extending the availability of DC power and instrument air (e. g. by installing additional or larger accumulators on the valves), but also by ensuring that the state in which those valves fail on loss of actuation is carefully considered to maximise safety. Therefore the robustness could be enhanced by systematically analysing the consequences and, as necessary, changing the logic to ensure safety is carefully considered and maximised.

Many of the control elements could, as the ultimate choice, be operated by hand. However, SBO and/or loss of DC might lead to a blocked access if the turnstiles are electrically operated or electrically interlocked. A systematic review of the possibilities for access to critical equipment in power loss situations needs to be undertaken. Having access to critical equipment in all circumstances will increase the robustness of the plants.

Shutdown state risk/mid-loop operation

Although it was already well-known from various safety studies, the shutdown state and in particular mid-loop operation is, for many designs, the most unfavourable state in the event of SBO. Robustness could be increased through a systematic analysis of the shutdown state/mid-loop operation, in order to reduce or inhibit this operating mode and/or increase safety by adding dedicated hardware or procedures/drills. Use of other available water sources (e. g. from hydro-accumulators) may allow for longer operating time, thus increasing the robustness. Requiring the availability of SGs during shutdown operations but also the availability of feedwater in all modes up to cold shutdown (mode 5) would directly increase the robustness for some designs.

Other specific issues

Numerous areas for safety improvements that do not fall into any of the categories discussed above were identified and in some cases have already been implemented. Nevertheless, systematic investigation with introduction of specific improvements, if possible and if so justified, might further increase plant robustness. This includes considering the use of temperature-resistant (leak-proof) primary pump seals in some of the designs, enhanced ventilation capacity during SBO to ensure equipment operability, as well as analysis and enhancement of SFP integrity in overheating/boiling conditions. A related issue is the possibility of venting steam out of buildings, which might be of particular relevance in a case of boiling in the SFP. In the event of SBO, and in particular the loss of DC, the operability of the main control room (MCR), the emergency control room (ECR) and emergency control centre (ECC) might be compromised. As these are the key locations in which any actions to prevent escalation and/or mitigate the consequences will be undertaken, a systematic analysis and subsequent improvement would add to plant robustness.

6.2.5 Measures already decided or implemented by operators and/or required for follow-up by regulators

A range of measures have been identified by operators and regulators to provide increased protection for BDB events. Some of those were identified during regular PSRs, while others were defined within the stress tests framework. The majority of measures already decided and in some or many cases implemented, are related to the availability of power sources, i.e. the provision of mobile devices.

Many countries reported on other measures that are already implemented or being prepared for implementation, including enhancements of the heat sink function (increase robustness of the UHS or provision for alternate heat sink), measures to ensure cooling in the absence of AC power (e.g. primary or secondary feed and bleed), but also a variety of procedures to enhance the operability of specific equipment in adverse conditions. The countries also reported on the ongoing activities where more complex programmes of modifications are being developed, to be approved by the respective regulators and implemented in the next period.

Other measures already implemented or planned are related to SFP, to ensure water inventory or cooling. Nevertheless, additional measures were reported as under preparation, including provision for additional heat exchangers (e. g. submerged in the SFP), 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), etc. Further studies are in particular related to the integrity of the SFP and its liner in the event of boiling (which is a BDB condition for the SFP) or external impact.

The measures already identified and in many cases implemented include the guaranteed availability of fuel and lubrication oil for DGs or gas turbines, the means of transferring the fuel on-site (from storage tanks to day tanks) and similar. While the analysis is being carried out, additional analysis might be needed in some cases in order to optimise the operating times of these power sources. This is in particular relevant for mobile sources which would need to be resupplied, given that skid or trailer mounted tanks would only provide enough autonomy for a few hours, and in any case less than a day in most cases.

Identified as an issue by many plants, implementation has been decided on or initiated to reinforce the areas where the mobile equipment is stored. In some cases, mobile equipment, including fire trucks, is housed in fire stations that are often not resistant to a seismic event (or to a flood, but due to the slower nature of flooding, this is generally less of an issue). It has been decided that a significant fraction of European plants will implement a "hardened core" of equipment and organisational measures that is designed for significantly beyond design basis external hazards.

Many plants reported a need for dedicated diesel driven pumps for primary or secondary injection, for service water/ultimate heat sink or even for transfer of diesel fuel. In some cases the equipment was identified and procured. In other cases the acquisition of dedicated pumps, in particular including the construction of a dedicated, easy access and simple to operate connection point, and ensured availability of water in tanks or other sources (in which case a suction source needs to be assured) still need to be implemented. Related analyses are mainly to decide on the optimum size and number of these mobile pumps and to decide on positioning them in appropriate, secure locations.

As a general issue, the improvements related to the increased resistance to seismic events, floods or other extreme conditions might need to be evaluated and measures put in place. In some cases the original design basis of the plant might be reviewed. In such a case, the analysis of the possible impact on DGs, batteries, mobile equipment and its storage as well as fuel and water storage tanks needs to be undertaken. Any necessary improvements would need to be implemented.

With regard to the operability of control equipment (mainly valves) during the SBO, additional analysis is needed to ensure that cooling using natural circulation would not be interrupted. Depending on the outcome, additional or alternative means to operate control devices, in particular including the feedwater control valves and SG relief valves, main steam safety valves, isolation condenser flow path, containment isolation valves as well as depressurisation valves, might be needed.

An assessment of alternate/additional heat sinks has been undertaken. In some cases, a more detailed analysis might be required. As a consequence, actual measures might be needed that could for example include the air-cooled cooling towers, deep water wells on-site or in the vicinity and/or new or alternate fixed or temporary connections to reservoirs or other bodies of water.

In addition to hardware provisions, improvements might be related to procedures and preparedness for disrupted conditions. Some plants reported that battery load-shedding procedures were being considered. To develop a procedure that could be followed in the event of SBO, a systematic analysis of specific battery loads, considering different scenarios, could be undertaken. The same applies for the studies on how to refill the SGs using alternate means, such as gravity flow from the feedwater reheater or tanks, using other sources of water (for instance condensing towers in one design) or even fire tankers with fire truck-mounted pumps. All these might need specific arrangements, dedicated procedures and drills by the staff for implementation in emergencies.

Additional studies might be needed to assess operation in the event of widespread damage, for example, following an earthquake. This may identify the needs for different equipment (e. g. bulldozers) and plans on how to clear the route to the most critical locations or equipment. The logistics of the external support and related arrangements (storage of equipment, use of national defence resources, etc.) is another area that might need further studies, and possible improvements.

It is also noted that in some countries, the set of the most important improvement measures has been defined as a "hardened core" of equipment and organisational measures qualified to withstand beyond design basis events, although the degree to which they are qualified has not yet been decided. Analysis might be needed to define the full extent of equipment and measures in a "hardened core" of this type.

