

Post-
Fukushima
accident

United Kingdom

Peer review country report

Stress tests
performed on
European nuclear
power plants

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1 GENERAL QUALITY OF NATIONAL REPORT AND NATIONAL ASSESSMENTS

The accident at the Fukushima nuclear power plant in Japan on 11th March 2011 triggered the need for a coordinated action at EU level to identify potential further improvements of Nuclear Power Plant (NPP) safety. On 25th March 2011, the European Council concluded that the safety of all EU nuclear plants should be reviewed, on the basis of comprehensive and transparent risk and safety assessments - the stress tests. The stress tests consist in three main steps: a self-assessment by licensees, followed by an independent review by the national regulatory bodies, and by a third phase of international peer reviews. The international peer review phase consists of 3 steps: an initial desktop review, three topical reviews in parallel (covering external initiating events, loss of electrical supply and loss of ultimate heat sink, and accident management), and seventeen individual country peer reviews.

Country review reports are one of the specific deliverables of the EU stress tests peer review process. They provide information based on the present situation with respect to the topics covered by the stress tests. They contain specific recommendations to the participating Member States for their consideration or good practices that may have been identified, and to some extent information specific to each country and installation. Draft country review reports were initiated during the topical reviews based on discussions with the country involved in the three topics and on the generic discussions within each of the three topical reviews. Issues identified for each country during the topical reviews, due to only limited time available for each country, have required follow-up discussions in more detail, both between the topical reviews and the country reviews, and during the country reviews.

The current Country Report was finalized at the end of the Country Review, after final discussion with the reviewed country and visit of nuclear power plant. It is a part of the Final Report combining the results of the Topical Reviews and Country Reviews.

General Information:

The UK (United Kingdom) predominantly uses CO₂ gas-cooled reactors (two types: Magnox and Advanced Gas Cooled Reactors, AGR's). Of 18 operating reactors 3 are Magnox, 14 AGR's and one Pressurised water reactor (PWR) (Sizewell B). There are 15 reactors in the state of defueling, 13 Magnox and 2 fast breeders (Dounreay Fast reactor – DFR and Prototype Fast Reactor – PFR). Other reactors have been unloaded and fuel has been removed from the fuel pond for off-site reprocessing or dry storage. Operating Magnox plants maybe defueled in about six years.

Sizewell B is only 16 years old. The age of the AGR's is 23-35 years. Based on lifetime extension reviews most of them will continue to operate till a range of dates from 2023 to 2045, subject to PSR and consent of ONR.

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

The UK national report is well structured and generally complies with the guidance provided in the European Nuclear Safety Regulators Group (ENSREG) stress tests specifications. Within the UK national report, Office for Nuclear Regulation (ONR) have identified that the licensees have not adequately addressed the margins to cliff edge effects for earthquakes, flooding and extreme external events. This is subject to an ONR finding and is being progressed with the licensees.

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

The adequacy of the information supplied is consistent with the guidance provided by ENSREG. The structure of the report generally includes a description of the information provided by the licensees followed by ONR's view of the corresponding information. This allows the reader to clearly identify the view of each party.

In the area of extreme natural hazards all the issues are addressed in the report. During the stress test process, Electricité de France Energy Nuclear Generation Ltd (EDF-NGL) concluded that it was not in

a position to carry out meaningful margin assessment for seismic, flood or extreme weather conditions in the timescales of the stress test assessment. ONR considers the design basis requirements to be robust and that the design basis events used by licensees are reasonable. Nevertheless ONR considers that existing methodologies may benefit from a review against the latest approaches and that additional, more systematic work on margins is required for beyond design basis events and identification of cliff edges. It is therefore difficult to fully evaluate safety margins at this time.

As a result of the UK's response to the Fukushima events and participation in the EU stress-test process for UK NPPs some areas for further enhancement of NPPs robustness and resilience to loss of power supply and ultimate heat sink events have been defined already and presented in the report. ONR have required that the licensees provide progress reports on all of the "considerations" and findings in this report by June 2012, along with details of how they expect to respond to the recommendations already made in the Chief Inspectors report (REF). As a result technical details of those measures as well as time-scales for their implementation (in accordance with the recommendations on format of National Reports) are not yet available.

1.3 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

All of the UK's NPPs had Design Basis Accident (DBA), Probabilistic Safety Assessment (PSA) and Severe Accident analysis undertaken during their design or in subsequent Periodic Safety Review (PSR). PSR also includes a review of the safety of the plant in response to event such as earthquake, flood, fire and explosion. From this point of view, the plant safety cases are in line with the scope of the stress tests.

However, full scope Level 2 PSAs have not been yet performed for all AGRs and Magnox reactors, though some Level 2 PSA results are provided. ONR have recommended improvements in this area and licensees are already working on improving their PSAs.

Compliance with the safety case is checked by inspections and assessments. The inspections are based on a yearly plan to check the compliance with the license conditions through a matrix approach. Site inspectors visit power plants every month. The national report states that a number of corrections have been made. The matrix will be enhanced to look into the resilience measures.

ONR identifies some cases where the safety demonstration by licensees can be improved, but it considers that plants are compliant with safety goals.

Some cases are identified where a line of defence doesn't totally fulfil its mission, so that the safety relies on the next line of defence (such as water penetrating over static protections relying on the performance of drain system).

1.4 Adequacy of the assessments of the robustness of the plants: situations taken into account to evaluate margins

In the area of determination of margins against extreme hazards, ONR identifies shortcomings of licensee's reports to the regulator with respect to the assessment of safety margins and cliff edge effects. It is stated that operator's reports do not sufficiently answer the ENSREG requirements. The insufficiently explained methodology for assessing safety margins, and the mostly non-quantitative results, hinders the identification of further options for improvement of robustness against seismic hazards. The review of the margins against beyond design basis earthquakes has not been sufficiently systematic and therefore opportunities for improvement have not yet been identified. ONR has also raised a finding on the identification of cliff edge effects regarding flooding. ONR expected a more systematic review for beyond design basis flood events, although in this case the licensees have identified some opportunities for improvement. There is a similar recommendation for a structured assessment of beyond design basis margins to equipment failure for all meteorological hazards, and their combinations.

In the area of loss of power supply and loss of ultimate heat sink, most assessments are adequate and based on the safety case, but further assessments had to be based on a very conservative approach because of the time constraints and will be addressed further. In some cases the assessment will be done as part of the implementation of potential improvements. Reactor and spent fuel pools situations have been taken into account.

In the area of accident management, the UK regulator believes that the use of conservative design, defence in depth, good operational practice and adequate maintenance and testing should minimise the likelihood of faults. The DBA should ensure that the facility has been designed to cope with or withstand a wide range of faults without unacceptable consequences. In addition to DBA, PSA have been generally used to confirm that the overall risk presented by the NPP lies within targets set by the licensees themselves and by ONR in the Safety Assessment Principles (SAPs.) for Nuclear Power Plants.

1.5 Regulatory treatment applied to the actions and conclusions presented in national report (review by experts groups, notification to utilities, additional requirements or follow-up actions by Regulators, openness,...)

The UK regulatory system is a goal setting, risk informed approach. By law, the licensees are responsible for safety. The over-riding safety principle is that nuclear risks are to be kept As Low As Reasonably Practicable (ALARP).

There are 36 standard licence conditions, that include: *Emergency arrangements (LC11), Arrangements for preparing safety submissions (LC14), Periodic Safety Review (LC15), Const. Of new plant (LC19), modifications to existing plant (LC22), Operating Rules (LC23) require safety case, Inspection & maintenance (LC28), Decommissioning (LC35), Organisational Capability (LC36)*. ONR Inspectors are warranted to enforce these regulations using ONR procedures and consistent with: *Licence Condition requirements, H&S law generally, Compliance inspection / assessment inspection*. The ONR has developed and published technical principles, which are used to judge the licensees' safety cases. These are set out in the Safety Assessment Principles for Nuclear Facilities (according to ONR the latest version has been benchmarked against IAEA Safety Standards). In addition to the SAPs, more detailed Technical Assessment Guides (TAG) are available to ONR assessors to assist them in making judgements on licensees' safety submissions. In the areas relevant to the accident at the Fukushima site, the SAPs and TAGs set out regulatory expectations for protection against hazards such as extreme weather, flooding, earthquakes, fire, explosion etc. and for provision of essential services.

There is clear evidence that regulatory engagement in the UK has been applied extensively, as demonstrated by stating the ONR position in all parts of the report.

Immediately after the accident HM Chief Inspector of Nuclear Installations (the national regulator ONR) asked the licensees to review the lessons from it. In addition, the ONR requested licensees to carry out the European stress test. Also ONR was informed about the results of the WANO-sponsored inspections. ONR published an interim report containing 11 conclusions and 26 recommendations. In the subsequent final report a further 6 conclusions and 12 recommendations were formulated. Further to the additional studies and potential improvements identified by the licensees ONR's review has resulted in 19 findings. Some findings reinforce or extend those identified by licensees while others are to be considered as additional. Findings generally relate to more specific aspects of the recommendations. The licensees are requested to report by June 2012 about the progress of implementation of the 19 findings and details of solutions and planning. Licensees' responses are addressed under License Condition 15: Periodic Review. Therefore they are subject to normal regulatory approach. The strategy of ONR is that a lot of resilience measures are implemented in 2012, even if they were temporary simple solutions. Further improvement opportunities identified during the EU peer review process will also be taken into account by ONR.

As a result of ONR's inspections and technical exchange meetings with the licensees along with a review of the licensees' submissions, ONR states in their national report that the UK licensees have completed adequate stress tests reviews in line with ENSREG specification. Notwithstanding this, it is also clear to ONR that, to date, the licensees have concentrated on demonstrating compliance with modern standards for "design basis" events and identifying means to ensure greater robustness for events "beyond design basis" rather than, at this time, undertaking detailed theoretical calculation of margins for which there are likely to be considerable uncertainties. This is a reasonable strategy given the timescales but does not negate the need for licensees to address the totality of ONR's findings.

2 PLANT(S) ASSESSMENT RELATIVE TO EARTHQUAKES, FLOODING AND OTHER EXTREME WEATHER CONDITIONS

2.1 Description of present situation of plants in country with respect to earthquake

2.1.1 DBE

2.1.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country,...)

According to the national report all licensees in UK apply the same “philosophy for definition of the Design Basis Earthquake (DBE)”. The DBE is accordingly targeted to be an event with an annual frequency of exceedance of 10^{-4} per year (or 1 event in 10,000 years). This definition of the DBE is considered adequate by ONR and is in line with ONR’s expectations in the safety assessment principles. The definition is also in line with IAEA suggestions for the safety level SL-2.

2.1.1.2 Derivation of DBE

Due to the relatively low level of seismic hazard in the UK, seismic requirements for NPPs were established only after 1980. The methodology used to derive the seismic hazard for all the sites that currently have operating reactors were developed under the auspices of the Central Electricity Generating Board (CEGB) by an interdisciplinary panel of experts referred to as “Seismic Hazard Working Party (SHWP)”.

The DBEs for the nuclear facilities in UK are defined by ground motion values for an annual frequency of exceedance of 10^{-4} per year. The outputs from the DBE evaluation are site-specific response spectra (uniform risk spectra, URS) produced for annual frequencies of 10^{-4} . The approach for deriving the DBEs is, however, not consistent for all the sites because the later AGR reactors (Heysham 2, Torness) incorporated seismic loading during the design process in the 1970s, and this involved an early DBE definition, before URS were developed. During the country visit ONR advised that these early DBE definitions are generally more demanding than the equivalent site-specific URS spectra.

With the exception of three NPPs (Heysham 2, Torness and Sizewell B), seismic provisions were not part of the original design. Seismic hazard analyses and evaluations of the plants’ seismic capacities were performed mainly as part of the Periodic Safety Reviews (PSRs).

