



Japanese Earthquake and Tsunami: Implications for the UK Defence Nuclear Programme

A Regulatory Assessment by the Defence Nuclear Safety Regulator

July 2012

Not Protectively Marked

This page is deliberately blank

Not Protectively Marked

Executive Summary

Following the events at Fukushima, Japan, on 11 March 2011, the nuclear industry throughout the UK responded quickly to review both its civil and defence facilities against seismic and flooding hazards, under the direction of the respective Regulators for these sectors. The Defence Nuclear Safety Regulator (DNSR), as the MOD regulator for both the Naval Nuclear Propulsion Programme and the Nuclear Weapon Programme, has a key role in regulating nuclear safety at UK defence sites and for defence assets and is the competent regulatory authority for the design of both naval reactor plant and nuclear weapon.

As a first response within the UK's Defence Nuclear Programmes (DNP), DNSR sought reassurance that operations remained safe, and requested Authorisees¹ to respond to the same initial four questions that the Office for Nuclear Regulation (ONR) asked of the UK's nuclear licensees. The responses provided by authorisees allowed DNSR to advise in May 2011, that there was no evidence to undermine the continued safe operation of the nuclear powered (and including nuclear armed) submarine fleet, or land-based nuclear activities supporting the DNP in the UK.

In the subsequent months, DNSR continued to work with Authorisees, and alongside ONR, to ensure that the DNP's response was consistent with that in the civil sector in the UK, in accordance with Secretary of State for Defence's policy requiring "equivalent arrangements". This process led to DNSR requesting all Authorisees to undertake two specific actions: to conduct a programme of "Stress Tests" based on those developed by the European Nuclear Safety Regulatory Group (ENSREG), and to respond to the Recommendations made by ONR within HM Chief Inspector of Nuclear Installations' Interim Report. When both requesting and assessing DNP Authorisees' responses to these actions, DNSR recognised the differences between the defence and civil sectors, and sought evidence that the approaches adopted by Authorisees had been appropriate to identify all the "lessons to be learned" from the underlying accident causes and effects rather than focusing too narrowly on the specific events at Fukushima.

Publication of this report demonstrates DNSR's commitment to be open and transparent in its regulatory activities, subject to normal national security considerations. The study of the Fukushima event has brought forth lessons for the whole nuclear industry, from designers to operators and regulators. Many of these lessons are, and will be, long term and cannot be implemented within a year long time frame. DNSR identifies in this report areas where recognition of lessons from the event will continue to influence DNSR's and Authorisees thinking. Whilst DNSR does not intend to routinely publish further updates on the DNP response the present report should not be seen as "closure" of lessons from the Fukushima event. DNSR will continue to engage with Authorisees to gain assurance that lessons are appropriately monitored and acted upon.

The work undertaken by Authorisees in response to the Stress Tests has not identified any major issues; having reviewed this work DNSR concurs with this conclusion. For the sites providing support to the Navy's submarine fleet, a significant factor in reaching this conclusion is the inherent robustness and Defence in Depth within the Naval Reactor Plant (NRP) itself. The NRP is designed for prolonged periods of autonomous operation at sea with no external support, and is required to perform all of its functions in potentially hostile military and marine environments. This endows it with unusual resilience against external hazards of the kind which initiated the Fukushima event. When berthed alongside, the NRP places very little demand on shore facilities, and whenever NRP systems need to be taken out of service alongside, robust procedural controls ensure that sufficient back up systems are in place, be they on-board or shore facilities. Similarly, the Nuclear Warhead (NW) is inherently robust with multiple Lines of Defence, and is designed to withstand launch and re-entry environments.

Following events at Fukushima, the DNP Authorisees have concluded that it is safe to continue their current operations and that risks are still controlled and minimised so far as is reasonably practicable. Having reviewed the reports produced by the Authorisees, DNSR is satisfied with these findings, and that the DNP are safe to continue to operate.

The Authorisees have reported that generally, all of their facilities have been designed or assessed against an appropriate set of Design Basis Events, whose derivation is consistent with the civil sector. DNSR agrees

¹ Under MOD regulation, Authorisees are the equivalent of Licensees; DNP contractors (AWE, BAES, Babcock) are both Licensees and Authorisees because they conduct some licensable activities and some that are exempt from licensing.

that no obvious deficiency in estimating design bases of the kind identified at paragraph 3.14 relating to the Fukushima event has become evident. The seismic design basis for UK nuclear installations is not undermined by the Fukushima event (see paragraph 6.2). The thorough application of Periodic Review of Safety (see paragraph 3.15 and Conclusion 2) and Continuous Improvement processes will ensure that the extant safety cases are up to date and take account of modern standards. When coupled with the robustness of the NRP and the NW, this results in good performance against the Stress Tests. Nevertheless, Authorisees are committed to the principle of continuous improvement and to assess the lessons from Fukushima and the application to their nuclear operations; this work will be pursued robustly by DNSR.

The ONR Recommendations were collated and presented under the headings of “General”, “Relevant to the Regulator” and “Relevant to the Nuclear Industry”. Many of these Recommendations relate to long term objectives of ensuring that all potential lessons are learned and acted upon. Having reviewed Authorisees initial responses (in the “General” and “Industry” categories), DNSR is broadly satisfied with the proposed forward actions, and will monitor progress against these as part of its normal regulatory processes.

For those ONR Recommendations under the heading “Relevant to the Regulator”, DNSR intends to continue its existing arrangements of working alongside ONR in the development of regulatory policy, and to ensure an appropriately consistent approach.

The majority of lessons identified for further consideration have resulted from the requirements for Authorisees to review their Severe Accident Management arrangements on a deterministic basis, assuming progressive loss of each protective measure. DNSR considers that there are potential gains from development, sharing and implementation of relevant good practice across the DNP, and that consequently, further “*Considerations*” (see Glossary and paragraph 3.10) to those already presented by Authorisees may be identified. DNSR will pursue this with Authorisees as part of his future intervention strategy.

Nuclear Operators and Regulators internationally are examining accepted good practice regarding their emergency arrangements in light of the Fukushima event. DNSR expects DNP Authorisees to be actively involved in this process to capture appropriate lessons learnt and best practices..

DNSR will ensure that the opportunity is not lost to identify and act on appropriate lessons which might affect the design of the next generation of nuclear submarine reactors while this is still at the design stage.

Contents

0. GLOSSARY AND ABBREVIATIONS	7
1. PURPOSE AND SCOPE	12
2. UK DEFENCE NUCLEAR PROGRAMMES	13
Introduction.....	13
The Naval Reactor Plant	13
The Nuclear Weapon.....	14
3. RELEVANT ASPECTS OF DNSR REGULATORY REGIME	15
MoD Regulation of Defence Nuclear Programmes	15
Authorisation.....	15
ALARP and Continuous Improvement	15
Safety Cases.....	16
Periodic Review of Safety.....	17
Regulation of New Reactor Designs	18
4. THE FUKUSHIMA ACCIDENT	19
The Tōhoku Earthquake and Tsunami	19
Effects at Fukushima Dai-ichi.....	19
5. MOD RESPONSE	21
Initial Reassurance Sought from Authorisees.....	21
Stakeholder Management.....	21
Expectations Placed on Authorisees	22
Engagement with ONR.....	24
6. STRESS TEST ASSESSMENTS	25
Introduction.....	25
General Discussion of Stress Test Aspects	25
AWE	31
Vulcan.....	31

BAES Barrow	31
Devonport	32
Clyde	33
NRPA	33
Navy Command	34
Transport	34
New Designs	35
7. RESPONSES TO ONR RECOMMENDATIONS	36
Recommendations Relevant to Authorisees	36
Recommendations Relevant to the Regulator	37
8. CONCLUSIONS	40
9. REFERENCES	42
10. WEB-LINKS	42
APPENDIX A – UK DEFENCE NUCLEAR PROGRAMME ARRANGEMENTS	43
The Nuclear Weapons Programme	43
The Naval Nuclear Propulsion Programme	43
NNPP Organisations	45
APPENDIX B – ONR REPORT RECOMMENDATIONS	48
APPENDIX C – ENSREG STRESS TEST SPECIFICATIONS	57

0. Glossary and Abbreviations

A summary of some of the terms and acronyms used in this report is provided below.