The action plans for further analysis and improvement measures have already been defined, or will shortly be drafted, in all countries. The general aim is to make improvements as soon as possible, with the initial focus on those measures that can be implemented quickly, thereby providing immediate benefit. The completion schedule of all aspects of the action plans will vary, depending on the agreed scope, the urgency of the measures and the general plans for future operation.

6.3 Peer review conclusions and recommendations specific to this area

In response to the ENSREG specifications, the following scenarios were considered:

- Loss of off-site power (LOOP)
- Station blackout (SBO)
- Loss of ultimate heat sink (UHS)
- Loss of the primary UHS combined with SBO

These scenarios have been assessed regardless of their cause or frequency. LOOP and loss of UHS are evaluated at all NPPs currently in operation. Consequently, plants are well protected by a range of redundant and diverse systems. SBO and the loss of UHS combined with SBO are beyond the original design basis for most of the plants. Nevertheless, practically all the plants have (some) means of protection in both of these situations. In some cases the protection is primarily provided by means of physical processes (natural circulation, gravity feed, etc.) while in other cases engineered systems have been added (e. g. completely independent, fully powered and supplied systems located in well-protected bunkers).

It should be noted that in the analysis of the stress tests no credit is claimed for the repair and recovery of electrical power or the UHS, or the use of mobile equipment to provide the necessary safety functions. The outcome of these aspects of the stress tests should be seen in this context.

Based on the evidence of the national stress tests reports, the country presentations, the answers to questions, and the country visits it is apparent that all NPPs are compliant with their current licenses and are well protected against all of the design basis accidents. The plants are, on the whole, protected to some extent against beyond design basis sequences that were assessed within the stress tests.

The review of the national reports and the discussions within the country presentations confirmed that all of the plants have already analysed the need for eventual safety enhancements as a consequence of the lessons learned from the Fukushima accident. The range of improvement measures has been identified and many already implemented. Additional analyses are underway, to support the programme of measures to be implemented in the future, under the supervision of the national regulators. The action plans for further analysis and subsequent implementation of the improvement measures have already been defined, or will shortly be so, in all countries.

The review process determined that in most cases the design is robust, with strong safety features. Nevertheless, the improvement measures to further enhance robustness were identified, and have already been implemented or are underway at many plants. The review process also identified the fact that due to considerable variations in the design concept or features, site specifics but also past approaches to safety upgrades and modifications, not all improvement measures are applicable to all plants. To be the most effective every plant needs to consider a specific range of measures and ensure that it is compatible and well-integrated into the broader safety and operational features, supporting defence in depth and enhancing robustness.

Nevertheless, in terms of added value and the overall safety benefits, several areas were identified as being of broader interest. It is recommended that national regulators consider the following findings:

1) Availability of a variety of mobile devices, with prepared quick connections, procedures on how to connect and use and staff training for deployment of such equipment. It is important that the equipment is to be stored in locations that are safe and secure even in the event of general devastation caused by events (significantly) beyond the design basis. Mobile sources of power would enable the use of existing equipment; mobile pumps would enable direct feeding of the primary or secondary side, even using alternative sources of water. Mobile battery chargers or mobile DC power sources will allow extended use of instrumentation and operation of controls. Fire-fighting equipment, including fire trucks, diesel pumps, generators, emergency lighting, etc., is normally readily available at the plants. Engineered and prepared connections as well as drills on the use of this equipment significantly add to the robustness for BDB events.

2) Using alternative means of cooling including alternate heat sinks. SG gravity feeding, or using other sources of water, supply from stored condenser cooling water, alternate tanks or wells on the site, or water sources in the vicinity (reservoir, lakes, etc) is an additional way of enabling core cooling and prevention of fuel degradation. Some plants identified possible actions, including additional analysis that might be needed.

3) Operational or preparatory actions such as ensuring the supply of fuel and lubrication oil, battery load-shedding to extend battery life are examples of measures that are small (in many cases procedural) but that could make a considerable difference in response to initiators. All in all, most of the plants have already considered these measures and might be adding to them in the future.

4) Within the stress tests evaluation the bunkered system proved its worth in ensuring an additional level of protection, able to cope with a variety of initiators, including those beyond the design basis. The concept is taken even further in the form of the "hardened core" where in addition to equipment, trained staff and procedures designed to cope with a wide variety of extreme events will be available.

5) The stress tests evaluation identified issues and consequently led to improvements in preparedness for the events that could affect multiple units. Previously, the multi-unit site protections were sometimes designed to cope with a serious challenge facing one of the units. During the stress tests, it was identified that robustness could be enhanced if additional equipment and trained staff were to be made available to deal with events affecting all the units on one site. While the process of improvement is not yet completed, it has been initiated on many sites.

The stress tests confirmed that all the units in Europe are well protected for all of the design basis events. It also confirmed that all of the units possess some resistance to the highly unlikely events that are significantly beyond the design basis. In general, the European plants are robust, also thanks to series of PSRs that required the operators to enhance their plants and introduce modifications. Nevertheless, the assessment undertaken during the stress tests identified additional areas for improvement, in particular by adding flexible mobile systems and arranging for connections, sources of power, water, etc. Many of the plants have undertaken the measures to cope with extreme BDB events. Others are to follow in the very near future. Analyses still need to be undertaken and systemic improvement programmes that may be expected to bring all of the EU plants to the highest level of safety are being envisaged.

7 EUROPEAN PLANTS ASSESSMENT RELATIVE TO SEVERE ACCIDENT MANAGEMENT

7.1 Description of present situation of plants at the European level

7.1.1 Regulatory basis for safety assessment and regulatory oversight

The status of the legislative basis for accident management (AM) varies across the participating countries: some have relevant national guidelines or legislation already in place since the 1980s or 1990s while others are at different stages of preparation for new legislation. In several countries, licensing requirements are based on the regulations of the country of the reactor vendor. All the countries participating in this review, however, recognise the usefulness of the WENRA RLs applicable to AM for setting legal requirements (these are mainly in areas: F (design extension of existing reactors), LM (emergency operating procedures and severe accident management guidelines) and R (on-site emergency preparedness)). Nevertheless, there are considerable differences, country to country, in how the RLs are incorporated into legislation. Some countries have developed specific regulations to address the RLs. In other countries the RLs are included as conditions within the operator's licence or operating permit. Elsewhere, the RLs are incorporated into the general national legal framework.

All national legal frameworks provide for regulatory oversight of AM, including provision for regulatory assessment and inspections of this topic.

7.1.2 Main requirements applied to this specific area

The main requirements for AM are currently internationally defined in the WENRA RLs and in IAEA safety standards. Most operators' strategies are defined in their EOPs and SAMGs (or equivalent). These are often based on the reactor vendor's suggested strategies, but are suitably amended for the particular plant design. Where the reactor vendor has not yet developed SAMGs, the utilities have developed their own strategies based on international research and knowledge transfer (e.g. through owners' groups). The original source of the SAMGs can have a strong influence on the depth and comprehensiveness of their coverage.