The report provides the Peak Ground Acceleration (PGA) values for the DBE for all the UK nuclear sites. ONR considers that the design basis events derived based on this methodology are a reasonable representation of the likely hazard level in the UK, but considers that there would be benefit in performing a detailed review of the SHWP methodology against modern standards and raised a finding, in this regard.

DBE values for the sites range from 0.13 to 0.25g (PGA).

2.1.1.3 Main requirements applied to this specific area

In the UK, the design basis criterion for natural hazards, including extreme weather, is defined in the SAPs as conservatively having a frequency of exceedance of less than 1 in 10,000 years ($10^{-4}/\text{yr}$). The licensee’s approach is to provide at least one line of protection (bottom line) against this hazard level (termed “infrequent event”) and two lines of protection (second line) against the less onerous, but more frequent 1 in 1000 year event (termed “frequent events”).

The safety logic is:

At design basis

- Hazard to be isolated by a barrier to $10^{-4}/\text{yr}$ level
- $10^{-3}/\text{yr}$ – 2 lines of protection
- $10^{-4}/\text{yr}$ – 1 line of protection

Beyond design basis

- *Margins identified for relevant Structures, Systems and Components (SSC)*
- *Using analysis/engineering judgment*
- *Some limited PSA treatment.*

2.1.1.4 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

For most of the NPP sites in the UK, DBEs are established by a panel of experts referred to as the SHWP. The methodology is a probabilistic Seismic Hazard Assessment (SHA) using a logic tree approach. Analyses produce ground motion values for different annual probabilities of exceedance of between 10^{-2} and 10^{-8} per year. The outputs are site-specific response spectra (uniform risk spectra, URS). ONR confirmed during the country visit that the SHA methodology included the assessment of individual fault contribution to vibratory seismic motion, with some consideration of capable faulting, i.e. fault movement at or close to the surface at a site. The derivation of the DBE for the (now defuelling) sites of Calder Hall and Chapelcross in the early 1980s used a different approach, which is assessed as “outdated by modern standards, however the hazard level is plausible at this return period in the UK” according to ONR.

2.1.1.5 Periodic safety reviews (regularly and/or recently reviewed)

Seismic safety improvements were developed through PSRs from the late 1980s onward. These included: site-specific hazard analysis; analyses of the seismic capacity of the plants; modifications to operating plants; improvements to the seismic robustness of safety-critical SSCs, seismic walk downs and use of Seismic Qualification Utility Group experience data; addition of seismic monitoring equipment.

No technical details on safety improvements are provided in the National Report. It is, however, mentioned that both, the establishment of DBEs and seismic qualification measures have been implemented during PSRs in the 1980s and 1990s since most of the UK plants originally were not designed to withstand seismic loads. The reviewers have been informed that seismic improvements were made to operating NPPs. Some of the improvements were also observed during the Heysham 2 visit.

Based on the regulatory reviews performed, the ONR considers that the AGR, Magnox and PWR plants are essentially compliant with the requirements of the safety case. However, some areas for further verifications have been identified based on the licensees' self-assessments (e.g. review of operator actions credited in the response to external events and the review of the potential for seismically-induced fires). These have been raised as "findings" in the UK report.

2.1.1.6 Conclusions on adequacy of design basis

Reviewers conclude that several uncertainties exist with regard to the DBEs, which were established by different methodologies for different sites during the 1980s and 1990s.

ONR clearly identified these uncertainties together with the fact that the SHWP methodology, which has been used for the assessment of most of the sites, “has not been tested against modern standards”. This leads to ONR’s “Stress Test Finding” that: “The nuclear industry should establish a programme to review the SHWP methodology against the latest approaches”. The regulator further concludes that refined state-of-the art SHA for the plants in defueling stage (Calder Hall, Chapelcross and Dounreay) will be of little benefit with regard to the life cycle of the plants.

2.1.1.7 Compliance of plant(s) with current requirements for design basis

According to ONR there was no provision for earthquakes in the original design of most of the nuclear facilities in UK except for the sites Heysham 2, Torness and Sizewell B. Assessments of the seismic design base were introduced between the late 1980s and mid 1990s at the occasions of regular PSRs for the individual sites.

No systematic detailed descriptions of the compliance of buildings and SSCs for the individual plants are provided, although the UK report notes that compliance against seismic hazard and all other safety

case areas is routinely tested through the PSR process, generally every 10 years. The ONR's approval is based on the evaluation of the safety case, which is wider concept than design validation. The licensees have confirmed their plants remain compliant, in line with ONR request following the Fukushima event. Some opportunities for improvement have been identified, which are followed-up by the ONR as part of post Fukushima work initially, but subsequently will pass into routine regulatory work.

2.1.2 Assessment of robustness of plants beyond the design basis

2.1.2.1 Approach used for safety margins assessment

The report claims that margins in SSC capability can be attributed to conservatism in the design process, codes etc. It is claimed that justification for this is based on: "Hazard curves increase smoothly with decreasing exceedance probability; Fragility curves vary smoothly with increasing hazard severity". It is claimed that sound design provides approximately a High Confidence of Low Probability of Failure (HCLPF) point on representative fragility curves.

2.1.2.2 Main results on safety margins and cliff edge effects

Specific margins to reach cliff edge effects beyond the design basis have not been established in a consistent manner. The ONR has raised a finding in this regard ("Licensees should further review the margins for all safety significant SSCs, including cooling ponds, in a structured systematic and comprehensive manner to understand the beyond design basis sequence of failure and any cliff edges that apply for all external hazards") and has identified in the report the units to which this finding applies.

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

All licensees have undertaken extensive post Fukushima work in response to ONR reports and ENSREG stress tests and confirmed that the safety standard is appropriate to enable reactor sites to continue operating pending further assessments.

2.1.2.4 Possible measures to increase robustness

A review of operator actions is proposed to provide additional confidence on mitigating the effects of external hazard events at the design level and beyond design basis. A systematic review of the potential for seismically induced fire to affect safety critical SSCs is also proposed. No specific improvements are proposed at the design level. For beyond design basis events it is proposed to review margins for all relevant SSCs, including cooling ponds, to understand beyond design basis sequence of failure and cliff edges. This includes assessment of the margin to failure of the various primary containment pressure boundary components to establish a loss of pressure boundary integrity.

2.1.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

As identified in 2.1.2.4 above.

2.1.3 Peer review conclusions and recommendations specific to this area

The design basis has been explained. There is good evidence that a PSR process has been applied effectively.

A beyond design basis capability is inferred but not quantified and no specific evidence is provided that margins to cliff edges and potential specific improvements have been considered systematically for all the NPPs. ONR has identified this is an area for improvement and raised a specific finding, to support further work by the licensees. This work will be monitored by ONR as part of the post stress test programme of work.

There is a substantial work related programme arising from the ONR report which will generate additional confidence relevant to the stress tests. The reviewers note that the UK licensees are

committed to provide a specific programme for the additional work noted in the UK National Report by mid-2012, to improve the margin assessment and identify specific potential plant improvements.

2.2 Description of present situation of plants in country with respect to flood

2.2.1 Design Basis Flood (DBF)

2.2.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country,...)

The approach is broadly similar to that adopted for earthquake events:

Sea - 10^{-4} /yr sea water level

- Defences mainly site platform level and engineered static sea defences
- Some temporary flood barriers for selected building doorways
- Inconsistent design basis definition across AGR fleet

Tsunami - deterministic design basis

- Not limiting for UK sites (Note: the UK report implies that tsunami is the limiting flood mechanism at Dungeness B; this is an error and para. 473 in the report and should be ignored.)

Rain - 10^{-4} /yr rainfall

- Site topography and engineered drainage
- Protection: e.g. bunds for some essential electrical equipment
- Building basement stands above site level.

2.2.1.2 Derivation of DBF

DBF level at each reactor site are provided in the UK report. The report states that all the sites provide evidence of site specific flood analysis and most provide details of methods, contractors and data sources.

2.2.1.3 Main requirements applied to this specific area

Flood hazard is defined as a conservative infrequent event 10^{-4} per year frequency in accordance with the UK SAPs. Evidence of sufficient margins to cover the uncertainties in the method is required in the safety cases. Regarding flooding, precipitation, high tides, storm surge, barometric effects, overflowing of rivers and upstream functions, coastal erosion, seiches and tsunamis are taken into account. The design basis flood, should take into account as appropriate, the effects of tides, wind effect, wave actions duration of flood and flow condition. In addition, cliff-edge effect shall be verified so that a small change in the design basis assessment shall not lead to a disproportionate increase in radiological consequences.

The hazard design basis fault is assumed to occur simultaneously with the most adverse normal facility condition. Physical margins are in the implementation of flood defence beyond the design basis (e.g. height to overtopping). The SAPs are composed of a number of general principles that apply generally to many hazards and fault conditions. A number of principles apply specifically to external hazards. General principles cover the identification of safety relevant equipment, automated systems design and emergency arrangements, and these are applicable to all significant external hazards including flooding.

ONR doesn't prescribe specific flood analysis methodologies, but as noted above the Safety Assessment Principles provide a set of high level principles that represent good practise and specifically identify a number of external hazards that should be considered by licensees, including flooding. Licensees have to consider how they meet these principles and it is up to them to select how they wish to do this, subject always to being able to demonstrate that the risks (from flooding in this case) are ALARP. ONR inspectors assess the adequacy of licensee safety submissions against these principles. Thus the technical files, safety submissions etc., by different licensees may differ both in detail and scope, since the significance of flood hazard and the consequences of flood initiated plant faults will differ from site to site and by plant type. ONR has to be satisfied that licensee safety submissions on flooding are adequate, although it uses a sampling regime to concentrate its resources

on those issues judged to be most important to nuclear safety, so the extent of scrutiny by ONR may also vary from site to site.

ONR notes that on several sites wave overtopping of the sea wall is tolerated because drainage behind the sea wall limits the accumulation of flood water on site. The general principles of defence in depth concept are depicted in the SAPs document but it does not include a detailed guidance on their practical implementation regarding the protection against flooding issues.

The potential for instability of the coastal area or river channel due to erosion is investigated. Water waves induced by local earthquakes or other geological phenomena have been assessed by a national study and found to be not significant. The same study also found that hazards associated with tsunamis or seismic induced seiches are not significant in relation to other flooding mechanisms. Flood protection arrangements are identified for all sites.

For some, active site drainage is claimed where pumping of surface run-off water is possible. Most sites also identify that any water ingress to main building basement areas can be pumped. ONR highlight that flood can adversely affect active plant and equipment, especially electrical systems.

Key SSCs which are needed for achieving safe shutdown state and are supposed to remain available after the flooding are identified except for the PWR Sizewell B which is considered as a dry site. Other effects linked to the flooding itself or to the phenomena that originated the flooding (such as very bad weather conditions) are taken into account, including:

- Loss of external power supply
- Situation outside the plant, including preventing or delaying access to access of personnel and equipment to the site.

The main provision to protect the site against flooding are identified and a surveillance programme is implemented, as well as main operating provisions (including emergency operating procedure, mobile equipment, flood monitoring, alerting systems...). Off site mobile equipment is not considered necessary for DBA; however their inclusion in the emergency arrangement will increase robustness against beyond design basis events. Requirements regarding mobile equipments (maintenance, operability) shall be defined. An environmental monitoring system is used but the safety status of equipment and related procedures should be clarified.

2.2.1.4 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

Plant design and safety cases are not homogenous due to the difference of age between the plant, the differences among the operators and due to the fact that regulatory requirement are only high level requirements.

2.2.1.5 Periodic safety reviews (regularly and/or recently reviewed)

The flood hazard is included in the PSR process. PSR is identified as an opportunity for a licensee to provide a consistent and update justification file. Requirements for site autonomy are identified. The high level requirements for flooding in the SAPs are the same for all sites but the detailed implementation depends on site characteristics.

2.2.1.6 Conclusions on adequacy of design basis

Data, including historical data, both meteorological and hydrological, were collected. ONR has some remarks on the consistency of these data.