ALARP	As Low As Reasonably Practicable (see SFAIRP).
Authorisation Condition (AC)	Regulatory requirements applied by DNSR to Authorisees – these mirror the License Conditions applied by the statutory regulator.
Authorised Site	A defined location within which nuclear activities are controlled by an Authorisee in compliance with the Authorisation Conditions and Further Authorisation Conditions.
Authorisee	The individual authorised to operate in compliance with the Authorisation Conditions and Further Authorisation Conditions.
AWE	The Atomic Weapons Establishment (AWE) provides and maintains the warheads for the Nuclear Weapons which comprise the UK's nuclear deterrent.
BAES Barrow	BAE Systems (BAES) is contracted by the MoD to build and commission nuclear submarines, including the nuclear reactor used for propulsion. The work is undertaken at Barrow-in-Furness.
Consideration	An indication of how the Authorisees currently plan to take forward potential improvements into a decision making process.
Continuous Improvement	The principle that standards of nuclear safety are expected to improve on an ongoing basis.
Creative Review	A term used by DNSR to reflect an expectation that, in learning the wider lessons from Fukushima, imagination needs to be applied to the consideration of potential fault sequences and their consequences. (See paragraph 5.22)
Critical Safety Functions (CSF):	Critical Safety Functions are those identified as being particularly important in preventing significant radiological consequences. For the NNPP, four CSFs have been identified: control of reactivity; control of core temperature; control of release of radioactive material; and control of radiation exposure.
Decay Heat	Decay heat is thermal energy that continues to be released following reactor shutdown as a result of radioactive decay.
Defence in Depth	This is the fundamental basis of a modern standards Safety Case, and seeks to compensate for potential human and mechanical failures, based on adopting a hierarchy of multiple measures aimed at prevention, protection and mitigation of all challenges to the CSFs (see also Diversity and Redundancy).
Design Basis	The range of conditions and events taken explicitly into account in the design of a facility, according to established criteria, such that a facility can withstand them without exceeding authorised limits by the planned operation of safety systems.
Design Basis Earthquake (DBE)	Current practice at Authorised Sites is to derive a DBE seismic event which conservatively has a frequency of occurrence no greater than once in ten thousand years.

Design Basis Event	A fault or hazard (manmade or natural) which is considered as within the design basis of the facility or system, on the basis of frequency and consequence. Both the derivation and assessment of Design Basis Events use deterministic principles (as opposed to probabilistic).
Design Basis Flood (DBF)	Current practice at UK DNP facilities is to derive a DBF extreme high water level which conservatively is exceeded at a frequency no greater than once in ten thousand years.
Devonport, and DRDL	The Devonport site at Plymouth on the south coast of England consists of two parts: Devonport Royal Dockyard Ltd., (DRDL) and Her Majesty's Naval Base, (HMNB) Devonport. DRDL is the site licence company for that part of the site owned and operated by the Marine and Technology Division of Babcock International Group, for which ONR regulates day to day site nuclear safety. DRDL is contracted by MoD to refit and maintain the Royal Navy's nuclear powered submarines, and is consequently authorised by DNSR for its activities affecting through life reactor plant safety. The Naval Base (HMNB Devonport) is the base port for the UK's fleet of Trafalgar Class submarines, providing facilities for operational maintenance, together with the shore support services required by the submarine and crew, and is managed by MoD under the control of the Naval Base Commander. HMNB Devonport is authorised by DNSR for its activities affecting nuclear safety.
DHR	Decay Heat Removal.
Diversity	The presence of two or more systems or components to perform an identified function, where the systems or components have different attributes so as to reduce the possibility of common cause failure, including common mode failure.
DNP	Defence Nuclear Programmes – this phrase includes the Nuclear Weapons Programme (NWP) and the Naval Nuclear Propulsion Programme (NNPP).
DNSR	Defence Nuclear Safety Regulator
DSEA	Defence Safety & Environment Authority. The DSEA was created in February 2012, as part of MoD's response to one of the Key Recommendations in the Haddon-Cave Nimrod Inquiry, that in order to avoid a conflict of interest, those responsible for the regulation of safety should be independent of those responsible for delivering output. DNSR was recently transferred into the DSEA.
DSMP1	Dounreay Submarine Prototype Reactor 1 – DSMP1 was the test facility for the NRP installed in earlier classes of submarine. This reactor has been decommissioned and defueled, and is awaiting dismantling.
Duty Holder	Within the DNP, this is a person who has direct responsibility for, and control of, activities that influence, directly or indirectly, the safety of the Programmes.
EHJ	The Explosives Handling Jetty facility at RNAD Coulport.
ENSREG	European Nuclear Safety Regulatory Group. ENSREG is an independent, authoritative expert body created in 2007 following a decision of the European Commission. It is composed of senior officials from the national nuclear safety, radioactive waste safety or radiation protection regulatory authorities from all 27 Member States in the European Union and representatives of the European Commission. ENSREG's role is to help to establish the conditions for continuous improvement and to reach a common understanding in the areas of nuclear safety and radioactive waste management.

Further Authorisation Condition (FAC)	Specific attributes of the DNP and the remit of DNSR require conditions additional to the LCs; hence, four Further Authorisation Conditions (FACs) are also applied by DNSR.
HMNB	Her Majesty's Naval Base
HMNB Clyde	HMNB Clyde is an operational Naval Base on the west coast of Scotland comprising facilities at both Faslane and RNAD Coulport for the berthing and maintenance of nuclear powered submarines when not at sea. The facilities at RNAD Coulport (including the EHJ) are primarily provided for weapons support activities, whereas the facilities at Faslane provide shore support services required by submarines and crew.
HSE	Health and Safety Executive.
HSWA	Health and Safety at Work etc Act, 1974. HSWA is the primary legislation covering occupational health and safety in the United Kingdom. A fundamental feature of the Act is that risk to the workforce and the public is to be reduced So Far As Is Reasonably Practicable (SFAIRP).
IAEA	The International Atomic Energy Agency.
INES	The International Nuclear and Radiological Event Scale – used to describe the safety significance of nuclear and radiological incidents and accidents.
JSP 518	This Joint Services Publication (JSP) defines and promulgates the MoD policy (requirements and guidance) for regulation of the Naval Nuclear Propulsion Programme (NNPP). Those responsible for implementing the programme are to comply with the requirements, and DNSR is tasked with regulating in accordance with the policy therein. Its sister publication, JSP 538 covers regulation of the NWP.
JSP 538	This defines and promulgates the policy for regulation of the Nuclear Weapons Programme (NWP), in a similar manner to that in its sister publication, JSP 518.
Licence Condition (LC)	Regulatory requirements applied by ONR – the equivalent for DNSR are AC and FAC.
Licensed Site	A site in respect of which a Nuclear Site Licence has been granted by HSE under the Nuclear Installations Act 1965 (as amended), whether or not that Licence remains in force.
Licensee	The body corporate that has been granted a Nuclear Site Licence under the Nuclear Installations Act 1965 (as amended), which permits it to carry out a defined scope of activities on a delineated site.
Lines of Defence (LOD)	An approach used to ensure Defence in Depth within the Nuclear Weapons Programme, requiring the presentation of a structured deterministic argument to demonstrate that sufficient protection is provided.
Navy Command	The duty holder for the operational berths used by submarines.
NEAG	Nuclear Emergency Arrangements Group.
NERO	Nuclear Emergency Response Organisation.