International standards require EOPs and SAMGs to be available in all NPPs. Symptom-based EOPs, focused on prevention of a severe accident, have been implemented in all countries following the Three Mile Island (TMI) accident. SAMGs focused on mitigation of severe accidents, once steps to prevent fuel damage have failed, are still being implemented in some countries.

7.1.3 Technical background for requirement, safety assessment and regulatory oversight

In the absence of any European standards, IAEA safety standards and WENRA RLs are used as guidance when establishing national requirements for NPP safety features. Some countries have adopted requirements from the reactor vendor's country. The depth and detail of these requirements as well as the implementation of the regulations differs between the countries. Whereas some countries are very specific in their requirements, others only define general safety goals.

The majority of participating countries use probabilistic approaches to help determine weaknesses and to focus safety improvements. Level 1 and 2 PSAs form an essential part of these evaluations. However, the scope and depth of these analyses differ and in some cases there is a need for improvement, in order to bring them up to accepted international standards. Common tools to assist with this process include IAEA and World Association of Nuclear Operators (WANO) review missions, the European Framework Programmes, as well as operational experience feedback through international information exchange systems, such as the Institute of Nuclear Power Operations (INPO), WANO, IAEA/NEA International Reporting System, Clearinghouse, etc.

Some of the time schedules appear to delay unnecessarily the correction of known SAM weaknesses that were an issue at Fukushima. Implementation of current SAM requirements in some countries is not well established and this leads to differences in the upgrading of safety functions and the robustness of the operating plants. The stress tests have, however, provided an impetus to accelerate improvements, by highlighting the strengths and weaknesses of the different national approaches to international peer reviews.

7.1.4 Periodic safety reviews

The peer review process has confirmed that PSRs are performed in all participating countries with the usual period of 10 years, in line with international standards. As noted above, PSRs are considered to be a highly effective means of improving SAM in NPPs. That said, the level of detail and depth of the PSRs differs between countries. The Fukushima accident and the related stress tests have triggered a new wave of safety reviews seeking to learn lessons from the accident, particularly with regard to SAM. The peer review concluded that PSRs should be maintained as a key tool for ensuring the continuous enhancement of defence in depth in general, and the provisions of SAM in particular.

7.1.5 Compliance of plants with current requirements

Though operating NPPs comply with their national requirements, not all comply with all aspects of the IAEA safety standards related to SAM. Moreover, some NPPs are behind with their commitments to comply with the WENRA RLs, particularly with regard to the implementation of hardware provisions. In addition, SAMGs are, for the most part, only developed for full-power conditions; only in a few cases are there SAMGs for low-power and shutdown conditions, spent fuel pools or long-duration multi-unit events. When SAMGs do not apply to all plant states, most operators have plans to extend them within a few years. A trend was observed in many countries to increase the scope of SAMG to include all plant power states and accidents in the spent fuel pools. This trend was recognised and was firmly supported. Verification and validation of SAMGs is also essential to ensuring their practicability, robustness and reliability and should therefore form an intrinsic part of their implementation process.

7.2 Assessment of plant robustness beyond the design basis

7.2.1 Approach used for safety margins assessment

In general, when new safety standards are developed, they are expected to be applied not only to new NPPs, but also to existing plants, to the extent possible. This is usually addressed during the PSR.

The approach to SAM used by the countries within the stress tests focused on verification whether necessary components of SAM are in place and they are effective. The required scope of SAM is defined internationally through the IAEA safety standards and WENRA RLs (in particular in areas LM, F and R). In addition, some countries are applying the WENRA safety objectives for new reactors to existing plants. The ENSREG stress tests specifications provided further guidance on the scope of the reviews with regard to SAM.

In some countries, existing regulations include a specific requirement for the implementation of equipment dedicated to severe accidents. Sometimes, compliance with single failure, diversity and independence criteria is also required. In these cases the support systems and power supply sources need to be independent. In other countries, the use of existing equipment is preferred and the SAM requirements are less specific. With regard to the stress tests, these countries indicated the need to implement additional, dedicated SA provisions.

Comprehensive Level 2 PSA is considered to be an important 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. Extension of the scope of existing Level 2 PSA to shutdown states, SFPs and consideration of external hazards is, however, still needed in most countries in order to ensure that the PSA can appropriately inform improvements to SAM. Moreover, it is important that PSA be applied in a manner complementing other analyses, e.g. deterministic design basis analysis and analysis of severe accidents, and not be used to exclude scenarios on the basis of their low estimated risk. The PSA should instead inform an appropriate defence in depth approach, so that adequate SAM measures are in place in the unlikely event that design basis provisions fail to prevent the onset of a severe accident.

7.2.2 Main results of peer review and areas for safety improvement identified in the process

The stress tests and their peer review confirmed that AM is recognised and being implemented by all participating countries, although at different levels. During the peer review process, a general commitment and trend towards accelerated implementation of AM measures within regular or extended plant refuelling or maintenance outages was observed.

Generic findings and observations for different components of AM are summarized in the text below for different areas relevant for AM. Potential safety improvements in these areas were also identified during the peer review process; these potential improvements are summarized for consideration by the countries in section 7.2.4 of this report. More detailed descriptions for individual countries can be found in the annexed country review reports.

<u>Procedures and guidelines</u>

Accident management programmes (AMPs) that include EOPs and SAMGs already exist or are being developed in all NPPs.

EOPs, focused on the prevention of core melt, were implemented in all countries following the TMI accident. These procedures are primarily symptom-based in combination with event-based elements. The scope and status of implementation of SAMGs is less advanced, although the extent differs between countries. SAMGs have mostly been developed for full-power conditions. However, in some cases there are also valid SAMGs for shutdown conditions, SFPs and long-duration multi-unit events. Where the SAMGs are incomplete, there are plans to extend them in the near future, or such plans are under consideration.

EOPs and SAMGs use various formats and are typically implemented in line with generic guidance provided by the vendors and/or owners groups. The trend to increase the scope of the SAMGs in order to include all plant states and accidents in the spent fuel pools is being strongly supported. When implementing SAMGs, their validation should also be included, as per the WENRA RLs.

<u>Special equipment for accident management</u>

The prevention of a simultaneous loss of systems due to common-mode failures can be achieved through suitable redundancy, diversity, physical separation and protection against external hazards. Aspects such as flexibility, independence, simplicity and multiple means of connectivity will most likely be important for AM equipment. That said, it is crucial that the equipment functions when needed. There is thus the need for stringent requirements to ensure that the equipment survives the external hazard that can lead to a severe accident (e.g. by means of qualification against extreme external hazards, storage in a safe location) and has the capability for use in the environment in which it will need to operate (e.g. engineering substantiation and/or qualification against high pressures, temperatures, radiation levels, etc). Consideration also needs to be given to aspects such as the functional capacity of the equipment, e.g. whether it will deliver enough flow, power, etc., possibly for several units; how the equipment will be classified (so that it is adequately maintained, tested, inspected, etc.); and how it can be operated within a probably highly degraded infrastructure.