The potential for flooding due to one or more natural causes such as runoff resulting from precipitation or snow melt, high tide, storm surge, seiches and wind wave that may affect the safety of the nuclear installation are considered, though ONR has some remarks on the quality of assessments. ONR identified that some operators will have to complete their file as there are not uniformly consistent and their methodology does not meet modern standards. Licensees agree on this point though they consider their demonstration adequate and sufficiently robust regarding the safety goals. The approach to defining flood requirements is broadly consistent with international standards; however the report identifies areas of inconsistency which is being addressed by future work. The ONR has raised a regulatory finding in this regard ("Licensees should undertake a more structured and systematic study

of the potential for floodwater entry to buildings containing safety significant SSC from extreme rainfall and / or overtopping of sea defences.")

ONR identifies for some licensee the need for additional justification on:

- The justification of safety up to the decommissioning of plants
- Hazard combination
- Seiches (ONR advised at the country visit that Para. 469 in the UK national report is an error and should be ignored and that ONR are content with the licensees' responses on the basis that seiche is accounted for in general tide data)
- Performance of barriers and drain systems (noticeably possibility and consequences of clogging phenomena)
- Access to the site due to snow falls.

Major UK Government reports were published on tsunami hazard to UK coastlines in 2005/6, following the tragedy which occurred on 26 December 2004 when an undersea earthquake caused a tsunami which devastated coastal areas in parts of south Asia. This work found that the worst tsunami generic process was a major earthquake in the Lisbon region and would result in elevated sea levels of 1-2m with maximum run-ups of 2-4m in SW England. Other causes, such as submarine slides in the North Sea and local offshore earthquakes were considered and discounted as significant hazards. For nuclear sites in the UK, tsunami has been recognised as a credible hazard but one that is less significant than other flood events.

The existing DBF assessment regarded tsunamis as "not significant" for all the UK sites (except Dounreay site). The reviewers are aware of recent technical literature that provides alternative views on the significance of tsunami to the UK and has advised ONR of this. ONR has made a preliminary assessment of this more recent data and has concluded that the original national reports of 2005/6 remain valid. However, ONR is seeking a more detailed consideration of tsunami hazard as part of revised site-specific flooding studies by licensees, in response to the a recommendation in the HM Chief Inspector's final report.

The reviewers note from the UK National report that there is inconsistency between different site-specific flood analyses and this has, in part, prompted the requirement to revise these analyses. While recognising the UK regulatory system does not prescribe the type of analysis methodology to be used, the reviewers suggest that ONR should assure itself that the methods used meet relevant good practise and are fit-for-purpose. Nevertheless ONR considers that licensees comply with their licensing basis.

2.2.1.7 Compliance of plant(s) with current requirements for design basis

Compliance in the case of the flooding safety issue depends on the conformity of equipment and structures to their design basis. The UK National Report doesn't provide detailed information about the conformity check but the ONR confirms that flood protection SSCs are identified on plant maintenance schedules. It is stated in the report that there are no deviations from their licensing basis identified at any reactor sites, although some sites have identified extant findings related to flooding from their periodic safety review arrangements. The UK report (on ONR's assessment of plants' compliance with its current licensing basis) also identifies some areas that require further verifications. The report indicates that in some circumstances the performance of drain system or pumping water inside rooms may be required.

It was not clear to the reviewers that systematic inspections by expert engineers organized in a formal plant walk down have recently been undertaken. It is recommended that the regulator should confirm that such inspections have indeed taken place recently and will continue to be undertaken at appropriate routine intervals in the future, to verify that safety functions can be delivered and that there are no unanticipated problems or degradation of the sea defence structures.

Guidance on the implementation of the concept of defence in depth concerning this issue, i.e. protection and mitigation of water penetration on the site and inside relevant rooms was further discussed during site visit. The reviewers note that beyond design basis analysis of floodwater entry into buildings, both of which are relevant to demonstrating defence-in-depth have, have been captured as findings in the UK report.

During the country visit it was explained that a warning system is available so that it is possible to detect a potential flooding of the site to complete the safe shutdown of the plant if appropriate (together with the implementation of adequate emergency procedures).

2.2.2 Assessment of robustness of plants beyond the design basis

ONR identified that the licensee haven't addressed this issue. Some operators provide consideration in implementing temporary flood protection.

2.2.2.1 Approach used for safety margins assessment

ONR reports that licensees claim for margins before flooding significantly impairs safety. ONR notes that a cliff edge margin assessment was not reported. ONR recommends that an appropriate assessment should be carried out. The ENSREG requirements regarding the evaluation of margins have not been addressed.

2.2.2.2 Main results on safety margins and cliff edge effects

Cliff edge assessment has not been reported for any of the sites. The ONR is aware of this and anticipates further information.

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

ONR identifies that operator's justification files shall be updated and that margin assessment over design basis shall be addressed in a comprehensive way.

2.2.2.4 Possible measures to increase robustness

The reviewers were concerned whether adequate attention has been paid on the potential for floodwater entry to buildings (containing safety related SSCs) from extreme rainfall and wave overtopping of sea defences, but note that the UK report contains a specific finding on this issue, . Operators identify a very few possible modification to implement, but don't provide any information on decisions taken or action plan, although the UK report advises that plans are being prepared by the licensees. ONR identifies that safety relies also on the conformity of protection structures, the performance of drainage systems and a few equipments.

Concerning SSC equipment the report doesn't specifically address the flooding issue as a common cause failure mode for all the reactors of a site, in particular regarding the need to share mitigation or mobile equipments. Although the reviewers note that the UK Chief Inspector's final report makes a recommendation to review/revise site-specific flood analyses, ONR is urged to ensure that common cause failure modes from flood hazard are comprehensively taken into account.

2.2.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

Future work as considered by EDF NGL and Magnox Ltd: review of existing flood hazard analyses against modern standards and update.

2.2.3 Peer review conclusions and recommendations specific to this area

The peer review has been an opportunity for ONR to focus on the flooding issue, which is considered as complying with the design basis. The DBF assessments use different approaches which are not satisfactorily explained. This leads to partly inconsistent results. ONR note that further work is required to address this.

Reviewers conclude that the currently available DBF assessments have not accounted for some recent tsunami research work, although ONR are content that such work is unlikely to significantly affect previous work on maximum credible tsunami heights. There is no satisfactory evidence of capability of the plants beyond the design basis. It is recommended that the UK regulator considers providing a specific programme for additional review regarding the design basis approach and an adequate response regarding margin assessment and identifies specific potential plant improvements. ONR has

raised this as findings in the UK report. It will be addressed as part of the licensees programme of revising their flood analyses and as part of their programmes to respond to these findings.

The ONR main requirements for operators are:

- The licensee should undertake a more detailed analysis of the potential for floodwater entry into the building containing SSCs
- A more comprehensive cliff-edge analysis should be undertaken by licensees
- The ability of operators to perform safety-related tasks during and following a flood event should be analysed in more detail.

ONR identifies that operator will have to update their design basis assessment with consistent data and state of the art methods.

ONR were requested to consider clarifying its technical requirement in the implementation of the defence in depth principle regarding flooding, and consider requirements for warning and prevention of flooding of the site, protection against flooding of rooms and mitigation, for the whole site. ONR have accepted this and already raised findings on beyond design basis/margins. The EU peer review team has confirmed with ONR that this will include the defence in depth principle.

2.3 Description of present situation of plants in country with respect to extreme weather

2.3.1 DB Extreme Weather

2.3.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country,...)

The extreme weather issue is composed of: extreme temperature (air and sea temperature), snow, precipitation, wind, lightning, drought, and combinations of phenomena. The UK national report doesn't provide information on the way meteorological phenomena are documented and for which period of time. The basis design criteria for natural hazards, including extreme weather, is defined in the safety assessment principle document, as conservatively having a frequency of exceedance of less than 1 in 10,000 years.

2.3.1.2 Derivation of extreme weather loads

The approach is broadly similar to that adopted for earthquake events current requirements are:

- Wind - 10^{-4} /year: essential systems protected by building qualification; wind borne missiles considered for external plant
- Temperature - 10^{-4} /year: safety cases not strongly dependent on precise temperature values
- Snow - 10^{-4} /year: roofs loadings compliant with design codes with allowance for drifting.
- Lightning: protection provided according to design codes; Sizewell B has 10^{-4} /year criterion defined.
- Drought: slow development of the event; no specific design basis provisions identified.

2.3.1.3 Main requirements applied to this specific area

The requirements are similar to the requirements for earthquake, see 2.1.1.3 above. Some warning systems to complete the safe shutdown of the plant in sufficient time, together with adequate emergency procedures are implemented.

2.3.1.4 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

ONR treats extreme weather conditions in the same way as any external hazard in accordance with SAPs. However, the SAPs do not provide a detail guidance, on the practical implementation regarding the protection against such hazards.

The design basis event for any naturally occurring external hazard (including weather) should conservatively have a predicted period of exceedance of 1 in 10,000 years. For these weather conditions adequate provisions for protection against the hazard should be provided and substantiated.

Licensees define the site specific weather conditions for the design basis criterion described above. The licensees approach is to provide at least one line of protection against core damage for all design basis external events (including weather). Two lines of defence are provided for more frequent, less severe events, generally having a frequency of exceedance of 1 in 1,000 years.

The design basis conditions and protection capability are reviewed by the licensee's Periodic Review Process.

2.3.1.5 Periodic safety reviews

ONR has identified that some hazards were not addressed in the initial design of some plants, or that some of them required review due to updated standards. ONR identifies that this issue has been addressed by PSR although not all issues have yet been resolved. ONR has raised a finding to ensure that the additional work includes the identification of relevant safety equipments and structures to face external hazards and that their robustness is clearly evaluated. This should include consideration of an alert system and monitoring. EDF-NGL has raised considerations at all sites to receive site specific forecasts. ONR expects the licensee to progress all considerations according to a plan to be agreed in June.

2.3.1.6 Conclusions on adequacy of design basis

The approach appears to be similar to international standards. Nevertheless ONR identifies a need for further work to establish consistency and will be followed up by ONR. EDF-NGL has raised a consideration across all AGR sites to develop a fleet wide consistent methodology for evaluating extreme wind and temperature conditions and ONR believes this consideration should be extended to other external hazards as appropriate. ONR expects all licensee considerations to be progressed according to a plan to be agreed by June 2012. In some cases relevant extreme weather phenomena were not addressed by the licensees but ONR confirms that additional hazards safety cases are in production.

2.3.1.7 Compliance of plant(s) with current requirements for design basis

ONR notes that "Depending on date of construction, not all stations were designed against the current UK design basis criterion of 10^{-4} per year exceedance frequency. Furthermore not all extreme weather conditions were recognised as safety significant hazards for which a design basis definition was appropriate. However as part of the PSR process, safety cases have been developed for extreme meteorological hazards and plant modifications implemented to achieve this design basis standard."

ONR considers that the licensees have met the intent of the stress tests analysis of the design basis but have raised a number of observations. ONR has identified the need for consistency in reference data and methodologies. In particular it was noted that there has been an example where the design value of a plant has been briefly observed, this point requires an update of hazard definition. The need for mobile equipment is not directly addressed nor their sharing between the different installations of each site.

2.3.2 Assessment of robustness of plants beyond the design basis

This issue hasn't been addressed in a comprehensive way by every licensee, since in some cases the study of the consequences of some hazards is under development according to appropriate standards. The progressive loss of safety functions regarding hazards was not addressed.

2.3.2.1 Approach used for safety margins assessment

The licensees have claimed that the assessment of design basis conditions is sufficiently conservative to provide for safety margins against hazard levels beyond the design basis. However, the ONR considers that this claim does not meet the requirements for a systematic assessment, as specified for the "stress tests" and regulatory findings have been raised in this regard.

The beyond design margin assessment is currently not quantitative. ONR identifies that licensee has to provide a significant work, mainly regarding extreme wind and temperature and cliff edges.