Next Generation Nuclear Propulsion Plant (NG NPP):	The UK is currently in the preliminary stages of developing the Naval Reactor Plant to be used in the next generation of submarines.
NNPP	Naval Nuclear Propulsion Programme.
NPP	Nuclear Power Plant.
NPW	Nuclear Powered Warship.
NRP	Naval Reactor Plant – the propulsion plant used within the UK’s Nuclear Powered Warships (NPW). Also referred to as the Nuclear Steam Raising Plant (NSRP).
NRPA	Naval Reactor Plant Authorisee. NRPA discharges both an Authorisee role in ensuring day to day safety of the authorised Naval Nuclear Propulsion Programme (NNPP) activities outside site boundaries, and the role of Approving Authority, to ensure through-life safety of the NRP.
NSRP	Nuclear Steam Raising Plant – see NRP.
NW	Nuclear Warhead.
NWP	Nuclear Weapons Programme.
ONR	Office for Nuclear Regulation – an agency of HSE tasked with regulation of the UK nuclear industry.
OPEX	Operating Experience.
Periodic Review of Safety (PRS)	A comprehensive assessment of the safety case (including equipment and operations) against modern standards to determine whether there are reasonably practicable improvements that could be made, in order to demonstrate that the plant is safe to continue to operate for the next defined period.
PSA	Probabilistic Safety Assessment – Level 1 addresses incident and accident frequency and Level 2 estimates the magnitudes of potential radiological release and consequent dose from improbable events.
Redundancy	Provision of alternative (identical or diverse) structures, systems or components, so that any one can perform the required function regardless of the state of operation or failure of any other.
RRMPOL	Rolls Royce Marine Power Operations Ltd.
SAPs	HSE Safety Assessment Principles.
SDF	The Safety Directors Forum (SDF) is a forum at which UK civil and defence duty holders in the nuclear industry share good practice. The SDF formed a Fukushima Sub-group in response to the events in Japan, in an effort to ensure a comprehensive and consistent response.
Serco RSD	Consultancy providing regulatory support services to DNSR.
SFAIRP	So Far As Is Reasonably Practicable (and the related term As Low As Reasonably Practicable, ALARP): A legal requirement emanating from the Health and Safety at Work etc Act 1974 (HSWA).

SONART	Staff Officer Nuclear Accident Response & Training – provides a central co-ordinating function for MoD exercises and assists Duty Holders with planning and conducting exercises.
STF	Shore Test Facility – a land based reactor at Vulcan NRTE in Dounreay, Scotland, providing technical and safety performance information to support operating submarines.
Stress Tests	The ENSREG Stress Tests are defined as ' <i>a targeted reassessment of the safety margins of nuclear power plants in the light of the events which occurred at Fukushima: extreme natural events challenging the plant safety functions and leading to a severe accident</i> '.
TAG	Technical Assessment Guide – internal guidance documents used by both ONR and DNSR to assist their Inspectors and Assessors in reviewing the adequacy of safety case submissions.
Vulcan NRTE	Vulcan Naval Reactor Test Establishment (NRTE) is located on the north coast of Scotland, adjacent to the Dounreay Licensed Site, and provides a full-scale land-based prototype reactor to aid plant design, research and development, operation and evaluation.

1. Purpose and Scope

1.1 This report presents the findings from DNSR's review of the work undertaken and presented by Authorisees as a near term response to the events surrounding the nuclear accidents at Fukushima in March 2011. The work undertaken by Authorisees is part of a comprehensive response by all the UK's nuclear duty-holders, both civil and defence, which has been co-ordinated and reviewed by the relevant Regulators (ONR and DNSR).

1.2 DNSR requested all Authorisees to follow good practice and provide responses to the same "question sets" applied to the civil industry namely: to respond to the ONR Recommendations within HM Chief Inspector of Nuclear Installations' Interim Report (Reference 1), and to conduct a programme of "Stress Tests" (Reference 2) based on that developed by the European Nuclear Safety Regulatory Group (ENSREG).

1.3 In determining how Authorisees in the Defence Nuclear Programmes (DNP)² should fulfil these actions, DNSR considered the nature of UK defence operations and activities, and the differences compared to the UK civil industry and Nuclear Power Plants and Fuel Storage Facilities at Fukushima. DNSR highlighted to Authorisees that, in light of these differences, their responses would not be directly compared to those in the civil sector, where there were known to be very different drivers. Instead, DNSR stated that it would look for evidence that Authorisees had adopted a wider approach in order to determine all of the "lessons to be learned" from the underlying accident causes and effects, rather than focusing too narrowly on the specific events at Fukushima. Within this report, DNSR refers to this as undertaking "Creative Reviews" (5.22).

1.4 This report is presented in separate sections, as follows:

- Section 2 presents a brief discussion of the sites and facilities supporting the DNP, with further information presented in Appendix A.
- Section 3 explains the background to MoD regulation of Authorisees within the DNP.
- Section 4 provides a very brief outline of the accident at Fukushima, with references and Links³ to publicly available documents providing further detail.
- Section 5 discusses the DNP response in the aftermath of the earthquake in Japan, as the events at Fukushima were still unfolding, explaining how DNSR required all DNP Authorisees to respond.
- Section 6 discusses the findings from DNSR's review of Authorisees' responses to the "Stress Tests", whilst Section 7 briefly discusses the Authorisees' responses to the ONR Recommendations.
- Section 8 discusses the conclusions from DNSR's reviews of the Authorisee responses.
- Sections 9 and 10 provide References and Web-links

1.5 It should be noted that due to the nature of defence operations and the associated security considerations, many of the responses provided by Authorisees contained classified information. In the spirit of openness and transparency, this report has been prepared to not require a security classification such that it can be distributed to the widest possible audience. Whilst this means that, in some areas, the discussions presented herein are necessarily constrained, DNSR has, and will continue to, interrogate the underlying work to an appropriate level of scrutiny.

² The Defence Nuclear Programmes (DNP) include the Nuclear Weapons Programme (NWP) and the Naval Nuclear Propulsion Programme (NNPP).

³ Throughout this report, whenever a "clickable" link is provided to an external publicly available source, the URL for that source is also provided in Section 10, to assist those who only have access to a paper copy of the report.

2. UK Defence Nuclear Programmes

Introduction

2.1 The DNP include the Nuclear Weapons Programme (NWP) and the Naval Nuclear Propulsion Programme (NNPP). The major sites / facilities supporting the DNP covered in this report are:

- AWE;
- Vulcan NRTE;
- BAES Barrow;
- Devonport (DRDL Babcock and HMNB Devonport);
- HMNB Clyde (RNAD Coulport and Faslane).

2.2 Since the realisation of the potential consequences of a nuclear accident stemming from the time of the 1957 Windscale fire there have been developments in expectations, knowledge and safety provisions in both the civil nuclear sector and the DNP. In the last 50 years, the expectation with respect to resilience against extreme natural hazards has increased significantly. This has led to legacy issues at civil nuclear sites as the continuing presence of radioactive material can limit the modifications that can be undertaken to bring the facility up to "Modern Standards". This is less of an issue at UK defence nuclear sites as the nuclear material is generally transportable and can be moved when required.

2.3 Facilities in the DNP have been continually updated when either ageing or modern standard shortfalls were identified or new requirements emerged. This has been evidenced over the years by the construction of a number of new facilities. Review processes have also been used to ensure that So Far As Is Reasonably Practicable (SFAIRP), existing facilities have been improved where necessary, to meet modern expectations. In some instances further improvement works are still appropriate, consistent with the ongoing expectations of continuous improvement and defence in depth.

2.4 The facilities and organisations supporting the DNP are discussed in detail in Appendix A. A brief introduction to the withstand capabilities of the Naval Reactor Plant (NRP) and the nuclear weapon is provided below.

The Naval Reactor Plant

2.5 The UK Royal Navy (RN) operates three classes of submarine, Trafalgar, Vanguard and Astute which normally rely on the NRP for propulsion and supplies to onboard services. The mobile NRP offers significant redundancy and diversity in systems to guard against accidents. The crew who operate the NRP are highly trained and are conditioned by exercises and simulator training. There is a highly reliable system for controlling reactivity and rapidly shutting down the reactor. There are multiple systems for cooling the reactor including a system rated to dissipate heat loads associated with a shutdown from full power which is passive in nature for both initiation and continued operation (works by natural convection). There are multiple barriers to prevent radioactive material escaping in an accident and affecting either the crew or the submarine external environment.

2.6 Onboard equipment is rugged, generally more so than that found in a civil NPP, since a submarine is designed to withstand hostile marine and military environments (including external underwater explosions). Differences between civil and defence nuclear energy generating plants indicate that a submarine would be expected to be of generally higher resilience when faced with the same extreme natural hazard.

2.7 However, compared to a civil nuclear power plant, there are severe space constraints on a submarine and this creates challenges in optimising the segregation and diversity of onboard safety systems.