Some countries have already decided to implement special sets of dedicated equipment needed for SAM or to perform design modifications to improve defence in depth.

<u>Reactor coolant system depressurisation</u>

Depressurisation of the reactor coolant system (RCS) after core melt is considered to be a crucial action to avoid high-pressure core melt ejection from the reactor pressure vessel (RPV) (which could potentially challenge containment integrity during the early phase of a SA) as well as to facilitate water injection from low-pressure sources. The prevailing approach uses existing design basis means, such as opening the pressuriser relief or safety valves. Attention in SAM is therefore focused on aspects such as the availability of power supplies and instrument air, and a means of manual action to achieve depressurisation. In some countries dedicated and single failure proof depressurisation lines and valves, designed for severe accident conditions, are used to enhance the robustness of defence in depth.

Hydrogen

Risks from hydrogen and other flammable gases represent a key contributor to potential containment failure and therefore need to be effectively eliminated. Reactor type as well as containment type, size and internal configuration and the selected SA mitigation strategy (in-vessel or ex-vessel molten corium cooling) are determining factors with regard to the severity of this issue.

Several provisions are generally available for mitigation of hydrogen risks, including containment venting, inerting, mixing, use of hydrogen igniters and passive autocatalytic re-combiners (PARs). Rates of hydrogen production need to be determined when sizing the capacity of these systems. Hydrogen risks associated with the use of containment venting have been discussed, as have potential hydrogen leaks to auxiliary buildings in particular for reactors without re-combiners. Risks from hydrogen production in the SFPs have also been discussed during the peer review, but no counter measures have been implemented at NPPS, so far.

Means for mitigation of hydrogen risk inside the containment have already been installed in many plants. Nevertheless, there are still plants with limited PAR capacity (e.g. these are for design basis accidents only), or with limitations in supplying electrical power to igniters (e.g. in the event of a station blackout).

Molten corium stabilisation

Stabilisation of molten corium is recognised as essential if a safe and stable state is to be reached following a SA. The strategies being used by the countries for existing reactors include:

- In-vessel retention of molten corium ensured by early flooding of the reactor cavity and heat removal by external cooling of the RPV;
- Early flooding of the reactor cavity or lower drywell prior to any escape of molten corium from the RPV, assuming in-vessel retention is not successful (i.e. so that fragments of the damaged core are quenched in the water pool);
- Keeping the reactor cavity dry until molten corium relocation into the cavity has occurred and then pouring water on top of the corium layer.

Selection of the corium stabilisation strategy has implications for other AM strategies, e.g. for long-term containment heat removal, hydrogen mitigation, filtered venting and the minimisation of radioactive releases. The choice of an appropriate strategy depends on many factors, in particular reactor power; the reactor type (e.g. PWR or BWR); the size and shape of the reactor cavity; and the availability of water and an injection system for flooding. Therefore, even in the same country, different strategies have been selected for different reactors. In a few countries, no final decision has yet been reached on an appropriate strategy, or work is still ongoing to better underpin the existing strategy.

Containment venting

Filtered containment venting has been considered and implemented in many NPPs as a means of preventing containment over-pressurization. It is clear that the efficiency of filtering depends on the design solution. Some countries are considering improvements to increase this efficiency.

The need for containment venting depends on the reactor and containment types, and on the selected strategy for mitigation of SAs. Filtered venting seems to be less important, if ex-vessel severe accident phenomena are effectively prevented; this aspect requires further evaluation. In the majority of other cases, the implementation of filtered venting was identified as the ultimate means for protecting containment integrity, as well as reducing radioactive releases from any containment leaks. The issue of preventing excessive containment under-pressure after venting has also been discussed, but it was not considered a difficult issue.

Re-criticality

Reactor core or SFP re-criticality in severe accidents is considered very unlikely due to inherent safety features such as geometric configurations or the use of fixed neutron-absorbing materials. In many countries, rules to ensure that only borated water is used for fuel cooling are adopted as an additional layer of protection. Nevertheless, based on the discussions held during the peer review, the potential for re-criticality cannot always be ruled out when emergency cooling uses un-borated water and the fuel is no longer in its original configuration. The potential for re-criticality should therefore be considered for analysis when developing relevant SAM strategies.

Accident management for gas cooled reactors

Accident management for gas cooled reactors represents a special case due to their unique design features. On one hand they are not equipped with standard containment and therefore the robust concrete reactor pressure vessel is the ultimate barrier against releases of radioactive materials. On the other hand, very large thermal inertia of the reactors provides for large time margins for performing recovery actions. In addition, many severe accident challenges to confinement integrity such as hydrogen explosion, high pressure melt ejection, steam explosion and direct containment heating are not present due to inherent features of these reactors. Therefore the AM measures are mainly focussed on protection of reactor vessel integrity, or on mitigation of releases in the case of loss of vessel integrity, including repair of possible cracks in the vessel.

Spent fuel pools

Depending on the reactor design, SFPs may be located within the containment, close to the reactor or elsewhere on the plant/site. In all countries, prevention of radioactive releases from the SFPs is to be ensured by maintaining sufficient coolant inventory in the pool and providing for reliable residual heat removal. Design provisions are in place to ensure the structural integrity of the pools, minimising the potential for loss of coolant, and to compensate for reduced coolant inventory from various reasonably accessible resources (e.g. from inside the units or from outside via mobile means). Some countries are verifying the safety margins BDB in this respect. The considerable thermal inertia of the SFPs in most cases offers reasonable time margins for taking recovery steps if cooling is lost. However, it should be remembered that these margins are significantly shortened in the case of complete core offload into the SFP. In the frame of the stress tests, severe accidents involving molten fuel in the SFP have not been considered in any country.

Radiological issues

The expected radiological conditions inside plant buildings and outside during SAs, as well as the limitation of radiological releases, were only partially addressed in the national reports. Similarly, post-accident fixing of contamination and the treatment of potentially large volumes of contaminated water were not covered in detail. Nevertheless the important issues of continued habitability of control locations (e.g. main and emergency control rooms) and the feasibility of SAM measures were recognised and appropriate provisions including radiological monitoring were considered, as demonstrated in the written answers to additional questions and during national presentations within the peer review. Limiting the radiological consequences of severe accidents by prescribed limits in the country regulations is not usually considered, but in some cases was referred to as a safety objective for upgrade projects in terms of frequencies, maximum releases or effective doses.

On-site emergency arrangements

In all countries, initial responsibility following the start of a severe accident remains with control room/plant personnel until technical support is activated. The arrangements include different levels of activation depending on the severity of the situation. It should however be noted that emergency response organisations have generally been developed assuming a single accident on a given site, rather than considering the potential full range of severe accidents that might occur.