2.3.2.2 *Main results on safety margins and cliff edge effects*

- Temperature and wind: no margin analysis is currently available; EDF-NGL identified a requirement to calculate the margins
- Snow: margin on roof structures are expected but not quantified
- Lightning: protection provided according to design codes
- Drought: long timescales allow for remedial action shall be defined.

2.3.2.3 *Strong safety features and areas for safety improvement identified in the process*

Some of the licensees have included forecasts for the evolution of external hazard due to climate change. This is a noticeable point, which will be managed through the PSR process.

2.3.2.4 *Possible measures to increase robustness*

- Lightning: new cases under development for AGRs
- Drought: new cases under development for AGRs
- Wind – 10⁻⁴ year: Tornado under review.

Consideration should be given in the safety analysis of the possible duration of extreme events. In addition to the completion of safety case, and margin assessment, licensees have been requested by ONR to address the site access and autonomy issue.

2.3.2.5 *Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators*

- Future work by EDF NGL: Development a consistent approach to significant weather hazards across the fleet
- Future work by EFG NGL: Consider operator actions and human factors; Consider the adequacy of wind, temperature analyses and margin to freezing for essential water systems; Consider the consistency of weather forecast information across the fleet; Consider the adequacy of personnel access to site in severe weather

2.3.3 Peer review conclusions and recommendations specific to this area

The peer review has been an opportunity for ONR to focus on external hazards which are considered compliant with design basis. ONR recognizes that some safety case methodologies are dated and not consistent across all plants.

For some specific external hazards, beyond design basis capability are inferred but not quantified and no specific evidence is provided that margins to cliff edge effects and potential specific improvements have been considered systematically for all NPP. In some cases there is no satisfactory evidence of capability of plant beyond design basis (e.g. tsunami, lightning).

Cliff edge effects beyond design basis have not been established in a consistent manner for external hazards, ONR has raised findings on these issues.

The review team noted that the UK regulator has raised a finding for additional review regarding the design basis approach and an adequate response regarding margins assessment beyond the design basis and identifies specific potential plant improvements. The review team encourages the ONR to establish a strong regulatory oversight programme on this matter.

3 PLANT(S) ASSESSMENT RELATIVE TO LOSS OF ELECTRICAL POWER AND LOSS OF ULTIMATE HEAT SINK

3.1 Description of present situation of plants in country

3.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country, ...)

ONR has developed Technical Assessment Principles (Safety Assessment Principles, SAP, and Technical Assessment Guides, TAG) which are regularly updated and benchmarked against IAEA Standards and comply with the Western European Nuclear Regulators' Association (WENRA) Reference Levels.

3.1.2 Main requirement applied to this specific area

In accordance with the requirements, at least two connections of the plant to the national grid shall be provided and maintained. Electrical supply systems shall have redundant and diverse provisions to provide high confidence that power supplies are available in a range of fault conditions. Reactor shutdown shall not be dependent on electrical power.

Loss of Off-site Power (LOOP) is considered in the design basis; Station Blackout (SBO) is considered as a beyond the design basis accident. Loss of UHS is considered in the design basis, loss of UHS and alternate heat sink is considered beyond the design basis. These events are covered by Level 1 PSA.

Detailed guidance can be found in the Safety Assessment Principles and associated Technical Assessment Guidelines which is public information.

3.1.3 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

In the safety case approach, as defined in the SAP's, the analysis of design basis accidents is required. Deterministic approach is very important on one hand (compliance with deterministic targets) but also PSA is generally used to confirm that the risk targets set in the SAP's are met. Extremely unlikely initiating events are handled with severe accident management.

Operating Magnox and AGR stations have claimed to have Level 2 PSA, but ONR considers them hybrid Level 1 PSA's because they do not explicitly consider progression of severe accidents. It considers only power operation, including start-up, and some treatment of internal and external hazards. Each of the AGR PSAs is now moving to living PSA approach. A generic strategy for the development of fuel route PSAs for the AGR fleet is developed. Sizewell B has a full scope Level 3 PSA. In the UK PSA reviews by IAEA International PSA review team (IPSART) or IPSART like missions have taken place on initiative by ONR (AGR) or licensee (Sizewell B). In the light of Fukushima a recommendation has been formulated to require a full scope Level 2 PSA (including fire, full range of external and beyond design event and shutdown PSA). During the country visit ONR explained that although the PSAs produced Level 2 PSA results that met regulatory criteria, they do not provide sufficiently detailed information to support severe accident management guidelines.

Operating experience feedback is a required process in the UK (continuous improvement and experience feedback requirements in the license).

3.1.4 Periodic safety reviews (regularly and/or recently reviewed)

Periodic Safety Review is based on License Condition 15. PSRs are usually carried out every ten years. PSR also cover the issues of the reliable provision of power supply and ultimate heat sink. It is required that the overall design intent is met and a reassessment is performed against the latest safety standards and technical knowledge. Reasonably practical modifications shall be made. The operating experience of the plant is also considered in the review.

During the country visit the Wylfa Back up Feed System Pump House and the Dungeness B Electrical Overlay System were mentioned as examples of improvements in this area.

3.1.5 Compliance of plants with current requirements

The regulator has concluded that the plants comply with the license requirements. In a number of places in the national report it was stated that a non-compliance was found but corrected. The UK has recently introduced WENRA Reference Levels (RLs) and as noted in 3.1.3 in respect of PSA, not all plants fully comply with the relevant RL's yet. Several potential improvements have been identified in the National Report, some of them are reinforcements of on going actions, including provision of Level 2 PSA.

3.2 Assessment of robustness of plants

3.2.1 Approach used for safety margins assessment

A three step approach was adopted to assess the safety margins with respect to the loss of electrical power and loss of heat sink aspects of the stress test requirements. Firstly the relevant systems available together with the associated level of redundancy and diversity of equipment were described. Secondly, the timescales by which various safety functions need to have been established by this equipment in order to prevent significant fuel damage are then presented. Finally the level of autonomy with respect to fuel or coolant supplies is quantified. These aspects are considered in Section 3.2.2 below.

Licensees have applied the arrangements under LC15 (periodic review), which provided a structured approach using standard processes including independent oversight (e.g. by their Nuclear Safety Committee) and groups carrying out inspections and assessments of the work performed. EDF had the opportunity to engage with the French side for consistency of approaches. ONR created an expert team that reviewed the licensee reports through a targeted sampling process, technical meetings and inspections. During the development of licensee reports there have also been interactions:

- Technical meetings
- Inspections of the stress test process, including development of improvements
- Inspections of compliance with the safety case.

The ONR National Report has been independently reviewed by a Technical Advisory Panel.

3.2.2 Main results on safety margins and cliff edge effects

• Power Supplies

External power voltages are either 275kV or 400kV with some sites having additional connections at 132kV. These provide power to the electrical AC and DC systems which are distributed throughout the plant at multiple voltage levels with provisions for diversity, redundancy and segregation. Emergency power systems supply those AC and DC systems required to fulfil essential safety functions. Some of the AGR and Magnox sites have additional diverse local electrical back-up generators. The minimum design discharge time for batteries varies between thirty minutes and two hours. During the plant visit information was provided that the actual discharge times, based on measurements, were at least 2h. This meets the current safety case requirements; however, ONR has raised a finding in its Stress test review on licensees to review battery discharge times. The EU peer review team noted that the discharge times in the UK are small compared to other countries and suggests to increase them or provide alternative means to recharge (it is noted that at Sizewell B battery charging diesels are installed for this purpose).

On initiative of ONR the nuclear industry has created a working group that is reviewing the robustness of the offsite power system against external events. During the country visit it was explained that in the past a single government owned organisation (Central Electricity Generating Board) owned and operated both the nuclear power plants and the national grid. As a result, the grid has been designed and operated to high availability and redundancy requirements. After the separation of power generation and distribution the UK grid is still strong. Evaluation of robustness of substations to support the grid and the quick recovery of a collapsed power line were mentioned as examples

discussed in the working group. Recommendations are expected in June 2012. It should be noted, that unlike in some other countries the nuclear regulator has no legal base to require improvements to the grid operator. Licensees do not have agreements with the national grid for prioritisation of restoration of supplies, In such situation on-site and off-site emergency arrangements and relevant legislation would come into force.

In the UK the load rejection and transfer to house load operation is not considered practicable or reliable and has never been used.

AGRs

- **LOOP-reactor**

Apart from at least two grid connections AGRs have four independent redundancies of gas-turbines or diesel generators (DGs) for stand-by power. Interconnection is possible. One redundancy is capable of supplying all post-trip cooling. Fuel is enough for at least 24h, but not always 72h. ONR have raised a finding in its Stress Test review on licensees to review the adequacy of consumables, including fuel supplies.

Some stations have diverse lower voltage back-up DGs to provide essential cooling and indication functions or on some other sites they provide support to systems required for post-trip natural circulation of the reactor core. The remaining AGRs have no diverse AC back-up sources and therefore only rely on natural circulation, which is part of the safety case. All sites have an alternative indication centre remote from the central control room supported by DG backed power supplies. Fuel for at least 24h is available. During the plant visit it was shown that from the indication centre the reactor can be shut down (only available for Heysham 2 and Torness). The EU Peer Review team agree with ONR's finding related to event qualified connection points and suggest this should specifically include the Alternative Indication Centres.

For all AGRs SBO is considered the case when all AC power is lost. SBO is not part of the design basis analyses but is covered in the PSA, and action is taken to evaluate the provisions to cope with it. Batteries are assumed to function for between as a minimum 30 minutes and two hours (safety case). The licensee states that adequate cooling can be sustained by natural circulation, supported by diesel or petrol driven pumps feeding water to at least one boiler. Water and fuel supply on-site is available for at least 24h. If required also diesel-driven pressure vessel cooling pumps can be used. To sustain natural cooling with a pressurized reactor for a longer time some options might be available to extend water supply to 72h depending on the site like local water authority or fire main system. It is assumed that within 24h fuel supply will be possible. If not successful the worse case situation would be that after 10h following the complete loss of supply structural failures will start to occur. During the country visit it was explained that this amount of time depends on the typical reactor and varies between 10-20h. By reducing pressure (Severe Accident Guideline) this can be extended further to 24-48h. For a depressurized reactor forced cooling is necessary unless the primary circuit is repressurised. Both options are not possible using installed equipment during SBO. Equipment to support forced cooling is held in trailers located off-site and takes less than 10 hours to get to the site.

- **LOOP-fuel-route**

Fuelling machine. At normal LOOP backup supply will be provided, which makes it possible to place fuel to a safer position. Failure of ordinary AC back-up power can be tackled with hand-winding.

Buffer store. Three independent lines of cooling, two of them are backed up by their own installed diesel-driven pumps (except Dungeness B, where either portable generator or fire tender pump is expected within 24 hours). For extended LOOP adequate fuel supplies are necessary. In the case of SBO on all sites enough fuel is available for 72h. Some sites have alternative DG driven pump.

Irradiated fuel dismantling facility (IFDF) and ponds. Extended LOOP makes external supply of fuel necessary. In case of loss of back-up power some sites have alternative supply systems for cooling of IFDF, but apart from that the maximum fuel temperatures reached are 560 – 580 °C, which will not cause pin failures for at least 10 days. For the ponds there is at least 40h available to restore cooling by mobile systems.

Sizewell B NPP

- **LOOP-reactor**

At the loss of the four 400kV circuits, which are normally interconnected, the four independent EDGs automatically start. One is enough for the essential functions. EDG backed batteries provide low

voltage power supply. There are also two dedicated battery charging DGs. Decay heat is removed by natural circulation. Fuel is available for at least 72h.

When the ordinary back-up AC power is lost several systems are used for safe shutdown:

- Steam driven equipment
- Gravity fed systems
- Pneumatic equipment
- Battery derived low-voltage electrical systems (minimum 2h, but DG supported for at least 80h).

When diverse AC back-up DGs are also lost only the battery power is available with a minimum discharge time of 2 hours. Cooling can be provided for at least 24h by steam-turbine driven pumps (two primary make up pumps and two emergency feedwater pumps) or (during refuelling) by gravity fed systems. If no feed to the Steam Generators (SGs) is possible within 3h the core uncovers if no action is taken.