The Nuclear Weapon

2.8 Safety in the NWP is maintained at all times by the presence of multiple independent Lines of Defence (LOD). They are designed to protect against the effects of adverse environments and insults including combinations assessed as extremely unlikely⁴. A system or barrier can only be considered a LOD if it is highly reliable and either reduces the probability of a particular threat happening or protects against the consequence of a hazardous event. Nuclear yield can only be achieved when multiple varied inputs are provided to the weapon. These inputs would be experienced only in the unique circumstances of planned ballistic delivery and, if not precisely sequenced, would prevent the weapon from functioning as intended. Inadvertent nuclear yield from a nuclear weapon is not considered credible. Even so, the principle of “Defence in Depth” is applied at all stages of a weapon’s life so as to ensure that the frequency of challenge to a LOD is extremely low.

⁴ A probability of occurrence less than or equal to 10^{-9} events per demand or a frequency of less than or equal to 10^{-9} events per year.

3. Relevant Aspects of DNSR Regulatory Regime

MoD Regulation of Defence Nuclear Programmes

3.1 The fundamental requirement for MoD regulation of the DNP derives from the fact that the programmes have certain exemptions from relevant legislation. Notwithstanding these exemptions, it is the Secretary of State (SofS) for Defence's policy that DNP should achieve standards that are, so far as is reasonably practicable, at least as good as those required by statute.

Where there are exemptions or derogations from either domestic or international law applicable to Defence, [I require that] we introduce standards and management arrangements that produce outcomes that are, so far as reasonably practicable, at least as good as those required by the legislation.

[extract from SofS's Safety, Health and Environmental Protection Policy Statement]

3.2 The Head of Defence Nuclear Safety Regulator (DNSR-Hd) has delegated authority (from SofS via the Director, Defence Safety & Environment Authority (DSEA) for the regulation of nuclear and radiological safety and environmental protection within the DNP. Under DNSR-Hd, nuclear weapons regulation is managed by the Nuclear Weapons Regulator (DNSR-NWR) and nuclear propulsion regulation is managed by the Nuclear Propulsion Regulator (DNSR-NPR).

Authorisation

3.3 Under the Nuclear Installations Act 1965 (NIA65), the operator of a site must be granted a licence by the HSE before conducting nuclear activities; this is subject to management arrangements being made to satisfy 36 Licence Conditions (LCs). A similar process, called Authorisation, is applied in the DNP.

3.4 MoD publications JSP 518⁵ and JSP 538⁶ both set out 36 Authorisation Conditions; these mirror the 36 LCs applied by the statutory regulator. Specific attributes of the DNP (for example the organisational structures and the mobility of naval reactor plant and nuclear weapons) and the remit of DNSR (for example, encompassing environmental protection and transport) require conditions additional to the LCs; hence, four Further Authorisation Conditions (FACs) are also applied by DNSR. An ongoing programme of inspections is undertaken by DNSR to check Authorisee compliance with the ACs and FACs. Because the NRP (in the NNPP) and the NW (in the NWP) are common features, DNSR directly regulates the design and approval of NRP and NW by interpreting and adapting AC and applying them to the business of the NRPA and NW Approving & Design Authority. Information derived by the designers / approvers of NRP or NW forms a vital part of the justification of activities by DNP Authorisees.

ALARP and Continuous Improvement

3.5 A fundamental feature of UK law (as required by the Health and Safety at Work etc Act 1974, HSWA) is that risk to the workforce and the public is to be reduced So Far As Is Reasonably Practicable (SFAIRP, also expressed as 'As Low As Reasonably Practicable', ALARP). It is also a requirement on those who design or supply articles for use at work to ensure that the article is without risks to health SFAIRP. These duties are directly applicable to defence contractors, and there being no general Crown exemption from the HSWA, MoD Authorisees are also bound by them.

3.6 When judging whether risks have been reduced SFAIRP in Defence generally and the DNP in particular, factors such as national defence priorities, battle survivability and the constraints of military platforms (e.g. on space or weight) may be taken into account. DNSR's regulatory stance takes account of these factors.

3.7 Cost Benefit Analysis (CBA) is often used to support ALARP justifications. This involves balancing the costs of implementing safety improvements against the safety benefits. In the case of very low frequency hazards, the use of CBA alone might indicate that the costs of further improvements outweigh the safety benefits. However, it is not sufficient for an ALARP case to be based on CBA alone: central to the justification that risks are ALARP is a demonstration that relevant good practice is being met.

⁵ Regulation of the Naval Nuclear Propulsion Programme, Issue 3.10, Sep 10

⁶ Regulation of the Nuclear Weapons Programme, Issue 2.10, Sep 10

The ALARP demonstration should consider first and foremost factors relating to engineering, operations and the management of safety. These expectations are often referred to by the general term "good practice".

What is accepted as relevant good practice may change over time because of technological innovation which improves the degree of control, cost changes or knowledge about the hazard.

[ONR guidance on the demonstration of ALARP, T/AST/005 Issue 4 Rev 1]

3.8 As indicated above, what is accepted as being relevant good practice may change over time as the industry learns from events and as there are new developments in technology, knowledge and experience. This drives an expectation for continuous improvement in standards of nuclear safety. Authorisees are expected to have arrangements in place to learn from operating experience (OPEX), both from within their own organisation and from external sources.

Lessons should be learned from internal and external sources to continually improve leadership, organisational capability, safety decision making and safety performance.

[HSE Safety Assessment Principles 2006, MS.4]

3.9 Authorisees assessments in response to the ONR Interim Recommendations and the ENSREG Stress Tests have identified no major issues; having reviewed this work, DNSR concurs with this conclusion.

Conclusion 1: All areas of the DNP have been subjected to assessments based on the European Stress Test and the ONR Recommendations. The continued operation of the nuclear powered (including nuclear armed) submarine fleet, and land-based nuclear activities supporting the DNP in the UK is supported by DNSR.

3.10 However, these assessments have resulted in *Considerations*⁷ for potential safety improvements. DNSR expects any reasonably practicable safety improvements identified through such studies to be implemented; indeed, there is a legal obligation (under HSWA) for Authorisees to do so. It is recognised that in many cases further work will be required to establish what additional improvements are reasonably practicable; in such cases, it is considered reasonable for the identified improvements and recommendations to be taken forward by Authorisees as part of normal business (e.g. fed into the existing ALARP processes for progressing improvement options and, where appropriate, Periodic Review of Safety initiatives). Judgements on whether potential safety improvements are reasonably practicable need to recognise that the Fukushima accident may bring about changes in what is accepted to be relevant good practice.

Safety Cases

3.11 The safe operation of a nuclear installation is influenced by many factors, including the design of the plant, its behaviour under normal and fault conditions, and the functions of the operators. It is essential that the totality of these often complex interactions is fully understood. Accordingly, Authorisation Condition 23 requires the Authorisee to produce adequate safety cases to demonstrate the safety of its operations.

3.12 DNSR has adopted the HSE Safety Assessment Principles (SAPs) 2006 (Reference 3) for the assessment of safety cases, having engaged with HSE in their development. JSP 518 provides additional guidance to assessors on the interpretation of certain SAPs and four additional NNPP specific ACs to account for constraints peculiar to the NNPP. JSP 538 includes additional NWR SAPs, which are complementary to the HSE SAPs, and cover specific NWP issues. The HSE and NWR SAPs are underpinned by a suite of Technical Assessment Guides (TAGs). DNSR engages in the development and update of HSE TAGs to ensure, where possible, that they are applicable to assessments in the DNP. DNSR also authors its own TAGs, as needed, to address issues specific to the DNP.

⁷ Within this report, DNSR has used the same definition of the term *Consideration* as used by ONR within the Final NPP Stress Test Report (Reference 8), viz.: A *Consideration* (in italic with a capital) is an indication of how the licensees currently plan to take forward potential improvements into a decision-making process. Note that a *Consideration* is not a commitment to undertake a specific activity or purchase specific equipment.

3.13 The SAPs and TAGs include regulatory expectations for safety cases in the following areas of particular relevance to the Fukushima accident:

- Fault Analysis (General):
 - HSE SAPs FA.1 – FA.3
 - HSE TAG 44
- Design Basis Analysis (DBA):
 - HSE SAPs FA.4 – FA.9
 - HSE TAG 6
- Probabilistic Safety Analysis (PSA):
 - HSE SAPs FA.10 – FA.14
 - HSE TAG 30
- Severe Accident Analysis (SAA):
 - FA.15 – FA.16
 - HSE TAG 7 (*under development*)
- External Hazards (including earthquake, extreme weather and flooding):
 - EHA.1 – EHA.17 (also see FA.5)
 - HSE TAG 13
- Periodic Review
 - HSE TAG 50

3.14 The ONR Final Report (Reference 4) concludes that the basic cause of the Fukushima accident was that the site was not designed with adequate protection against some foreseeable natural hazards (that is, the design basis of the reactors was deficient with regard to tsunamis). In accordance with Principle FA.5 of the SAPs, DNSR expects the design basis analysis in the safety case to demonstrate adequate protection against natural hazards with a (conservatively) predicted frequency of up to 1 in 10,000 years. The report of the Japanese government on the Fukushima accident (Reference 5) acknowledges that the design basis for tsunamis was not based on an equivalent rigorously analytical approach.