In some countries, the availability of an on-site emergency centre, protected against extreme natural hazards and contamination, needs to be ensured, together with the necessary arrangements for rapid intervention by specialized teams, availability of personal protection measures, portable equipment on the site and robust communication means are being ensured.

In some countries, in addition to providing an on-site emergency centre, decisions have been taken to either improve existing external emergency centres, or to build new ones. These will provide assistance to emergency crews and facilitate radiological protection measures (for example concerning equipment, dosimetry, etc). Where such new facilities are being constructed it is recommended that they should be designed to function after extreme external events. In addition, some countries are considering setting up centralised (e.g. national, regional) off-site rescue centres to provide similar functions within less than 24 hours to any affected NPP.

Some countries are considering providing additional means for assisting NPPs in severe accidents by utilising state resources (e.g. civil protection or military transport). The crucial role of communication (such as between plant personnel or between the NPP and the authorities) in the event of an emergency has also been highlighted, leading to improvements in the capacity and robustness of the existing systems. Typically this means installing new communication systems to increase redundancy and diversity, or making improvements to existing systems such as additional or dedicated power supplies.

Off-site emergency arrangements are considered important complementary components to on-site arrangements. However, these were only partially addressed in the stress test process and so remain a potential subject for future consideration.

<u>Further studies and development</u>

The stress tests and the peer review also indicated the need for future studies and development in the following areas:

- Systematic evaluation of the availability of safety functions required for SAM under different circumstances.
- Detailed studies of accident timing, including core melt, RPV failure, basemat melt-through, SFP fuel uncovery, etc.
- Enhancement of PSA analysis, including all plant states and external events for PSA levels 1 and 2.
- Further studies of the 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.
- Investigation of core cooling modes prior to RPV failure and of re-criticality issues for partly damaged cores, with un-borated water supply.
- Analysis of phenomena associated with cavity flooding and related steam explosion risks.
- Studies related to engineered solutions regarding molten corium cooling and prevention of basemat melt-through.
- Development of severe accident simulators appropriate for NPP staff training.

7.2.3 Possible measures to increase robustness

Based on the discussions during the peer review process, a number of possible measures to increase AM robustness have been identified. Development of specific post-Fukushima SAM action plans (to be proposed by the plant operators and then assessed by the regulatory bodies) should be considered as an urgent matter. Implementation of these plans should be accelerated and given a degree of priority that reflects the importance of individual provisions for protecting the public.

The discussions resulted in a wide-ranging, although not necessarily exhaustive, list of measures to be considered by the countries, as follows:

- When updating SAM and emergency arrangements, the potential interaction between the reactor and associated SFP has to be considered.
- A decision on a molten corium cooling strategy either in the RPV or in the cavity, appropriate for a given reactor design is to be reached by all countries.
- The feasibility of strategies for molten corium cooling aimed at protecting containment integrity needs to be further assessed, using available knowledge.
- Further attention is to be paid to potential re-criticality in SAM, taking into account potential geometry and material composition changes caused either by external hazards or by the progression of the severe accident.
- Maintained coolant inventory in the SFP needs to be ensured by verification or by upgrading SFP structural integrity, installation of qualified monitoring, and by provisions for redundant and diverse sources of additional coolant resistant to external hazards in order to practically eliminate risk of fuel uncovery.
- Preferable use of dedicated diverse and qualified SAM equipment resistant to extreme external hazards needs to be considered, either passive or powered from reliable sources, including instrumentation required for performing SAM actions.
- The use of mobile equipment could be advantageous due to its flexibility and the feasibility of its protection against loads caused by extreme external hazards. The connecting points and the infrastructure required for their use also needs to be adequately proven and robust.
- Due to the importance of RCS depressurization for the prevention of containment failure and for injection of coolant from low-pressure sources, additional attention needs to be paid to the capacity and reliability of the hardware provisions required for depressurisation.
- Whenever the severe accident assessment indicates a risk of long-term containment over pressurisation, which can not be reliably prevented by other means, containment venting must be considered via the filters designed for severe accident conditions, such as to ensure a sufficiently long venting time.
- High priority must be given to installing means for hydrogen mitigation designed for severe accidents, in order to practically eliminate containment failure due to hydrogen combustion. Installation of passive autocatalytic re-combiners seems to be the preferred option for future upgrading.
- Since hydrogen flammability depends on the composition of the containment atmosphere, which in turn depends on the operation of other systems such as the containment spray system, qualified monitoring of the hydrogen concentration must also be available to avoid such operation when concentrations that allow explosion exist.
- The potential for migration of hydrogen into spaces beyond where it is produced in the primary containment, as well as hydrogen production in SFPs, has to be carefully analyzed and adequate countermeasures adopted if necessary.
- The availability of an on-site emergency centre protected against extreme natural hazards and contamination needs to be enhanced, together with the necessary arrangements for rapid intervention by specialised teams, availability of personal protection measures, portable equipment on the site and robust communication means.
- In some cases, the regional off-site rescue centres established could be shared by several plants.
- The methods and tools for SAM training and exercises are to be further enhanced, utilising lessons learned from the use of all available means (such as desk-top training, use of multi-function or full-scope simulators).

7.2.4 Measures already decided on or implemented by operators and/or required for follow-up by regulators

Immediately after the Fukushima accident, regulators and operators started evaluating the events and possible improvements to the organisation of SAM, related procedures, needed hardware provisions and further studies or research and development needed. In the text below examples of such improvements are provided. Nevertheless the level of implementation varies among countries.

With regard to the organisation of SAM, many countries have decided that the WENRA SAM-related RLs should be reflected in the national regulations. The harmonisation of SAMGs and related training across units, sites, utilities and even across borders is envisaged. The enhancement and improvement of SAM organisation, staffing and logistics for long-duration, multi-unit events is of common concern and has already been addressed in most of the countries reviewed.

Cooperation agreements for emergency support, supplies, equipment, personnel, expertise etc. between countries, utilities, operators and vendors are already in place. Some countries already have or have started to establish national response centres and rapid response forces, as well as preparations for cross border co-operation.

The consequences of the possible adverse effects of external events (earthquakes, floods, heavy weather conditions, etc.) on the SAM infrastructure have been investigated, as well as preparations for emergency personnel supplies, logistics, dosimetry, protective equipment etc. under extreme conditions.

Regular and realistic SAM training exercises, including the use of the necessary equipment, with consideration of multi-unit accidents, long-duration events, etc. are part of the measures expected in almost all countries to improve SAM preparedness. 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. Regular inspection and testing of SAM equipment and validation of procedures are being further improved.