- **LOOP-fuel ponds**

Pool cooling can be powered by back-up EDGs. Complete loss of electrical supplies makes cooling by boiling necessary. Water make-up can be done in different ways. Failure of power and water supplies would result in fuel becoming uncovered after one and a half day (bounding case).

Magnox operating reactors

- **LOOP-reactors**

LOOP and the loss of backup AC power is in the safety case. Gas turbines (GTs) are the primary AC back-up power source in the event of a LOOP situation.. In the event of LOOP, depending on the site, within at most 30 minutes one or more gas-turbines synchronise to the emergency grid. Prior to these batteries are used to supply power.

Five or three GTs are available depending on the site. One is enough to support both reactors on a site. Each GT has a separate fuel tank which contains sufficient fuel for 24 hours. One of the ONR findings deals with evaluation of the fuel stock enhancement. The review team support ONR findings and suggests that the UK increase the stocks to at least 72h.

When ordinary back-up AC power is lost in Wylfa, diverse DG-system is available for cooling. Fuel is available for at least 24h. During the country visit it was explained that the natural circulation is part of the safety case for all Magnox reactors. In case that all power is lost natural circulation is maintained by diesel-driven pumps supplying power to the back-up boiler feed system.

Each site has an Remote Emergency and Information Center (REIC) supplied with ordinary back-up power and its own diverse back-up DG (also 24h fuel).

- **LOOP-fuel route**

No problems exist for many weeks for the fuel pool in Oldbury (passive natural cooling). Wylfa has only a dry storage that does not need electricity for fuel integrity.

- **Other sites LOOP**

Loss of all power is no nuclear or radiation safety threat for all defuelling sites.

- **Ultimate Heat Sink (UHS)**

AGR

During normal operation the sea is providing the primary UHS. Cooling is provided to a pressurised reactor by forced or natural circulation of CO₂ through boilers that are fed by one of the following: the main feed system, the post trip feed system and a back-up feed system. For a depressurised reactor forced cooling or repressurisation is necessary. Steam goes to the condenser or the atmosphere. Depressurisation of the boiler makes low pressure feed injection possible.

Steam discharge to the atmosphere is the alternate heat sink. While the condenser is cooled by the Main Cooling Water (MCW), essential reactor systems are cooled by the Essential Cooling Water (ECW) system; taking water from the primary heat sink. This system is 4x100% redundant, but also has a Back-Up Essential Cooling Water (BUECW) systems with their own petrol or diesel driven pumps fed by a different source of water (towns water, lagoon etc.). Each fuel tank contains fuel for 24h.

When the primary heat sink is lost (design basis event), the BUECW system provides protection. There is more than 10h (worst case depending on the typical reactor) available to achieve this before

severe damage to the reactor would occur. Fuel buffer systems are also supplied by the BUECW. The availability of backup systems to cool the fuel ponds varies, depending on the AGR design. It would take several days before boiling starts and therefore some stations rely on portable equipment should the main systems fail. Cooling could be restored by diesel driven pump systems like the fire main. Compared to other plants, the lack of installed backup cooling or backup power to the fuel ponds could be viewed as a weakness. The ONR believes that the ability to use portable equipment and the longer grace times, make these ponds less vulnerable to extreme hazards, which might damage installed plant systems. Additional independent means of cooling have been proposed by the licensees to increase resilience. The review team supports this further improvement of defence in depth.

When the alternate heat sink (atmosphere, town's water, air-based cooling systems) is also lost (beyond design) the first step, for a depressurised reactor, is to repressurise. Then the operator restores boiler feed. In the event of total loss of feed, severe damage to key components will occur in the worst case after 10 hours, even before severe fuel damage begins. This period can be extended 14 hours if boilers are fed for one hour post reactor trip. Best estimate grace time for severe damage to the reactor core structure is 24h.

A shutdown reactor has enough time to re-pressurise. Measures to improve the support equipment on site will be considered. On the other hand it would be possible to remove residual heat from the core by the direct injection of water if this was available. This has the disadvantage that water increases the mobility of any fission products released from damaged fuel. During the country visit this issue was discussed more deeply. The review team recognizes the necessary focus on the feeding of the boilers, but suggest it should be evaluated under what conditions water injection for heat removal would be possible and by what means (including the use of appropriate filtering).

Sizewell B NPP

The primary heat sink is the sea. Heat is transferred via the steam generators through the turbine and the condensers to the sea. Feed water systems consist of main and auxiliary pumps. Operation of the plant in recirculation mode is available as an alternative, but it requires that parts of the condensate system continue to function. Alternatively feed and safety-injection systems can use water on a once-through basis, with steam vented to the atmosphere and water provided from on-site storage tanks. Main feed water is taken from the condensers; the auxiliary feed water is taken from condensate tanks (capacity at least 29h) and can be supplemented by town water. Two of the auxiliary pumps are steam driven and autonomous from cooling and electricity.

With the loss of primary heat sink the condensers are lost, the reactor will be shutdown. The steam will be dumped to the atmosphere and the Reserve Ultimate Heat Removal System (RUHS) will be used with its air coolers, independent from the sea. This provides long term cooling. Reaching the required plant state takes about 3 hours.

During refuelling the Residual Heat Removal System (RHRS) is already in operation and this permits the RUHS to be used immediately. The RUHS uses off-site power or a DG. When the alternative heat sink is also lost (seawater and RUHS) the SGs can be supplied from diverse and redundant feed systems.

On the primary side two steam driven alternative reactor makeup pumps are available that can pump borated water through the RCP seals into the primary system. They can be used also for limited feed and bleed. During the country visit it was explained that the rooms where these pumps are located are not cooled very well and might lead to a loss of these pumps in the long run. Since these pumps could play a role in several scenarios, the robustness of their operating environment will be evaluated. The review team supports this as an example where margins could be gained with relatively low investment.

In worse case scenario, fuel ponds take at least 1.5 days before fuel uncover starts. Pipes are engineered to permit addition of water from a suitable fire tender or other alternatives. An option also interesting for other countries might be the use of reverse osmosis equipment for the use of seawater.

Magnox operating reactors

Primary heat sink is the sea like AGRs. Main feed water can be replaced by emergency feed systems if the sea is lost. The feed water storage tank can be used for one day. After that the Back Up Feed System (BUFS) with its own independent electrical supplies, or the autonomous Tertiary Feed System (TFS) can be lined up within a couple of hours. It takes about one day before core damage occurs if these options do not work. Water tanks have a capacity for several days. Probably because it takes 24h

for core damage, no further action is considered necessary. This complies with the stress test specification because it is assumed that within 24h portable equipment will be deployed. On the other hand, an alternative independent system for backup heat removal from the core might be considered as is the case in several other designs/countries.

Other reactors and fuel storages

Primary heat sink is the atmosphere.

- **Loss of UHS & SBO**

AGRs

Complete loss of cooling and electricity will lead to structural failures after 10h in the worst case if cooling to the boilers is not restored.

Sizewell B

The combination of loss of UHS and SBO is bounded by SBO. During refuelling outage with an open reactor, water would normally drain from the refuelling cavity into the reactor core. In conditions where this is not possible, the steam production maybe preventing gravity drain from the refuelling water storage tank until core uncover occurs. In the worse case, it will take only several hours to uncover the core and core damage can occur. Portable equipment to inject water into the core is considered as a solution. During the country visit it was explained that the water can be injected via the fuel pool to the reactor from outside, or directly to the reactor by fire hose.

The accident progression following a loss of RHRS decay heat removal (from whatever cause) in Mode 6 (RPV head removed) will depend on a number of factors including decay heat level, RCS inventory levels, plant configuration etc.

Gravity feed is a potential success path following a loss of RHRS with the RPV head removed and the RCS just below flange level. The task to initiate gravity feed was subjected to a plant walkdown with Design Authority and Station staff in 2011. The timeline subsequently produced indicated that it could take about 25-30 mins to initiate gravity feed (if no site incident declared by this point in the scenario) or about 45-50 minutes if a site incident has been declared and staff have had to muster. Core uncover would not be expected for about 90 minutes based on the analysis in SXB-IP-812065 (Analysis to Support Draindown Operations in Modes 5 and 6; August 2004).

If the refuelling cavity was filled it would take several hours before the water inventory started to boil and at least 36 hours to core uncover as shown in SXB-IP-812065 (Analysis to Support Draindown Operations in Modes 5 and 6; August 2004). Decay heat removal could be achieved by re-instating the RHRS, or a make-up source to replace the RCS inventory being boiled off, during this period.

Magnox operating reactors

Covered by earlier assessments.

Other reactors/ponds/fuel storage

No active cooling required.

For this scenario the increased/improved mobile backup water and power systems will be realised. During the country visit it was mentioned that EDF has decided to purchase amongst others:

- High pressure water pumping systems (boiler feed), including purification system for seawater
- Medium pressure water pumping systems (buffer store)
- High volume water pumping systems (pond)
- Modular electrical generation equipment.

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

Strong safety features are the different independent and autonomous systems and the diverse back-up AC power Diesel or Petrol Driven Generators and pumps or steam driven pumps on any site, the Gas-turbines at Magnox operating reactors and the four independent EDG's at Sizewell B. At Sizewell B the RUHS system and the two steam driven emergency feed water pumps and the two steam driven primary injection pumps can be considered as a strong feature.

Potential areas for improvement in addition to the National Report:

- Inject water into the reactor core as an ultimate means to provide residual heat removal from the core without use of the boilers and identify the means/equipment that would be used, including filtering (AGR/Magnox)
- Increase the robustness of the operating environment of the steam driven ECS pumps (Sizewell B)

- Stocks of fuel etc.. for at least 72h,
- Battery capacity is low compared with other countries and therefore should be increased or recharged by additional generators for most of the plants.

3.2.4 Possible measures to increase robustness

All potential measures put forward by the licensees and the requirement for further consideration by the ONR are extensively listed in the UK national report. An overview of measures per reactor type, reactor site or reactor is given. In the area of LOOP-UHS the The following highlights can be mentioned:

- Storing of autonomous diesel-driven pumps/power supplies in a hardened facility, EDG black start improvements, extra connection points for portable generators (Sizewell B)
- Enhance resilience of autonomous Back-up Feed System and TFS (Magnox)
- Standalone pond cooling facilities,
- Increasing robustness of re-pressurisation (AGR)
- Off-site provision to supply a nitrogen for primary circuit cooling and to enable boiler feed (AGR)
- Modification to make feeding of steam generator possible by fire tender/portable pump and venting the SG at a suitable pressure, injection of water from boric acid tanks for extra protection during outages (Sizewell B)
- Increase robustness of dry stores against severe accidents (Magnox).

3.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

ONR has formulated generic findings:

- Further investigate suitable qualified connection points for supply of essential equipment for beyond design events
- Further investigate enhancement of stocks (e.g. fuel, water etc.) and extending the autonomy time of support systems (e.g. batteries) for essential safety functions or emergency arrangements
- Identify safety-significant prime mover-driven generators and pumps that use shared support systems (incl. batteries, fuel, water and oil) and consider modifying those to make them self-sufficient.
- Consider resilience improvements to equipment associated with connection of transmission system to the essential electrical systems for severe accidents.

Specific to Magnox Ltd ONR has formulated two findings. One finding from the assessment of the progressive loss of electrical systems was not reported. The second finding is about the demonstration of fuel integrity when the natural draft air ducting of the dry fuel stores becomes filled with water.

ONR strategy is for the licensees to implement additional resilience measures in 2012 (connections and mobile EDGs). First step might be quick solutions, followed by engineered equipment.

3.3 Peer review conclusions and recommendations specific to this area

It is concluded that the plants comply with the license/safety case, but not all plants fully comply with all of the WENRA RLs yet. Improvements are underway to address the recommendations/findings that are reinforced by the action plan from the stress test. The proposed improvements by the licensee and endorsed, reinforced and extended by the regulator, are considered sufficient. For AGRs/Magnox the review team believes in the light of Fukushima, the longer grace times should not be used as an argument for not considering implementation of fixed hardware provisions.