Compared with the design against earthquake, the design against tsunamis has been performed based on tsunami folklore and indelible traces of tsunamis, not on adequate consideration of the recurrence of large-scale earthquakes in relation to a safety goal.

[Report of the Japanese Government]

Periodic Review of Safety

3.15 Authorisation Condition 15 requires the Authorisee to make and implement adequate arrangements for the periodic and systematic review and reassessment of safety cases. The objective of the Periodic Review of Safety (PRS) is to compare the safety case against modern standards to see if there are reasonably practicable improvements that could be made, to demonstrate that the plant is safe to continue to operate for the next defined period. The review should also consider changes in technology and knowledge, and feedback from operating experience. DNSR will expect lessons learned from the Fukushima accident applicable to the DNP to be considered as part of the PRS process, which is currently a focus of regulatory attention identified in the DNSR annual report for 2011.

3.16 ONR's Final Report (Reference 4) highlighted that the Fukushima accident has reinforced the need for Operators to give sustained priority to completing periodic safety reviews and implementing identified reasonably practicable improvements (Recommendation FR-1). DNSR supports this view and will continue to engage with Authorisees to gain the necessary assurance that PRS's are undertaken in an adequately thorough and timely manner.

Conclusion 2: DNSR will continue to engage with Authorisees to gain the necessary assurance that Periodic Reviews of Safety are undertaken in an adequately thorough and timely manner to support the implementation of lessons from the Fukushima accident.

Regulation of New Reactor Designs

3.17 The regulation of the design phase of new reactor designs is a new responsibility for both DNSR and ONR, but both are engaged in current design work to ensure that design solutions delivering ALARP nuclear risk are selected. DNSR will ensure that Duty Holders take account of any appropriate lessons from the Fukushima incident in assessing design proposals.

Conclusion 3: Regulation of the design of future reactors, military and civil, must incorporate any appropriate lessons from the Fukushima accident which might affect Reactor Design.

3.18 Further discussion of specific actions to be undertaken by DNSR is provided in Section 6, summarised in the conclusions, section 8, and the Executive Summary.

4. The Fukushima Accident

The Tōhoku Earthquake and Tsunami

4.1 On 11 March 2011 Japan suffered its worst recorded earthquake, known as the 2011 Tōhoku⁸ event. This was a magnitude 9.0 (M_W) undersea megathrust earthquake with an epicentre approximately 70 km east of the Oshika peninsula on the north eastern coast of Japan's Tōhoku region, with the hypocentre being at an underwater depth of approximately 24 km. The earthquake was a rare and complex double quake giving a severe duration of about 3 minutes. The main earthquake of 11 March was preceded by a number of large foreshocks, with hundreds of subsequent aftershocks. The first major foreshock was a 7.2 M_W event on 9 March, approximately 40 km from the epicentre of the 11 March earthquake, with another three on the same day in excess of 6.0 M_W . Following the main earthquake at 14:46 local time on 11 March, a 7.0 M_W aftershock was reported at 15:06, succeeded by a 7.4 M_W at 15:15 and a 7.2 M_W at 15:26 (this is at around the same time as the first of the tsunami waves reached the Fukushima Dai-ichi site). Over eight hundred aftershocks of magnitude 4.5 M_W or greater have occurred since the initial quake.

4.2 The main earthquake triggered powerful tsunami waves that reached record heights and travelled up to 10 km inland, inundating an area of around 600 km². In the city of Miyako, the run-up from the tsunami reached a height of 37.9 m above sea level. As a result of the earthquake, the Tōhoku region of Japan's main island (Honshū) moved around 2.4 m east, with the local coastline subsiding by around half a metre, and the Earth shifted on its axis by estimates ranging between 0.1 and 0.25 m. The earthquake was the most powerful ever known to have hit Japan and the fourth most powerful earthquake in the world since modern record-keeping began in 1900.

4.3 The Japanese National Police Agency has confirmed 15,846 deaths and 3,320 people missing as a result of the natural disaster. The earthquake and tsunami caused extensive and severe structural damage, including heavy damage to roads and railways as well as fires in many areas, a dam collapse, and over 125,000 buildings damaged or destroyed. Around 4.4 million households were left without electricity and 1.5 million without water. Subsequent investigations found that in most areas, damage from the earthquake itself was relatively light (despite its severe magnitude), and that most of the damage was caused by the effects of the tsunami waves.

4.4 The earthquake and tsunami affected a number of nuclear sites along the North Eastern coast of Japan⁹ including five nuclear power plant (NPP) sites (Higashidōri; Onagawa; Fukushima Dai-ichi¹⁰; Fukushima Dai-ni¹⁰; and Tokai Dai-ni), as well as the Rokkasho Reprocessing Plant. The introduction to the IAEA's "Mission Report" (Reference 6) discusses the reactor types at these sites, whilst Figure 1.1 thereto shows their locations relative to the earthquake's epicentre. Although all of these sites lost off-site electrical supplies due to the event, and had their on-site back up supplies disrupted to varying degrees, the most serious events occurred at Fukushima 1, as summarised below.

Effects at Fukushima Dai-ichi

4.5 The Fukushima Dai-ichi (Fukushima 1) NPP site was located around 175 km west-south-west of the earthquake epicentre. At the time of the earthquake, Reactor Units 1, 2 and 3 were operating at power, Unit 4 was on refuelling outage and Units 5 and 6 were shut down for maintenance. All reactors at Fukushima 1 were BWRs, though there were slight differences between some of the designs. Construction of Unit 1 commenced in 1967 with commercial production in 1971. Units 2 to 6 started commercial operation between 1974 and 1979. Thus, these are relatively old reactor units and are significantly different to modern nuclear reactor designs.

4.6 Units 1, 2 and 3 responded as expected on detection of the earthquake, and shut down. Off-site power was lost due to the earthquake and initially, emergency diesel generator (EDG) power was used to provide essential post-trip cooling. Around 40 minutes after the earthquake, a series of tsunami waves (peaking at around 15 m above sea level) reached the Fukushima 1 site, inundating it to a depth of around

⁸ Tōhoku is one of eight Regions in Japan and consists of six Prefectures, of which Fukushima is one. Tōhoku is at the northern end of the main island of Honshū, with Fukushima its southern-most Prefecture.

⁹ See Wikipedia Article "2011 Japanese Nuclear Incidents"(Link(a))

¹⁰ Dai-ichi simply means Number 1, whilst Dai-ni means No 2.

5 m (local ground level is around 10 m above sea level at Units 1 to 4 and 13 m at Units 5 and 6). The tsunami disabled all but one of the site's thirteen EDGs, leaving almost all of the site with no capability for on-site generation of AC electrical power. The tsunami also took out the DC (battery) power supplies to the instrumentation systems, such that it was not possible for operators to check important reactor parameter information.

4.7 With the loss of electrical supplies to the cooling systems, Reactor Units 1 to 3 began to overheat. As a result of the overheating, the zirconium cladding on the fuel reacted with water and steam, generating high levels of hydrogen which built up in the containment and led to several explosions, causing damage to building structures. Over the next three weeks, fuel element geometry and integrity was lost, containment was breached and major releases of radioactivity occurred, initially to the atmosphere but later by leakage to sea. The operator struggled to restore full control. The loss of cooling systems also affected the fuel ponds on site, particularly those at Units 1 to 4, resulting in varying degrees of damage to the stored fuel.

4.8 In September 2011, the UK's Chief Inspector of Nuclear Installations published his Final Report on the "Implications for the UK Nuclear Industry" (Reference 4), Pages 30 to 71 of which provides a detailed overview of the more significant factors in the accident. Further, more detailed descriptions of the events at Fukushima are contained in the IAEA's "Mission Report" (Reference 6), in a report presented by the Government of Japan to the IAEA, on 7 June 2011 (Reference 5), and in a report by the US Institute of Nuclear Power Operations (Reference 7) which was published in November 2011.