The extension of existing SAMGs to all plant states (full and low-power, shutdown), including accidents initiated in SFPs, is under consideration or development in all countries. Their extension to long-duration events, including the need for long-term energy supplies, mobile systems, long-term heat removal, safe release of combustible gases from the containment, ensured prolonged supply of consumables, and so on, is being envisaged.

To ensure the survivability of SAM instrumentation and equipment under severe accident conditions, long-term power savings (including battery load-shedding strategies to prolong battery discharge times) or the use of dedicated power supplies, have been addressed.

Many operators have implemented or plan to implement hardware AM measures. These include dedicated emergency core cooling provisions and related improvements to existing systems and equipment. The use of independent and diverse systems, such as auxiliary turbine-driven or air-cooled diesel-driven pumps and generators is being widely considered. The operation of isolation and depressurisation valves using mobile equipment, such as batteries, nitrogen cylinders, mobile generators, as well as provisions for additional manual operation of valves, are other elements designed to improve the robustness of SAM measures. The upgrading of instrumentation, including containment sampling systems for post-accident conditions and of independent water supplies needed for SAM, is complete or has been started in some units. One country is defining a set of essential equipment able to ensure the basic safety functions, even under external hazards BDB. Alternative, independent control rooms and areas for SAM, including safe shutdown provisions, and the manual control of equipment from sheltered locations, have been installed or are planned for enhanced SAM reliability.

The installation of alternative heat sinks, e.g. alternative cooling towers, sources of water, lakes, are considered to be essential prevention option in many countries.

The habitability of control rooms under severe accident conditions is an issue addressed and being resolved at many NPPs (e.g. by filtered air supply, maintaining over-pressure, use of air cylinders, etc.). In addition, more robust emergency centres for on-site and off-site support of the MCR in SAM, designed for internal and external hazards, are seen as a lesson learned from Fukushima. In that respect, improved communication systems, both internal and external, including transfer of severe accident related plant parameters and radiological data to all emergency and technical support centres, including the regulatory premises, are an essential aspect of the measures ensuring a reliable assessment of the emergency situation. Hydrogen management, monitoring and the re-combination of hydrogen in the containment and related rooms, as well as in the SFPs under SBO conditions, for example using PARs, electrical igniters powered by independent severe accident systems, including dedicated DGs, is seen as an area for improvement in some NPPs.

Filtered containment venting systems, including enhanced filters for retention of organic iodine and the use of dedicated internal or alternatively external containment spray cooling, are widely seen as the ultimate options for preventing containment failure and an uncontrolled release of radioactive materials into the environment.

The use of mobile equipment as alternative means of power and water supply, including prepared connecting points for fast and reliable configuration of these alternatives, has been implemented in many countries as an initial reaction to the Fukushima disaster. Water injection to the reactor pressure vessel, reactor cavity and containment, including primary and secondary feed and bleed operations at PWRs, are part of these provisions.

Improvements to the robustness of emergency facilities, SAM equipment storage (including bunkered buildings), seismic and severe accident qualification, the central storage of specialised equipment such as heavy machinery, mobile diesel driven generators and pumps, remotely controlled equipment, chemicals, personal protection equipment, etc. at a regional, national or even cross-border level, are improvements expected to be implemented in most countries.

The preparation of strategies, procedures and provisions for the post AM period and for handling large quantities of liquid waste, as seen after Fukushima, to avoid contamination of the surroundings and the general environment with radioactive releases, is already being envisaged in some countries.

7.3 Peer review conclusions and recommendations specific to this area

The peer review has confirmed that SAM is recognised by all participating countries as an essential component for defence in depth in NPPs. Moreover, the sharing of SAM experience, together with the current status and plans for improvement as part of the stress tests process, is considered to be making an important and helpful contribution towards improving safety standards across Europe.

Although SAM measures were initially BDB for operating NPPs, all countries are now committed to implementing the needed measures for upgrading safety. Basic components of SAM including organisational, procedural and technical means are already well-established. In spite of this, one of the lessons learned from Fukushima is that the scope of SAM needs to be extended, to take account of plant shutdown states, multi-unit events, long-duration events and accidents initiated in SFPs.

The peer review noted that the level of SAM coverage in national legislations varies from country to country. Nevertheless, suitable regulatory instruments appear to be available in all the countries, for adequate implementation of SAM using standard regulatory tools such as review, approval and inspections. There is an expectation and commitment from the regulatory bodies that the stress tests and their peer review will contribute to accelerated implementation of the necessary measures.

In general, the prevention aspects of SAM are more extensively developed than mitigation aspects. The state of implementation of mitigation features varies among the countries, from initial consideration through to very advanced stages of development.

On-site and off-site emergency arrangements are considered important and complementary components of SAM. While on-site arrangements were addressed by the stress tests, off-site arrangements remain an issue for potential further consideration.

Based on the lessons learned from the stress tests and this peer review exercise, the following recommendations are offered for consideration by the participating countries:

1) PSR should continue to be maintained as a powerful regulatory instrument for the continuous enhancement of defence-in-depth in general, and the provisions of SAM in particular. The lessons learned from the Fukushima accident and from the stress tests should be reflected in the scope of future PSRs.

2) In response to their previous commitments, regulators should incorporate the WENRA reference levels related to SAM into their national legal frameworks, and ensure their implementation as soon as possible.
3) Effective implementation of SAM requires that adequate hardware provisions are in place to perform the selected strategies.
4) The means for maintaining containment integrity should in particular include depressurization of the reactor coolant system, prevention of damaging hydrogen explosions, and means of addressing long-term containment over-pressurization, such as filtered venting.
5) A systematic review of SAM provisions should be performed, 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.
6) The assessment of SAM provisions should take account of the need to work with a severely damaged infrastructure (i.e. in which the usual means of communication and access, etc. are disabled), of plant level, corporate-level and national-level aspects, and of long-duration accidents affecting multiple units at the same time (on individual and nearby sites as appropriate).
7) The SAMGs should be comprehensively validated taking due account of the potential long duration of the accident, the degraded plant and the surrounding conditions. Pre-planned SAM actions should be designed to function effectively and robustly for suitably lengthy periods following the initiating event. In most cases, durations of at least several days should be assumed for planning and assessment purposes.
8) Training and exercises aimed at checking the adequacy of SAM procedures and organisational measures should include testing of extended aspects such as the need for corporate and national level coordinated arrangements and long-duration events.
9) When developing SAM action plans, conceptual solutions for post-accident fixing of contamination and the treatment of potentially large volumes of contaminated water should be addressed.
10) Radiation protection of operators and all other staff involved in the SAM and emergency arrangements should be assessed and then ensured by adequate monitoring, guaranteed habitability of the facilities (hardened on-site emergency response facility with radiation protection) needed for accident control, and suitable availability of protective equipment and training.
11) 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.