The following further improvements are suggested for consideration:

- Inject water into the reactor core as an ultimate means to provide residual heat removal from the core without use of the boilers and identify the means/equipment that would be used, including filtering (AGR/Magnox)
- Stocks of fuel etc.. for at least 72h,
- Battery capacity is low compared with other countries and therefore should be increased or recharged by additional generators for most of the plants.

- Increase the robustness of the operating environment of the steam driven ECS pumps (Sizewell B).

4 PLANT(S) ASSESSMENT RELATIVE TO SEVERE ACCIDENT MANAGEMENT

4.1 Description of present situation of plants in Country

4.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country, ...)

As already stated, ONR has developed and published the technical assessment principles, which it uses to judge licensees' safety cases; these are set out in the Safety Assessment Principles for Nuclear Facilities (SAP). The latest version of the SAPs, published in 2006, was benchmarked against the IAEA safety standards. In addition to the SAPs, more detailed Technical Assessment Guides (TAG, accessible at www.hse.gov.uk/nuclear/tagsrevision.htm) are available to ONR assessors to assist them in making judgments on licensees' safety submissions. The TAGs also incorporate the WENRA reference levels.

Concerning Post Fukushima Stress Tests, 18 Stress Tests Findings (STF) have been identified by ONR, four of them directly related to Severe Accidents.

4.1.2 Main requirements applied to this specific area

The principle of defence in depth expressed in SAPs and relevant TAGs requires that fault sequences leading to severe accidents are analysed and provision made to mitigate their consequences. The UK analysis of severe accident events are performed on a 'best estimate' basis to give realistic guidance on the actions which need to be taken in the unlikely event of such an accident occurring. Severe accident analysis may also identify if providing the plant with further equipment for accident management is 'reasonably practicable'.

4.1.3 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

All of the UK licensees have processes to assimilate, review and disseminate lessons learnt from significant events, both in the UK and overseas. These arrangements are part of the continuous improvement and operational experience (OPEX) feedback processes which are required in the relevant Licence Conditions (LCs).

Probabilistic techniques and numerical safety criteria have been used in the UK since the early 1970s in the design of the AGRs. In particular, for Hartlepool and Heysham 1, a probabilistic analysis was used to complement the deterministic approach that had been used until then. This was followed by Heysham 2 and Torness where Level 1 PSAs were carried out during the design process for internal initiating events. ONR confirms that currently all nuclear power plants in the UK have at least Level 1 PSA available which is regularly updated.

The production of the PSA is the responsibility of the licensee. ONR does not require licensees to use any specific analysis methods, models or data in their PSAs so that the licensees are free to carry out the analysis in any way they choose as long as it can be justified that they are suitable / fit for purpose. For Magnox and AGRs reactors, the licensee claims that Level 2 PSAs have been produced, but given that the PSAs do not explicitly consider the progression of severe accidents, from the point of fuel damage to release ONR still considers that Magnox reactors and AGRs have hybrid Level 1 PSAs and not full Level 2 PSA. This is recognised by ONR to be an area for further improvement in accordance with IAEA standards and ONR's own PSA guidance. By the end of 2012, it is expected that each of the AGR PSAs will have been changed to a 'living PSA' approach.

Sizewell B PWR has produced a full scope Level 3 PSA. The PSA addresses all modes of operation of the plant (full power, low power and shutdown modes), internal initiating events, and internal and

external hazards. The PSA was produced as part of the safety case leading up to fuel load in 1994 and has been revised so that it can be used as a living PSA during station operation. In 2004 the Sizewell B PSA was subjected to a licensee led IPSART review which, upon request from the licensee, mainly focused on the suitability of the PSA to support risk informed decision making.

4.1.4 Periodic safety reviews (regularly and/or recently reviewed)

The operator of a nuclear installation is required by a specific Licence Condition (LC 15) to periodically review its safety case for the plant. This PSR usually takes place every ten years and requires the operator to demonstrate that the original design safety intent is still being met. In addition the reassessment is performed against the latest safety standards and technical knowledge. The operating experience of the plant is also considered in the review. If the PSR identifies any 'reasonably practicable' safety improvements, then it is a legal requirement that these should be made by the licensee. In addition, any life limiting factors that would preclude operation for a further ten years should also be identified in the review. ONR independently assesses licensees' PSR reports using its SAPs and TAGs.

4.1.5 Compliance of plants with current requirements (national requirements, WENRA Reference Levels)

In the areas relevant to the accident at the Fukushima site, the Safety Assessment Principles for Nuclear Facilities (SAP) and Technical Assessment Guides (TAGs) set out relevant regulatory expectations. ONR considers that the TAGs also incorporate the WENRA reference levels relevant to the field of Severe Accident and Emergency Planning.

The WENRA RLs seems to have been fully incorporated in the UK regulatory guidance documentation; however they have not been fully implemented by all NPPs so far.

4.2 Assessment of robustness of plants

For AGRs, Beyond Design Basis events are considered through the Symptom Based Emergency Response Guidelines (SBERG) and, if these are unsuccessful in controlling the event, the Severe Accident Guidelines (SAGs). These may use the same systems as used for the design basis faults, but are supplemented by more novel arrangements (including the ability to mobilise specialist equipment, including back-up power sources) supported by emergency plans. Following the visit to the plant it appears that these guidelines will need further development to be in line with the international standards as noted in an ONR finding.

Sizewell B NPP has in place SAGs (embedded into its Station Operating Instructions (SOI)) and the means to deal with accident situations, e.g. once all core cooling capability has been lost. ONR believes that the current operating Magnox reactors and AGRs have characteristics, such as low power density relative to the heat capacity of the large mass of the graphite moderator and single phase coolant, that provides long timescales before fuel damage can occur in the event of loss of post trip cooling. There is time available for operator interventions that aid the survival of the massive reinforced concrete pressure vessel. For all systems, radiological consequences in design basis faults are considered acceptable. However, once in beyond design basis conditions, reliance is placed on SBERGs, SAGs and the emergency scheme arrangements to limit radiological release and consequences.

4.2.1 Adequacy of present organizations, operational and design provisions

4.2.1.1 Organization and arrangements of the licensee to manage accidents

All UK power stations have a site emergency plan approved by the regulator which describes the organisational arrangements in the event of an accident. These arrangements include appointing designated persons to carry out specific functions in response to an event. At all times there are staff on site authorised to act as the emergency controller, who will be supported by other personnel trained in emergency response.

The review team suggests that the ONR verifies whether the existing arrangements are sufficient also under conditions of multi-unit accidents and in case of deficiency to take adequate corrective action.

All sites have: a Main Control Room (MCR); an Alternative Indication Centre (AIC); Emergency Control Centres (ECC); and Access Control Points (ACP). These emergency response centres work together to provide a coordinated and focussed response following the declaration of an incident or emergency. However, improvements have already been identified on several plant for ECC, as many of ECC do not have proper ventilation system to cope with severe accident conditions or are not sufficiently protected against radiation in case of a severe accident. The MCR has been designed for situation covering only Design Basis Accident. Following site visit it has been confirmed, none of the AGRs and Magnox reactors have a full function Backup Control Room (ECR) - allowing control and shutdown to safe condition of the plant if the MCR become uninhabitable. The Emergency Control Centres (ECC) have online access to the Plant Parameters through computerised systems however no specific power supply being available for these computer, the access to the Plant Parameters will not be possible in case of Station Blackout.

There is also a Central Emergency Support Centre (CESC) able to provide engineering support to the different NPPs but the type of information available at the CESC is variable from one NPP to another. Plant parameters, for example, are not available online for each NPP.

Following detailed review of the Fukushima event, the subsequent review of UK station safety cases and examination of the associated risks on plant; it is not believed that the fundamental risk profile on the power stations has changed. Therefore, licensees conclude that their current arrangements remain fit for purpose. The Emergency Plan and organisation for accident response seems to have been designed to cope mainly with Design Basis Accidents. However there is provision for an extendable response. In addition, the licensee explained during the plant visit that they are planning to upgrade their capabilities to be self sufficient in case of extreme hazards which cause widespread damage.

It is the view of the review team that the existing arrangements for management accidents (MCR in combination with emergency indication centre) is not equivalent to plants equipped with an alternative emergency control room or remote shutdown facility (with the exception of Sizewell B). Habitability of both MCR and ECR in case of severe accidents is also considered as important precondition for feasibility of accident management action. Radiation protection of operators and other staff involved in accident management and emergency arrangements should be assessed and then ensured by adequate monitoring, safe habitability of the relevant facilities, availability of protective equipment and training. In the UK the state of the facilities is monitored and site personnel are relocated if required.

4.2.1.2 Procedures and guidelines for accident management (Full power states, Low power and shutdown states)

All operational reactors in UK, have SOI, SBERGs, and severe accident guidelines (SAG) that outline operator actions for the management of accidents. The Magnox defuelling sites have detailed procedures to be followed in the event of an emergency which are described in the relevant site emergency handbook.

If application of SOI and SBERGs fails to prevent the onset of core degradation, or if a degraded core appears possible, then further management of the accident would be based on advice given in the SAGs. These provide advice to actions to limit the release of fission products to the environment. They are deliberately non-prescriptive as prescriptive advice is only appropriate when the fault sequence is reliably predictable, and almost by definition this will not be the case under severe accident conditions. Instead, the SAGs highlight the physical phenomena likely to be of importance, and focus on measures which could be adopted to recover critical safety functions, using non-standard or improvised plant configurations if necessary. This could include existing plant systems and equipment available on site or, more likely for a significant event, equipment provided from off-site sources. This means that a set of actions would have to be decided upon in real time during the course of the accident in response to the specific event.

As explained during the country visit for Sizewell B, the severe accident management guidelines is generally entered when a Core Exit Temperature of 650°C is reached. It was stated by ONR, that as

part of the response to Fukushima, the severe accident management procedure will be reviewed and any required improvements implemented. For Magnox and AGRs, no such transition criteria exists.

The SAG for Magnox plants were last reviewed in 2005. The suite of SBERGs are station specific and are to be reviewed and extended as part of the post Fukushima enhancement plan. For EDF NGL plants the Severe Accident Guidelines which are in two separate volumes and are generic across the Advanced Gas-cooled Reactor fleet were last reviewed in 2009. The SBERGs are maintained in the Engineering Change process.

Following the visit at the plant it appears that the SBERGs and SAGs need further development to be in line with international standards. This is supported by an ONR finding.

All of the UK licensees are confident that they have robust arrangements for dealing with design basis accidents at their NPPs. They have confidence in extendibility of the arrangements into beyond design basis / severe accident conditions for full power states and low power and shutdown states. However SAGs are currently not available for shutdown/maintenance stages. This is to be addressed by the licensees in response to ONR's recommendation.

It is recognised by that ONR that training and exercises relating to beyond design basis faults should be improved. SBERGs and SAGs are not being fully exercised. In this regard, development and use of advanced simulation methods applicable for severe accidents may be considered.

4.2.1.3 Hardware provisions for severe accident management

The licensees have a number of beyond design basis containers that contain a range of mobile equipment and materials that could be beneficial when responding to a beyond design basis accident. These containers are located remotely off site at a central UK location and are available to be transported to an affected site within a ten hour timeframe following declaration of an off site nuclear emergency.

The gas reactors (AGR and Magnox) do not have a separate containment buildings. For the current operational UK gas reactors, the final containment is a large concrete pressure vessel. For these reactors the timescales under which severe accident damage occurs is greater than for light water reactor designs, thus offering convenient time margins for recovery actions. The primary focus for accident management is provision, restoration and maintenance of core cooling capability, which also support pressure vessel integrity.