4.9 The Fukushima accident was a major nuclear accident, rated at an International Nuclear and Radiological Event Scale (INES) level 7 (the highest level). The Japanese authorities instigated a 20 km evacuation zone, a 30 km sheltering zone and other countermeasures. Three Tepco employees at the Daiichi and Daini plants were killed directly by the earthquake and tsunami, but there have been no fatalities from the nuclear accident. There were no radiation casualties (acute radiation syndrome), and few other injuries reported. However higher than normal doses are being accumulated by several hundred workers on site as a result of the accident.

4.10 Post-event investigators generally concluded that the operators at Fukushima plant displayed extremely courageous behaviour that could be considered 'above and beyond the call of duty'. The operators remained on site for many days trying to ensure the plant conditions did not deteriorate, even though they must have been extremely concerned, not just for their own safety, but also for that of their friends and relatives in areas adjacent to the site, and for their homes. The operators' commitment played a key role in minimising the magnitude of the accident, and demonstrated the importance of operators to nuclear plant safety.

5. MOD Response

Initial Reassurance Sought from Authorisees

5.1 The Japanese earthquake and tsunami occurred on 11 March 2011. As events subsequently unfolded at Fukushima, DNSR immediately sought reassurance that operations remained safe within the UK's DNP. Authorisees within the DNP were asked the same initial four questions that ONR asked of the UK's civil operators:

- 1) *How confident are you of the robustness of your plant cooling systems and their capabilities for maintaining plant safety in normal, upset and emergency conditions?*
- 2) *How confident are you that your plant could safely withstand infrequent seismic events in the UK, do you have systems for detecting such events and initiating protective actions and if so what actions do you take to ensure that these systems are fully available?*
- 3) *Are you confident that plant safety systems and safety-related systems are capable of maintaining critical safety functions (criticality, cooling and containment) in the event of foreseeable external hazards, in particular flooding?*
- 4) *If hydrogen or other combustible gases could be generated by the plant under normal, upset or emergency conditions, do you have robust systems for detecting them and initiating protective actions and what actions do you take to ensure that these systems are fully available?*

5.2 Following assessment of the Authorisees' responses to these questions, DNSR concluded that there was no evidence to undermine the continued safe operation of the nuclear powered submarine fleet or land based DNP facilities in the UK. This conclusion was promulgated by DNSR in late May 2011. ONR was also informed and was supportive of this conclusion.

5.3 DNSR proposed that a more detailed review should be undertaken as more information became available from the events in Fukushima, to establish what lessons could be learnt to further enhance safety standards across the DNP. To support this review, it was proposed to gain stakeholder representation from each of the Authorisees within the DNP in a group drawn together for the purpose.

Stakeholder Management

Aims

5.4 DNSR convened an initial stakeholder meeting on 12 July 2011. The group comprised representation from each MoD Authorisee, defence Licensee, Navy Command, Staff Officer Nuclear Accident Response & Training (SONART), Nuclear Department of the Defence Academy, Rolls-Royce and Serco RSD; it was observed by representatives from ONR.

5.5 Whilst recognising that more information would continue to emerge from Japan in the coming months and years, the main aim of the meeting was to develop a 'question set' to be used as a basis for further assessment of each DNP operator/facility. This regulatory lead was seen by DNSR as an important opportunity to get the approach right, recognising the DNP's different 'modus operandi' (that is, mobile reactor plants and weapons) when compared with the civil nuclear programme.

5.6 Prior to the meeting, the following wider regulatory developments had occurred in relation to the Fukushima accident:

- **ONR Interim Report:** The Interim Report produced by ONR's Chief Inspector of Nuclear Installations (Reference 1) on the implications of the Fukushima accident for the UK nuclear industry was published on 18 May 2011. The report included 25 Recommendations, most of which were aimed at the nuclear industry Operators, but some of which were directed towards the Regulator. Licensees were requested to respond to the Recommendations within one month of the report being issued.
- **ENSREG Stress Tests:** In the wake of the Fukushima accident, the European Nuclear Safety Regulatory Group (ENSREG) had worked to define a set of Stress Tests to be carried out in European Union member states for NPP in operation or being constructed. These Stress Tests

(Reference 2) were adopted by the European Council on 26 May 2011. In the UK, ONR also requested non-NPP licensed nuclear installations to undertake the Stress Tests.

Summary of Discussions

5.7 DNSR emphasised that in reviewing the lessons to be learned from Japan, care should be taken not to focus too closely on the specifics of the problems at Fukushima and overlook the general learning opportunity. The events surrounding the unfortunate weapons explosion at a Cypriot Naval Base¹¹ the day before the meeting was a timely illustration of a similarly underestimated threat from a sequence of failures triggered by a single extreme event.

5.8 DNSR highlighted that work had already been undertaken to assess Authorisees against the 25 Recommendations made in the ONR Interim Report. Although it would have been possible to generate a question set specific to the DNP, it was agreed that there were distinct presentational benefits in responding to the recommendations made by ONR. It was also considered that such an approach would ease the burden on those stakeholders that are Licensees as well as Authorisees, and help demonstrate that the DNP have standards of safety that are, so far as is reasonably practicable, at least as good as those of the civil nuclear industry.

5.9 DNSR also emphasised that the ENSREG Stress Test specifications being asked of civil operators by ONR (including DNP Licensees) should not be dismissed, notwithstanding the inapplicability of EU nuclear directives to defence. DNSR concluded that a preliminary consideration of these should be undertaken by the Authorisees, where applicable, as part of their response to DNSR. It was again recognised that there were benefits in applying the Stress Tests in order to demonstrate that DNP standards remain consistent with the civil industry where practicable and appropriate. DNSR also referred to the unique aspects of the MoD programme review that would require assessment (e.g. the mobile reactor plant). DNSR recognised that some elements of the assessments might have to be rolled over into longer term work through forward action plans and PRS.

Safety Directors Forum (SDF) Fukushima Sub-group

5.10 During the period between the events in Japan on 11 March and the meeting held on 12 July, parallel activity occurred under the direction of the Safety Directors Forum (SDF), which is a forum for civil and defence duty holders to share good practice. The SDF agreed that a Fukushima Sub-group should be formed to facilitate good communication and alignment between duty holders on Fukushima related issues (ONR Recommendations, Stress Tests and resulting actions), and to ensure that work of common interest is shared where appropriate. DNP members of the SDF suggested at the meeting that their preference would be to coordinate their responses back to DNSR by utilising some of the output from this Fukushima Sub-group, acknowledging that the DNP stakeholders would combine outside of this sub-group when assessing specific plant or weapon issues. DNSR supported this approach and also looked for this DNP representation of the Fukushima Sub-group to interact with appropriate existing forums in relation to specific issues (e.g. the defence Nuclear Emergency Arrangements Group (NEAG) chaired by SONART).

Operational Berths

5.11 Prior to the events in Japan, Navy Command had initiated a routine periodic review of Operational Berths to ensure they remained fully justified for use by submarines.

Expectations Placed on Authorisees

5.12 Following the meeting in July 2011, DNSR wrote to Authorisees to outline what work they were expected to undertake to support the review of the Fukushima accident implications. DNSR requested Authorisees to provide the following:

- A response to the 25 Recommendations in the ONR Interim Report;
- A preliminary consideration of EU Stress Tests;
- Navy Command were requested to complete their review of Berth Safety Statements.

¹¹ Weapons Explosion at Evangelos Florakis Naval Base, Cyprus (Link(b))

5.13 DNSR subsequently re-emphasised the intent behind the requirement in responding to the EU Stress Tests: the assessment was not intended to be undertaken on the same basis as in the civil sector where there are different drivers. The aim for the DNP was to ensure that the lessons from Fukushima are properly learned and it was DNSR's view that consideration of the Stress Tests, where appropriate, would help facilitate this aim. It was therefore emphasised that by setting the requirement as a 'preliminary consideration' of the Stress Tests, DNSR anticipated '*a relatively short high level assessment of how each facility/plant compares against this question set*'.