8 CONCLUSION AND RECOMMENDATIONS

8.1 Summary of review process compliance with the ENSREG recommendations and of its quality

The judgement resulting from the peer review of the national reports is that the exercise generally complied with the ENSREG specifications and that the national analyses were done well, with the exception of the margin assessments relative to extreme natural hazards, which raised difficulties. The results were provided on time. The countries proactively sought improvements in safety. It is felt that all participating countries deserve recognition for the serious work that has been done.

With regard to the external hazards topic, overall the design basis events were well addressed in country reports. Most countries have demonstrated an adequate approach to seismic and flooding design bases, although there were significant differences in national approaches. However, the assessment of margins beyond design basis has been quite diverse, and very few countries assessed cliff-edges in the manner requested by ENSREG. This is possibly because of the short timeframe and the lack of a consistently recognised method in this area. Many regulators also indicated that work in this respect is either ongoing or planned in the near future. The situation is even less satisfactory with regard to extreme weather, and especially for combinations of extreme weather phenomena. **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.**

For the topic concerning loss of electrical power and loss of ultimate heat sink and the combination thereof, all countries complied with the ENSREG specifications by performing the analysis. For most of the reports the quality was good, with some of them providing analysis in outstanding detail. It should be pointed out that countries having multiple units typically chose to address type-specific rather than plant-specific analysis.

With regard to the accident management topic, the ENSREG specifications were generally addressed with a high level of quality by the national reports, although the level of detail varied among the countries. The national reports outlined the essential technical, procedural and organisational provisions required for accident management and on-site emergency arrangements.

8.2 Summary in relation to the scope of the stress tests of the licensing basis, background of licensing basis and plant compliance

It should be noted that the stress tests reports and the peer review could not provide exhaustive verification of the comprehensiveness and adequacy of the provisions. Consequently, this process cannot replace the more detailed work performed by the national regulatory bodies.

According to the information available to the peer review, national regulators have verified plant compliance with their current licensing/safety case basis before and during the stress tests, in addition to their routine regulatory oversight processes. Dedicated inspections and assessments have been performed and showed that the plants complied with the licensing basis. Minor deviations from regulatory requirements were resolved using standard regulatory procedures.

Regular verification through inspections and walkdowns is recommended to further demonstrate continuing regulatory compliance. Regulators and operators should be encouraged to develop procedures for plant inspections and walkdowns in order to provide a more systematic search for nonconformities.

The stress tests highlighted the importance of the PSRs for continuously improving plant safety and robustness. **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.**

Regulators should consider requesting the licensee to re-evaluate the external event design basis whenever new relevant information becomes available and as well as during the PSR.

8.3 Main results for margins, cliff-edge effects and areas for possible further improvements

As has already been stated, the evaluation of seismic and flooding margins was inconsistent. It is therefore difficult to identify general outcomes resulting from these evaluations. The existence of seismic margins, often based on engineering judgement, is a shared view.

Many countries have made a case that beyond design basis flood is an extremely low frequency event and therefore they have not evaluated the condition. It may be accepted that at some sites, due to local geography, any cliff edge effect associated with flooding can be practically eliminated. Only a small number of countries complied with ENSREG specifications relevant to the assessment of flooding margins. ESNREG asked for the evaluation of incremental increases in flood level beyond design basis and a determination of cliff-edges as well as potential improvements to address them. This approach proved to be fruitful. It is recommended that ENSREG encourages the national regulators to consider requesting flooding margin evaluations in accordance with ENSREG specifications, as it can provide a valuable insight into effective and practicable improvements.

As far as loss of electrical power and loss of ultimate heat sink are concerned, all the countries estimated the cliff-edge effects related to various combinations of losses of AC/DC power and/or cooling water. In some cases the methodology for determining the cliff-edge effects was extensively covered by the national reports and in other cases reported during the country presentations. In this regard, margin can be expressed in the time available before safety functions need to be restored. The results varied significantly depending on the type of facility and the cliff-edges considered. For the most severe total losses of cooling with no recovery actions credited typically the time to fuel heat up ranged from 1 to 10 hours. With recovery actions times extended beyond, 72 hours (the ENSREG specifications did not request an evaluation beyond 72 hours). Numerous improvements related to hardware and procedures have been identified; some have been implemented and others are still at the planning stage.

For accident management, it should be noted that although severe accident management measures were initially beyond the design basis for all operating NPPs, all countries are now committed to implementing the necessary measures for safety upgrading, including organisational, procedural and technical means.

In general, the prevention aspects of severe accident management are better developed than mitigation aspects. Implementation of mitigation features varies widely from country to country, ranging from initial consideration to very advanced stages of development. In particular, the provisions required for maintaining containment integrity need to be ensured.

The Fukushima accident highlighted new issues to be handled in accident management, for example the need to perform actions with severely damaged infrastructure and consideration of accidents affecting multiple units at the same time. Other new issues include assignment of responsibilities between the plant level, corporate level and national level.

8.4 Main results on possible means to improve robustness

For external hazards, national reports have identified significant plant-specific improvements, in particular, seismic upgrades and flood protection physical features to improve robustness. For example, the increased height of openings into protected rooms or the provision of additional temporary flood protection dams, are important and should be considered.

Similarly, in the area of loss of power and loss of heat sink, all countries identified improvements that would enhance robustness. The most promising improvements being considered by many countries are additional power and water supplies to be provided by mobile units, for which the connecting arrangements would be established in advance, extending battery capacity, additional sources of water, extended or additional supply of fuel, valve line-up accessibility as well as various operational improvements.

The regulators are overseeing operator improvement plans and should consider the most effective measures to increase robustness.

Within the scope of accident management, all countries are already committed to implementing the safety upgrading of the necessary measures for beyond design basis events. Basic SAM components including organisational, procedural and technical means are already well-established. Hardware provisions for maintaining containment integrity were already known to be important prior to the Fukushima accident and have been implemented in several countries. Where these provisions have not been implemented, they should be. **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.

One of the lessons learned from Fukushima is that the scope of SAM needs to be extended in these areas, in particular multi-unit long-duration accidents, devastated site conditions, harsh environments and contamination. **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.**

SAM guidelines are, for the most part, only developed for power operation and only in a few cases are there SAMGs for shutdown conditions, spent fuel pools or multi-unit events. Where SAMGs do not apply to all plant states, operators have plans to extend them within a few years. SAMGs should be developed for all plant conditions, accidents in the spent fuel pools, multi-unit accidents and long-duration events. Validation and verification of SAMGs is also essential for ensuring their practicability, robustness and reliability and so should form an intrinsic part of their implementation process.

The methods and tools for SAM training and exercises are to be further enhanced. SAMGs should be exercised periodically for severe accidents in very harsh conditions, taking account of the extended scope of SAM.

Equipment needed for SAM, including instrumentation and communication means, needs to be resistant to external hazards and sufficient reliability should be ensured under severe accident conditions. Any mobile equipment to be used for Accident Management should also be stored in a location resistant against extreme natural hazards.

On-site emergency centres should be available and designed against extreme natural and radiological hazards.