The issue of potential risk of hydrogen and other flammable gases was extensively discussed during the country visit with the conclusion, that this issue is much less sensitive than in the case of PWR. There are several reasons for this conclusion. First of all, due to the combination of cladding material (stainless steel) and coolant (carbon dioxide) there is no source of hydrogen in the reactor core and production of flammable gases can only start after core relocation and interaction of molten corium with concrete. Even in this case, the external building is not designed to provide containment and the vent routes connect directly the reactor to the external atmosphere. The issue is whether these vent routes could fail in such a way that gas is discharged into an enclosed space containing air, and this is judged to be unlikely. In addition, large quantities of inert gas, such as carbon dioxide or nitrogen, would be used to try and cool the core. These will mix with any flammable gases produced and reduce the likelihood of combustion. Accident management of a molten-fuel-concrete interaction requires ducting the off-gas through a filter. The SAGs advise that both the off-gas and the filter must be cooled. This may remove any tendency for the gas to auto-ignite. The further advice is that downstream of the filter, the gas may need to be 'flared'.

In addition, there is currently a study of the possible sources of combustible gases, their categorisation and an evaluation of the hazard being carried out. Arrangements for venting, or other methods of dealing with the flammability hazard are being reviewed and their adequacy re-assessed. This assessment allows for the probability of the accident in which the CO is formed. The large thermal inertia of gas cooled reactors and massive concrete structure beneath the reactor core contribute to the fact that potential damage of the molten corium can happen only after reasonably long time. Nevertheless, there are some provisions in place to mitigate/reduce releases into the environment in such case, including the aim to seal potential leakage paths and to get as much water and concrete into the areas around the bottom of the reactor as possible. This would include all rooms under the vessel and encasement of the gas circulators if they were no longer operable. The reactor is fitted with an

iodine absorption plant that may be used to remove radioactive iodine from the primary circuit gas and can, therefore, mitigate releases to the environment to some degree. However this system is only designed for DBA and is not comparable to a filtered venting system.

Provisions available for mitigation of severe accidents in case of Sizewell B PWR unit were also broadly discussed during the country visit and sufficient explanation was provided by the ONR staff. It was confirmed that Sizewell B has no specific design provisions for the mitigation of hydrogen generated in severe accident conditions. Two hydrogen recombiners are fitted that were designed for design basis accident generation rates and amounts of hydrogen. Therefore, these recombiners are of limited use during a severe accident in managing the hydrogen concentration, and, consequently, the severe accident analysis does not claim any benefit from these. The hydrogen purge system, which provides a diverse means of reducing hydrogen concentrations in design basis accidents, provides a means of connection to the emergency exhaust heating, ventilation and air conditioning system and could potentially be used to vent hydrogen from containment under severe accident conditions, however, restrictions on allowed upper hydrogen concentration and the fact that the fluid from the containment atmosphere would contain significant amounts of steam at high temperature and possibly aerosols would significantly limit the use of this route to vent hydrogen from the containment atmosphere during severe accident conditions. This route of hydrogen concentration control is, therefore, not claimed in the severe accident analysis.

Therefore, in spite of the fact that the Sizewell B containment is large and hydrogen burning was proved not to cause unacceptable containment pressure rise, a work package is being planned by the licensee to mitigate against the effects of beyond design basis accidents involving combustible gases (H₂) by installing passive autocatalytic hydrogen recombiners. It is suggested that the work package also includes a study of potential penetration of hydrogen into spaces adjacent to the primary containment, where hydrogen could be accumulated.

Sizewell B has no dedicated system for RCS depressurisation under severe accident conditions, instead depressurization is ensured by means of the pressurizer relief valves. Attention should be paid to the fact that DC power is needed for this mode of depressurization, which should be ensured with high reliability. This issue was discussed with ONR during the country visit. It was stated that the pressurizer valves are operable when the low voltage essential electrical system is operating, hence, would be available as long as the battery charging or essential diesel generators (BCDGs & EDGs) are operating. In the event of a complete failure of the BCDG system as well as the 3.3kV diesel backed essential electrical system, electrical supply to the valves is battery backed for a minimum of 2 hours. In addition, as it was stated by the ONR, for Sizewell B the threat to containment from HPME is small mainly due to the size and strength of the primary containment building.

In the plant design the licensee considered that the size and robustness of the containment provide sufficient time margin (about two days) against long term overpressurization and no special overpressure protection was installed except standard containment spray system. In view of the lessons learned from Fukushima, installation of a filtered containment venting system is considered by the licensee. This is important, since ex-vessel phenomena with molten corium-concrete interaction can not be ruled out with the present accident mitigation strategy. Leakage or release from the Sizewell B containment building is captured within the outer non pressure resistant shell and the adjacent buildings. This can be processed to some degree by the building ventilation system. However, this method is not comparable to a filtered venting system.

Regarding molten corium stabilization the ONR stated that flooding the reactor cavity will assist in cooling the core. Analysis performed is conservative by not claiming any mitigation, however the severe accident management does involve flooding the cavity prior to vessel failure which will remove heat from the core and thus act to delay vessel failure.

For the PWR containment protection equipment, essential Instrumentation and Control (I&C) needed for accident management is powered from the Essential Electrical System (EES); during SBO scenarios the I&C systems can be powered by the battery charging DGs. No instrumentation is specifically designed for the severe accident analysis apart from the ability to monitor containment pressure. EDF NGL judges that containment pressure indication will be present post-fault provided that low voltage essential power is available.

The review team supports plans of the licensee to strengthen containment robustness in case of severe accidents and suggest that the assessments also cover more comprehensively the issues of survivability

of the relevant instrumentation, containment isolation systems and molten corium stabilization outside the reactor vessel.

4.2.1.4 Accident management for events in the spent fuel pools

AGR fuel route facilities are located in a central block between the reactors, and transfer of fuel assemblies is achieved by means of a fuelling machine. There is a single fuelling machine that serves both reactors at each AGR plant.

When an irradiated fuel stringer (an assembly that includes a number of AGR fuel elements) is discharged from the AGR, it is placed in a sealed Buffer Storage Tube (BST) to decay for a number of months before being disassembled and the fuel elements discharged to the fuel pond. The BSTs are cooled by water jackets and therefore they can undergo loss of cooling faults that could possibly result in fuel pin failure and / or damage to the fuel assembly. With peak stringer decay heat, stagnant BST water jacket boil off would take at least 24 hours. However for average decay heat fuel assemblies, it would take several days for the BST water jacket to boil dry. With no cooling and no intervention, the seals on the BST would eventually fail.

There are no specific plant arrangements in place to mitigate flammable gas (hydrogen and carbon monoxide) risks in the region of an AGR pond because the pin power densities are too low to require this. Also the cladding material (stainless steel) is much less vulnerable to oxidation by steam in comparison with zirconium alloys used for PWR fuel. The main hazard in this case is the loss of radiation shielding provided by the water and accident management is focused on prevention of loss of coolant inventory from the pond.

At Sizewell B, there is no design or operational provisions in the fuel building for the management of hydrogen generated by zirconium oxidation; caused by overheating fuel in the fuel storage pond. For recovery actions to be successful, they would be needed before this point is reached.

Restoration of water level at AGR or PWR fuel pond only provides mitigation where the loss of water is due to boiling off, or from limited leakage in the civil structure. In the event of a large breach in the civil structure, water that is added would be lost immediately and water cover could not be restored.

4.2.1.5 Evaluation of factors that may impede accident management and capability to severe accident management in multiple units case

The risk that a site may be physically cut off by flood water or damaged or blocked roads following, for example, a storm or earthquake has been considered. Many of the sites have a single approach road; however, there are others with several access routes. Wylfa is dependent on two bridges that join the island of Anglesey and the mainland.

Several sites are reviewing their access to the site as they are concerned that access roads may become difficult for conventional vehicles (e.g. in a flood, heavy snowfall). All sites have areas where helicopters could land if that proved to be the only means of accessing the site following an event. In addition, all the currently operational UK NPPs are on the coast and therefore access by sea may be useful in the long term if the local road infrastructure is not usable. However at most sites, there are no quays installed to permit landing of heavy equipment.

The licensees use a wide range of communications systems and it is unlikely that they would all be affected in any reasonably foreseeable event; the diversity in itself provides resilience. The licensees are reviewing communications systems in the light of the Fukushima event in an attempt to identify the need for increased levels of resilience in this area. (for example; distribution of satellite telephones).

Most of the UK nuclear power stations are twin reactor design. As part of the safety case for each power station, the effect of neighbouring facilities has to be considered. This effect is not always a negative; some positive arrangements for use of the neighbouring facilities in emergencies, are included in emergency plans. However, the review team believes that more comprehensive assessment is appropriate in order to take into account accident affecting multiple units at the same time, taking into account the need to perform actions under conditions of severely damaged infrastructure.

4.2.2 Margins, cliff edge effects and areas for improvements

4.2.2.1 Strong points, good practices

AGR and Magnox reactors have a low power density compared to Light Water Reactors (LWRs) and therefore the timescale for most of the DBA accident sequences are much longer allowing more time for intervention than for LWRs.

For AGRs, the Pre-Stressed Concrete Pressure Vessel (PCPV) is at least 3 m thick (even 6 meter for the basemat) with a steel liner and operates at 40 bars. In case of overpressure faults, the PCPV is protected by a number of safety relief valves (and their filtered discharge routes). Heat transfer between fuel and boiler uses carbon dioxide gas which does not undergo a phase change in case of depressurisation fault (like for LWRs). For AGRs, as long as pressure can be maintained within the PCPV and even with only one boiler available, the residual heat can be removed from the core through natural circulation.

The PSA that has been produced for Sizewell B is a full scope Level 3 PSA. The PSA addresses all modes of operation of the plant (full power, low power and shutdown modes), internal initiating events, and internal and external hazards.

Approximately ten years ago the licensees established a number of beyond design basis containers that contain a range of equipment and materials that could be beneficial when responding to a beyond design basis accident. These containers are located remotely offsite at a central UK location, available to be transported to an affected site within a ten hour timeframe following declaration of an off site nuclear emergency. In addition, Magnox Ltd has some containers located near their Wylfa site as there was a concern regarding access to the site's island location should the main access bridge fail. All containers and their contents are maintained regularly, and their deployment has been exercised. It is the CESC team's responsibility to mobilise these trailers should they be required; most sites would be reached within two to four hours provided that the local site infrastructure is not significantly degraded.

4.2.2.2 Weak points, deficiencies (areas for improvements)

The PSAs produced for Magnox reactors and AGRs are still considered hybrid Level 1 PSAs by ONR and not full Level 2 PSA. Consequently no examples were provided during the review of improvement to Severe Accident Management coming from Level 2 PSA results. This is recognised by ONR to be an area of further improvement when compared to best international standards and ONR's own PSA guidance.

Following the visit at the plant it appears that the SBERGs and SAGs need further development to be in line with international standards.

It is recognised by ONR that training and exercises relating to highly unlikely beyond design basis faults could be improved. SBERGs and SAGs are not being fully tested and exercised. Before they commence down this route they need to review the SBERGs and SAGs in the light of any new arrangements and / or facilities that are being provided following the stress tests process and the ONR's Chief Nuclear Inspector's final report.

ONR is concerned that a severe external hazard could impact upon the structures, systems and components needed in the response to an accident. The Chief Nuclear Inspector's final report also expressed a concern that coincident damage at both the nuclear facility and the off site centre may be possible and should be considered by the licensees. These facilities, and on site command centres, should be capable of operating adequately in the conditions, and for the duration that they will be required, even in severe accident conditions. There is also no full-scope Backup Control Room allowing control and shutdown to safe condition of the plant if the MCR become inhabitable, although Sizewell, Heysham 2 and Torness AICs have a limited capability. The reviews offered by the licensees should address these concerns.

Severe accident hydrogen and carbon monoxide (CO) generation and associated risk were not considered in gas reactors when they were designed. In the 1990s, the Magnox and AGR SAGs included a discussion on the risk of hydrogen generation in pressure vessel due to water ingress at very high temperature faults, and highlighted the risk of hydrogen burning or exploding if it is released from the reactor into the reactor building. Hydrogen build-up in a gas reactor building is possible in

the event of gas release from pressure vessel penetrations, but this will be mixed with carbon dioxide and, to some extent, carbon monoxide. The ONR requested that EDF NGL review the flammability and explosive hazard relating to the generation of carbon monoxide (CO) during a beyond design basis event.