5.14 DNSR further noted that if Authorisee assessments identified any potential areas for improvement (that is, *Considerations* – see Footnote 7 above), these would need to be assessed in due course against the potential risk they present, their relative standing compared with existing areas for improvement, and in terms of ALARP.

5.15 DNSR originally set a date of 31 October 2011 for completion of the Authorisee responses. However, a revised completion date of 31 December 2011 was subsequently agreed recognising the need for an appropriate level of detail in the assessments, and the potential impact on existing work streams across the DNP.

ONR Interim Report Recommendations

5.16 ONR issued its Final Report (Reference 4) on the implications for the UK nuclear industry in September 2011; the report raised an additional 12 Recommendations above the 25 in the Interim Report. DNSR has not formally requested Authorisees to respond to the additional Recommendations in the Final Report, but notes that these are being considered via an appropriate forum¹². Those relevant to the Regulator are discussed in Section 7 below.

5.17 The ONR Recommendations from both the Interim Report and Final Report are reproduced in Appendix B.

ENSREG Stress Test Specifications

5.18 The ENSREG Stress Test Specifications are reproduced in Appendix C.

5.19 The Stress Tests are defined as '*a targeted reassessment of the safety margins of nuclear power plants in the light of the events which occurred at Fukushima: extreme natural events challenging the plant safety functions and leading to a severe accident*'. The tests involve evaluating the response of the plant to a set of extreme situations, including:

- a) Extreme Initiating Events:
 - Earthquake,
 - Flood, and
 - Extreme Weather.
- b) Loss of Safety Functions:
 - Loss of Electrical Power,
 - Loss of Ultimate Heat Sink, and
 - A combination of both.
- c) Severe Accident Management Issues:
 - Loss of core cooling,
 - Loss of pond cooling, and
 - Loss of containment integrity.

5.20 In these postulated extreme situations, sequential loss of the lines of defence is assumed, irrespective of the probability of this loss. The response of the plant to these situations is assessed with the aim of identifying potential safety improvements where there are weak points or cliff-edge effects.

5.21 The Stress Tests drive a different approach to Design Basis Analysis. The latter identifies the hazards and threats to the plant and then estimates the probability of their occurrence to establish whether the plant should be designed to cope with them. The Stress Tests similarly identify ways in which the delivery of

¹² The Safety Director's Forum

Critical Safety Functions (CSF) can be threatened, and then assumes this has happened, and only after this evaluates barriers to the event. The Stress Tests therefore provide a useful alternative discipline for high consequence events to guard against assumptions of the soundness of barriers. Put another way, it drives a regulatory expectation already expressed in the SAPs 2006:

The process of analysing safety requires creativity, where people can envisage the variety of routes by which potential radiological hazards can arise from the technology. A range of options can then be identified, from which the reasonably practicable ones can be selected and implemented. It requires an extensive understanding of the facility both in the present and in the foreseeable future, its behaviour in a variety of conditions, experience of failures in other facilities and the measures adopted to prevent their recurrence. It also requires an understanding of how people and organisations may affect safety. Imagination is required to identify potential failure modes arising in plant or people and opportunities for control and, if necessary, mitigation.

[SAPs 2006, Safety Case Processes, paragraph 80]

5.22 The implications of this are that a significant workstream which can be described as “Creative Challenge” or “Creative Review” might usefully be applied to the delivery of the CSF’s in particular circumstances. It is not a task which DNSR expects to be discharged within the timeframe of the present report, though areas where it is considered that such reviews might bring potential benefit are identified herein.

Engagement with ONR

5.23 Recognising that a number of duty holders in the DNP are subject to regulation by both the MoD and statutory regulators, DNSR has maintained engagement with ONR in the ongoing review of lessons learned from Fukushima, and will continue to do so going forward.

5.24 ONR’s final report on the Stress Test assessments for UK NPP (Reference 8) was published in December 2011. A progress report for UK non-NPP (Reference 9) was also issued in December 2011, and a final report has been prepared. ONR and DNSR have shared conclusions for non-NPP in development of their respective reports.

6. Stress Test Assessments

Introduction

6.1 Application of the Stress Tests by the Authorisees has resulted in the identification of *Considerations* that will be addressed; DNSR will monitor progression of the *Considerations* to gain assurance that they are appropriately sentenced and will engage with Authorisees to ensure that their programmes continue to take into account lessons learnt from Fukushima through existing periodic review. As a part of this process, DNSR's review of the assessments provided by the Authorisees has identified a number of areas where DNSR will seek the provision of further information or clarification and this will be taken forward as a normal part of the MOD's robust Regulatory regime.

Conclusion 4: DNSR has identified a number of areas where the provision of further information or clarification is needed; DNSR will engage further with Authorisees in these areas.

The following sections summarize the *Considerations* identified by the various authorisees regulated by DNSR. The number of considerations from each authorisee and their source, in terms of the stress test which gives rise to them is given, though they are not detailed in this report in all cases.

General Discussion of Stress Test Aspects

Seismic

6.2 Current practice at UK DNP facilities, consistent with the HSE SAPs (Reference 3), is to derive a Design Basis Earthquake (DBE) which conservatively has a frequency of occurrence no greater than once in ten thousand years. The resulting DBE events are generally of similar magnitude to those considered in the civil industry. The facility in question is then designed, assessed or shown not to respond adversely (in a nuclear safety context) to the DBE. Earthquakes are defined in terms of their peak accelerations, vibration frequencies and ground shaking durations at the site in question. For typical DBE events, the resulting earthquake accelerations are similar to those reported internationally as causing major and widespread structural failures to non-seismically designed buildings, such as is the majority of the UK building stock. UK earthquakes are generally considered very unlikely to last longer than ten seconds, as a damaging earthquake would be expected to be relatively close to the site at a shallow depth (Reference 10). This DBE, while much less intense than that applied to the Fukushima plant, is not undermined by the events there¹³.

6.3 The peak ground accelerations used within defence safety cases vary with the assessed seismic risk at the site. The ground accelerations at AWE and Vulcan NRTE are significantly lower than at HMNB Clyde, Devonport and BAES Barrow. The older Trident Facilities at HMNB Clyde have been designed for a slightly less onerous DBE than the newer (floating) Valiant Jetty and the Authorisee has identified that there may be a need to undertake a more accurate site specific seismic hazard assessment to determine which is more appropriate. DNSR is satisfied that the Authorisee has an appropriate work programme in place to progress this.

6.4 Upgrading of facilities at Devonport for refuel/defuel of submarines has specifically required the facilities to be designed to withstand the DBE using appropriate international nuclear design standards. At BAES Barrow failure of certain buildings is argued as being acceptable as it is not detrimental to nuclear safety. At AWE there is a requirement to ensure that heavy objects do not fall onto explosives during an earthquake. AWE's PRS process had previously identified some potential shortfalls in the seismic capability of an existing AWE facility when judged against modern standards. However, this will be resolved in a reasonable time frame by the ongoing construction of a new facility designed to the appropriate international nuclear design standards.

¹³ The events at Fukushima were initiated by a seismic event marginally outside the design basis, which is very different from the UK design basis given that Japan lies in an exceptionally active earthquake zone. The plant withstood the seismic event and safety systems functioned as intended; the eventual problems were caused by a significant underestimate of the consequent tsunami (see paragraph 3.14). The seismic design basis for UK nuclear installations is not undermined by the Fukushima event.

6.5 The Authorisee assessments have found the NRP to be resilient to seismic events in a submarine afloat (both at sea, and when berthed alongside), when docked in a Devonport dry dock, lifted on the HMNB Clyde Shiplift or permanently installed at Vulcan NRTE. At Vulcan NRTE, DNSR is aware of programmes in place to remove nuclear material from the site as an alternative to future upgrades of the storage facilities or more detailed analysis. DNSR will be monitoring progress on these programmes to ensure that site risks remain ALARP.

6.6 In the past certain cranes at defence nuclear facilities have been identified as having limited seismic withstand. The cranes in question have been removed from service, such as the original Devonport submarine refit complex crane, and either replaced by a seismic resistant crane or a lighter crane that if it were to topple would not have a critical effect on nuclear safety.

6.7 Seismic margins have generally not been explicitly quantified but are argued as being present as a result of either a margins study, considering an earthquake 40% greater than the DBE, or demonstrating a capability for a ductile response under earthquakes significantly in excess of the DBE.