Finally, necessary additional staff and material resources should be rapidly available to any plant experiencing an accident, taking into account the possible devastation caused by natural disasters.

In addition to the previously mentioned means to improve robustness, the concept of a "hardened core" was also discussed. The "hardened core" is defined as a limited set of material and organisational measures, designed to ensure basic safety functions in extreme situations. The "hardened core" function is to prevent a severe accident or limit its progression, limit large releases and enable operators to perform emergency management. The "hardened core" will be designed to withstand conditions which are significantly more severe than the design basis of the plant. A significant number of European plants have decided to implement the "hardened core." Many reviewers felt that the concept needs further assessment before it can be considered as a European reference.

8.5 Most important assessments, follow-up actions, decisions and measures already made by regulators and operators

There is good evidence that national regulators have been proactive in demanding improvements and further analysis from their operators, although with varying timescales.

Inspections have been performed in areas related to Fukushima in many countries. Further inspections should be undertaken to ensure that equipment is properly installed and maintained and it is recommended that national regulators establish programmes for such inspections, particularly for temporary and mobile equipment used to mitigate beyond design basis external events and subsequent accidents.

Hardware provisions, including mobile equipment, were implemented or were in the process of implementation before Fukushima. After Fukushima, regulators and operators re-evaluated the provisions and proposed improvements. There is a general commitment to implementing these provisions, so in some cases mobile resources have already been acquired. This is also the case for SAM measures.

Although there is common agreement on the scope of most measures, the scale of their implementation is still being approached differently, depending on the pre-existing situation and the regulatory environment. Such is the case, for example, of the on-site emergency centre, the availability of remote support, fixed or mobile equipment, upgrades and additional layers of protection.

8.6 Recommendations to ENSREG for future positions and actions

The action plans for further analysis and subsequent implementation of the improvement measures have already been, or will be shortly defined, in all countries. The general aim is to make improvements as soon as possible, with the initial focus on those measures that can be implemented quickly, thereby providing immediate benefit. However, the completion schedules of all aspects of the action plans vary significantly depending on the scope of the work and the regulatory process. It is recommended that, within the existing arrangements, ENSREG identify an approach to keep this large volume of work under review and to establish the mechanisms for reporting on the implementation of the improvements and for further experience sharing. Such reporting could, for example, be performed as part of the reports which have to be produced by Member States in the frame of the European safety directive.

The peer review identified four main conclusions in addition to many detailed findings and recommendations included in this report.

Overall, the compliance with ENSREG specifications was quite good. However, deviations from the stress tests specifications were highlighted by the peer review in the field of natural hazards, where significant differences exist in the national approaches and where difficulties were encountered for margins and cliff edge effects assessments.

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

Stress tests showed that periodic safety reviews are well-established in participating countries and form the basis for continuous plant improvements, as well as for regular reassessment of the licensing basis.

The peer review Board recommends that ENSREG underlines the importance of periodic safety review in the field of natural hazards. ENSREG should highlight the necessity to re-evaluate natural hazards as often as appropriate but at least every 10 years.

All the countries participating in this review recognise the benefit of the WENRA reference levels applicable to SAM.

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

The Fukushima event has also shown that defence-in-depth should be strengthened by taking into account severe accidents resulting from extreme natural hazards significantly exceeding the design basis. 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.

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.

One of the important results of the public interaction is a strong demand for a European initiative on off-site emergency preparedness. This subject was not part of the mandate of the peer review. However, the Board clearly recognises importance of dealing with off-site emergency preparedness in Europe, as a follow-up of the Fukushima disaster.

Finally, it should be mentioned that performing such a peer review was a challenge and required very significant resources from the participating countries. In that sense, it should be considered as an exceptional exercise, which cannot be reproduced frequently. Notwithstanding, it was judged very positively by most of the participants and is expected to contribute to enhancing safety in Europe and in each European country.

9 ANNEXES

List of acronyms

AC	Alternating Current
AGR	Advanced Gas-cooled Reactor
AM(P)	Accident Management (Programme)
BDB	Beyond Design Basis
BWR	Boiling Water Reactor
DBE	Design Basis Earthquake
DBF	Design Basis Flood
DC	Direct Current
DG	Diesel Generator
EC	European Commission
ECC	Emergency Control Centre
ECR	Emergency Control Room
ENSREG	European Nuclear Safety Regulators Group
EOP	Emergency Operating Procedures
EU	European Union
EU Council	European Council
IAEA	International Atomic Energy Agency
JRC	EC Joint Research Centre
LOOP	Loss of Off-site Power
MCR	Main Control Room
NPP	Nuclear Power Plant
PAR	Passive Autocatalytic Recombiner
PGA	Peak Ground Acceleration
PSA	Probabilistic Safety Analysis
PSR	Periodic Safety Review
PWR	Pressurized Water Reactor
RCIC	Reactor Core Isolation Cooling
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RLs	Reference Levels
SA(M)(G)	Severe Accident (Management) (Guidelines)
SBO	Station Blackout
SG	Steam Generator
SL1 / SL2	Seismic Level 1 / Seismic Level 2
SFP	Spent Fuel Pool/Spent Fuel Pond
SFSF	Spent Fuel Storage Facility
SSC	Structure, System and Component
TMI	Three Mile Island (accident)
UHS	Ultimate Heat Sink
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators' Association

Country reports

Statistics about questions received on national reports

Number of questions put per country of reviewers:

Austria - AT	147
Belgium - BE	118
Bulgaria - BG	37
Croatia - HR	16
Czech Republic - CZ	60
Denmark - DK	8
Finland - FI	27
France - FR	108
Germany - DE	148
Greece - GR	18
Hungary - HU	28
Ireland - IE	21
Italy - IT	50
Lithuania - LT	27
Luxembourg - LU	34
Netherlands - NL	128
Poland - PL	44
Romania - RO	44
Slovakia - SK	47
Slovenia - SI	50
Spain - ES	126
Sweden - SE	7
Switzerland - CH	102
Ukraine - UA	175
United Kingdom - UK	45
European Commission - EC	399

Number of questions received per country:

Belgium – BE	174
Bulgaria – BG	128
Czech Republic – CZ	137
Finland – FI	122
France – FR	144
Germany – DE	101
Hungary – HU	98
Lithuania – LT	62
Netherlands – NL	90
Romania – RO	96
Slovakia – SK	83
Slovenia – SI	139
Spain – ES	175
Sweden – SE	120
Switzerland – CH	123
Ukraine – UA	88
United Kingdom – UK	120
Generic to all countries - CG	14

The following numbers of questions were received concerning the following topical areas:

General quality of national reports and assessments	74
Assessment with regard to earthquakes, flooding and extreme weather conditions	422
Assessment with regard to loss of electrical power supply and loss of ultimate heat sink	587
Assessment with regard to severe accident management	931

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