In a loss of primary coolant accident, the depressurising AGR reactor still has relatively good heat transfer from the core and, therefore, the vessel, in severe conditions, would fail by creep rupture before gross fuel damage occurred.

In an AGR severe accident when core cooling is lost and if air enters a hot core there is a potential for oxidation of UO_2 to U_3O_8 . During the country visit EDF stated that limited modelling shows that accident management is feasible and if SAGs were followed it would alleviate consequential fission product release. The peer review suggests that this scenario requires further investigation.

For the AGRs, the discrepancies regarding MCCI and time estimate for basemat/vessel failure between the licensees (a few weeks) and ONR (a few days) needs to be explored and detailed analyses are needed in that field. The situation regarding penetration existing at the bottom of the PCPV is also not homogeneous over all AGRs and Magnox (Wylfa and Dungeness have penetration for example). This would have a significant influence during MCCI and could lead to earlier vessel failure.

In the UK, there are currently no specific accident guidelines for severe accidents involving the fuel route and ponds. The fuel uncover event is considered to be primarily a hazard because of loss of shielding of radiation from the fuel, rather than one of severe damage to the fuel. An ONR finding has placed a general requirement on licensees regarding fuel route severe accidents.

The severe accident analysis, presented in the Sizewell B safety case, considers the potential for hydrogen burns and deflagration in the containment during each phase of a severe accident. The licensee and regulator concluded that for DBAs hydrogen presents little risk to containment structural integrity and therefore the site has limited hydrogen mitigation provisions in the form of a small number of recombiners within the containment building. Enhanced measures to address severe accidents are planned.

At Sizewell B there is no design or operational provisions in the fuel building for the management of hydrogen generated by zirconium oxidation by overheating fuel in the fuel storage pond.

Sizewell B PWR does not include specific reactor pressure vessel depressurisation design provision but EDF NGL states that emergency procedures should result in pressure being reduced and cold borated water being injected into the core in a beyond design basis fault; therefore, the threat to containment integrity from High Pressure Melt Ejection (HPME) is small. This is only true if cold borated water can be injected in any case also against high pressure in the RPV. This would require essential electrical power.

4.2.3 Possible measures to increase robustness

4.2.3.1 Upgrading of the plants since the original design

As part of the PSRs, safety improvements have been implemented on all UK's NPPs. As an example, at Hartlepool power station it was identified that during a seismic event the 440V batteries could be damaged by the adjacent 50V batteries. In order to address this a new seismically qualified stand was installed.

4.2.3.2 Ongoing upgrading programmes in the area of accident management

UK licensees participate in the continuous improvement programmes arising from their membership of WANO. In normal circumstances, feedback from WANO peer reviews and evaluations required by WANO is not made available to ONR or other national regulators and such feedback is not requested. In light of the extraordinary circumstances of the Fukushima event, the output from the WANO sponsored evaluations from the major NPP licensees was voluntarily made available to ONR.

4.2.4 New initiatives from operators and others, and requirements or follow up actions (including further studies) from Regulatory Authorities: modifications, further studies, decisions regarding operation of plants

4.2.4.1 Upgrading programmes initiated/accelerated after Fukushima

Concerning Post Fukushima Stress Tests, 18 Stress Tests Finding (STF) have been identified by ONR, four of them directly related to severe accident. A number of reviews are being proposed by the nuclear licensees to consider how lessons identified from Japan and credible beyond design basis events can be reflected in facilities, procedures, training and exercise programmes. For example, EDF NGL is using experience from other response organisations and the military; from this they will consider enhancements to staff welfare, human factors and emotional aspects associated with emergency response. Some specific enhancements are already being considered, for example the provision of a hardened Emergency Control Center at Sizewell B.

Sizewell B has some design features that would limit the occurrence of over-pressurisation of the containment. It was confirmed during the country visit that EDF NGL (the licensee) will install a filtered containment venting system and passive autocatalytic hydrogen recombiners as part of SAM improvement measures. In addition, EDF NGL will consider a flexible means of injecting water into the containment using portable external equipment. This is also reflected in on the ONR findings.

Analysis of the Fukushima accident by EDF NGL has shown that for light water reactors it may be necessary to get additional emergency equipment onto site very quickly. Consequently, the licensee is reviewing the need for the provision of dedicated beyond design basis containers close to or located on the Sizewell B site.

EDF NGL and Magnox Ltd have concluded that further mitigation against beyond design basis accidents could be provided by additional emergency back up equipment. This equipment could be located at an appropriate off site location close to the station to provide a range of capability to be deployed in line with initial post event assessment.

EDF NGL and Magnox's individual stress tests reports indicate that consideration is to be given to improving the resilience of its existing equipment and critical supplies in the context of additional emergency back up equipment. This is reflected in one ONR finding.

ONR is aware that provision of satellite telephone communications equipment is being considered; however, if this route is followed then agreement will be required from all parties involved in accident management otherwise enhanced communications by this means cannot be guaranteed.

It is recognised by the licensees that it would now be appropriate to review the SBERGs and SAGs, and to follow this up with appropriate training in their use. Licensees have recognised that more people would benefit from training in the use of SAGs and they intend reviewing the adequacy of training and the feasibility of implementing the advice in real scenarios.

HM Chief Inspector's final report recommended that the UK nuclear industry should review, and if necessary extend, analysis of accident sequences for long term severe accidents. It is also stated that the nuclear industry should ensure that adequate Level 2 PSA is provided. A key intent of these recommendations is to inform potential improvements to severe accident management measures through a better understanding of severe accident progression and mitigation. It is expected by ONR that the SBERGs and SAGs will need to be revised to take account of developments in this area. It is also expected that revision will be required to cover the additional equipment that is likely to be available in the emergency containers. This is reflected in one ONR finding covering improvement of SBERG and SAGs.

4.2.4.2 Further studies envisaged

How the pilot PSA studies [Level 2 PSA; Fire PSA; Shutdown PSA] and the insights from them are taken forward across the AGRs fleet is currently being determined by the licensee and discussed between EDF NGL and ONR.

The licensees will consider further resilience enhancements to communications equipment and associated critical supplies arising from their stress tests reviews.

The potential explosive hazard arising from the production of CO during a severe accident is not currently fully understood and ONR has already requested that EDF NGL investigate this hazard further.

AGR pressure vessel basement melt through is predicted to take weeks; however, this assumes a three metre thick floor. In reality, many reinforced tendon ducts exist within the floor and melt through to these may be of the order of days rather than weeks. This leads to one ONR finding on prestressed concrete pressure vessel containment capability in severe accident conditions.

4.2.4.3 *Decisions regarding future operation of plants*

ONR believes that the current resilience, response and emergency arrangements are robust for design basis faults and they are extendable. No unanticipated cliff edge effects have been identified. However, further review beyond the design basis is encouraged so that additional, reasonably practicable enhancements may be identified and, when justified, implemented. This should result in enhanced margin in beyond design basis situations. At meetings with ONR, EDF NGL has stated that they will implement identified modifications by the end of 2014. Magnox Ltd is planning to implement its enhancements in an even shorter timescale due to the stage in the lifecycle of the Magnox sites. ONR expects to see programmes for the reviews and delivery of improvements so that a clear end date is defined and can be monitored against. This leads to one ONR finding dealing with the improvement of emergency facilities and arrangements.

4.3 Peer review conclusions and recommendations specific to this area

Importance of the SAM has been recognized in the UK as an important component of the defence in depth. Safety assessment principles and associated TAGs provide for adequate regulatory control over this area. Analyses of severe accidents have been performed for all operating reactors in the UK. Emergency arrangements are in place to address severe accidents. These are mostly established in accordance with the principles of self sufficiency of the licensees in emergencies. SBERGs and SAGs have been developed for all plants.

Accident management for gas cooled reactors represent a special case due to their unique design features, in particular absence of a separate containment building and very large thermal inertia. This large inertia provides comfortable time margins for performing recovery actions. Many severe accident challenges to confinement integrity such as hydrogen explosion, high pressure melt ejection, steam explosion and direct containment heating are not present. The majority of accident management measures are focussed either on prevention of severe accident e.g. protection of reactor pressure vessel integrity, or to measures for mitigation of releases in the case of loss of vessel integrity.

In spite of the robustness of the plants (in particular gas cooled reactors) against progression of an event into a severe accident, hardware provisions are being implemented in order to further strengthen plant capabilities to prevent unacceptable consequences.

Importance of further plant enhancements was also expressed in several specific ONR's stress tests findings. These include: addressing emergency facilities and arrangements, SBERGs and SAGs, long term behaviour of concrete under severe accident condition (for gas cooled reactors), and installation of filtered venting system and passive autocatalytic recombiners and additional sources for injecting water (in Sizewell B).

There are a number of provisions, many of them already considered by the licensee and the ONR, which are appropriate to be listed below:

- The current accident management arrangements seem to be structured and adequate to cope with accidents with different levels of severity. In accordance with the existing plans, the on-site emergency facilities should be strengthened in order to be resistant against external hazards and provide for working conditions in case of severe accident. A more comprehensive assessment is also needed regarding the occurrence of severe accident at multiple units and conditions of severely damaged infrastructures.
- The need for a backup control room providing for shutdown and cooldown to safe condition of the plant should be considered.

- The SBERGs and SAGs should be further developed to cover fully all spectrums of accident scenarios, including plant shutdown conditions. Training and exercises for implementation of the procedures should be improved.
- Radiation conditions which may potentially develop on site in case of severe accident, possibly at several units, should be more comprehensively analysed and appropriate measures to address them implemented.
- The existing plans to strengthen hardware provisions for SAM in all reactors, but in particular in Sizewell B, are supported by the review team. It is advisable to take into account the need for operability of newly installed equipment under conditions of extreme external hazards and prolonged SBO. Provisions for ensuring sufficient coolant inventory in the SFP should be further strengthened by providing e.g. additional delivery of coolant from external sources.

Acronyms

AGR	Advanced Gas-cooled Reactor
ALARP	As Low As Reasonably Practicable
BST	Buffer Storage Tube
BUECW	Back-Up Essential Cooling Water
BUFS	Back Up Feed System
CEGB	Central Electricity Generating Board
CESC	Central Emergency Support Centre
DB	Design Basis
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DBF	Design Basis Flood
ECC	Emergency Control Centres
ECW	Essential Cooling Water
EDF	Electricité de France
EDF NGL	EDF Energy Nuclear Generation Ltd
EDG	Emergency Diesel Generator
ENSREG	European Nuclear Safety Regulators Group
IAEA	International Atomic Energy Agency
IFDF	Irradiated fuel dismantling facility
IPSART	International PSA review team
LOOP	Loss of off-site power
LWR	Light Water Reactor
MCR	Main Control Room
MCW	Main cooling water
NPP	Nuclear Power Plant
ONR	Office for Nuclear Regulation (formerly the Nuclear Directorate of the HSE)
OPEX	operational experience
PCPV	Pre-Stressed Concrete Pressure Vessel
PGA	Peak ground acceleration
PSA	Probabilistic Safety Assessment
PSR	Periodic Safety Review
PWR	Pressurised water reactor
RHRS	Residual Heat Removal System
RUHS	Reserve Ultimate Heat Sink
SAG	severe accident guidelines
SAP	Safety Assessment Principle(s) (HSE)
SBERG	Symptom Based Emergency Response Guidelines
SBO	Station blackout
SHA	Seismic Hazard Analysis
SHWP	Seismic Hazard Working Party
SOI	Station operating instructions
SSCs	structures, systems and components
STF	Stress tests finding
TAG	Technical Assessment Guides
UHS	Ultimate Heat Sink
UK	United Kingdom
URS	Uniform risk spectra
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators' Association