6.8 It has not been normal practice to protect the site supporting functions and general activities from earthquakes when seismic failure would not undermine the correct functioning of a nuclear safety system. For instance administrative offices, canteens, stores, general maintenance buildings, fire stations and emergency control centres are not seismically qualified using the conservative rigorous approach applied at berthing facilities (when required by the safety case). The Stress Tests require that seismic failures of such structures are investigated to evaluate the effect on site resilience and the ability to provide an emergency response¹⁴. Authorisees are confident in their existing emergency arrangements and some have indicated that additional study of this aspect might be undertaken as part of their continuous improvement programmes. However, it is noted that a berthed submarine can operate autonomously in its sea-going state, when it places no reliance upon shore supplies.

6.9 Overall, DNSR is satisfied that the Authorisees' assessments of their facilities have generally found them to possess the necessary seismic withstand capability and that appropriate work is being taken forward as a result of the assessments and lessons learnt. However, DNSR considers that Authorisee studies are merited to develop understanding of whether targeted improvements to the general defence nuclear infrastructure might be of benefit in improving the emergency response following a severe earthquake that might cause major site disruption.

Flooding

6.10 There are a number of types / causes of flooding:

Inland Flooding – caused by intense precipitation, prolonged precipitation or snow melt, possibly combined with a restriction in the flow path between the water source and the sea.

Coastal Flooding – caused by high tides, waves and dynamic effects caused by the weather (for instance the storm surges that occur when southerly winds drive water into the increasingly narrow confines of the southern North Sea). Additional effects to be considered include climate change and the gradual isostatic readjustment with southeast England sinking.

Tsunami – caused by an earthquake induced sudden movement of the sea floor, or other event causing disturbance of the water, such as coastal or subsea landslip.

Seiche – standing waves set up on rivers, reservoirs, ponds, and lakes from earthquake induced ground movements.

Manmade – for instance caused by failure of an upstream dam.

6.11 Damage due to flooding arises either as a result of the presence of water or from materials and equipment being washed away as a result of high water velocities, which in turn can lead to an impact hazard. Whereas flooding would almost certainly disrupt normal site operations it would not necessarily affect nuclear safety, especially when the nuclear reactors in question are on board submarines that are designed for sea-going operation. Normally it is to be expected that there will be some advance warning of a flood, unlike for an earthquake, enabling some mitigating actions to be taken.

6.12 Authorisees have each derived a Design Basis Flood (DBF) extreme high water level which conservatively is exceeded at a frequency of no greater than once in ten thousand years. As floods can

¹⁴ And this is indeed a lesson promulgated from ONR's engagement in the post accident evaluation at Fukushima

arise for a number of reasons it is necessary to calculate a number of water levels that allow for possible combinations of effects. The highest water level calculated is then deemed to be the DBF.

6.13 For the UK, previous studies (References 11 and 12) have suggested that the potential hazards and water levels from tsunami are less than those from coastal flooding. However, this finding will be subject to review in response to ONR's Interim Report Recommendation IR-10.

6.14 The effects of flooding are very dependent on the site in question and the activities undertaken. At Vulcan NRTE the site is situated sufficiently high above sea level for flooding not to be an issue. Historically, an existing AWE nuclear facility was flooded from inland flooding. Although the effects of the flood did not lead to any erosion of nuclear safety margins, it disrupted normal site operations and led to delays to work programmes. As a result of these delays, a decision was made to put in place additional defences. Construction of a new facility is also underway, which will further address this availability issue. At BAES Barrow, the period when over-side services are provided to a submarine with a critical reactor is very short. During this period the submarine systems are fully intact such that there are large margins should over-side services be lost as a result of site flooding.

6.15 Owing to Devonport Naval Base's location it is reasonable to conclude that there is an increased risk to the facilities from flooding (compared to other DNP sites). For this reason considerable effort has been spent on understanding the hazard and providing defences. The application of the Stress Tests has identified that when considering beyond design basis floods there are areas which warrant further investigation to establish whether they should be taken forward. DNSR will monitor closely the approach taken.

6.16 At both HMNB Clyde and Devonport, the Authorisees' reviews have identified that the potential exists for the loss of over-side services under the Design Basis flood or an event slightly more severe than this. It is argued that in such circumstances the onboard systems, if required, will provide margins of safety before an accident of nuclear significance could develop. The HMNB Clyde Shiplift is not affected by flooding in the same way as the Devonport dry docks.

6.17 A very unlikely combination of extreme events could lead to a loss of water at a berth, resulting in a submarine grounding and the potential for the sea water level dropping below that of the water intakes. Submarines are designed to be stable on grounding and on-board back-up systems are capable of maintaining the cooling function.

6.18 Defence authorised sites have been shown not to be vulnerable to manmade flood hazards such as failure of an upstream dam.

6.19 DNSR considers that the Authorisees' investigations are sufficient to support their conclusions that the protection provided against the DBF is suitably robust and agrees with Authorisees the scope for improved resilience against beyond design basis floods should be considered as appropriate within continuous improvement programmes. Authorisees should continue to ensure that robust analyses and plans are in place to deal with such scenarios effectively. DNSR notes that ONR Recommendation IR-10 calls for an industry-wide review of UK flooding studies, with an objective of determining whether there is a need to improve further the site-specific flood risk assessments as part of the PRS programme. DNSR understands and supports the need for such a review and will seek to gain assurance that defence nuclear sites take appropriate actions as part of their PRS processes. The *Considerations* identified by the Authorisees in response to the Stress Tests provide a good basis for moving forward in providing more resilience if this should lead to tangible safety improvements.

Extreme Weather

6.20 Extreme weather has the potential to have an adverse effect on nuclear site safety for a number of reasons as illustrated below:

Wind – can cause structures to collapse, cladding to be removed from buildings exposing their contents to the effect of wind, wind blown debris to become dangerous missiles and external access to be lost.

Snow – can lead to loss of access, blocking of air inlets and collapse of roofs under the weight of snow.

Ice Build up – can lead to loss of access, blocking of air/water inlets and ice build up on cables leading to structural collapses.

High Temperature – can lead to overheating of mechanical and electrical equipment.

Low Temperature – can lead to freezing of unprotected cooling water systems and fracture of brittle materials.

Lightning – can cause detonation of unprotected explosive materials.

6.21 Submarines are designed to operate safely anywhere in the world's oceans in hostile marine environments. The extremes of the UK climate are relatively benign and the ability of the submarine to withstand UK extreme weather is not a dominant design consideration. Many of the structures at defence sites are not vulnerable to extreme weather, for instance extreme weather will have an insignificant effect on a dry dock that is constructed in the ground and designed to withstand earthquakes. Equipment can be protected from extreme weather by location within a suitably designed building. Floating structures, building external envelopes and equipment that may be vulnerable to temperature (such as freezing of water in pipes) are addressed within Authorisee safety cases.

6.22 Generally, extreme weather conditions to be included within the NRP and site design basis are conservatively derived so as to be of a magnitude that has a frequency of occurrence no greater than once in ten thousand years. For some conditions, such as lightning, the probability of the event is important rather than its magnitude. In such cases, a design basis event of similar likelihood is conservatively derived. Some nuclear facilities and systems at defence nuclear sites are not designed to withstand such onerous extreme weather but in these instances DNSR is satisfied that the arguments that this does not affect nuclear safety are made in the individual safety cases.

6.23 DNSR is generally satisfied that Authorisees have identified an adequate range of extreme weather events of appropriate magnitudes within their safety cases. A conservative approach has been followed to allow for the uncertainties associated with extrapolating currently available data to predict extreme low frequency events.

6.24 Updating of structures with the aim of achieving modern nuclear standards has been undertaken at Vulcan NRTE but there are limitations as to what is reasonably practicable. In particular, considering the used nuclear fuel contained in one of the ponds, the most appropriate way ahead seems to be to remove the fuel rather than update the surrounding building to withstand one in ten thousand year weather conditions. The stored fuel at Vulcan NRTE was removed from the reactors a number of years ago and, unlike at Fukushima, it no longer requires active cooling to remove residual decay heat (thus the fuel is benign in terms of the potential for self heating to lead to fuel damage leading to loss of containment). The radiological consequences from the stored fuel arising from a building failure would not develop with time and any impact would be limited and local to the building. There would be time to decide on and implement appropriate remedial actions. Vulcan NRTE has a programme to implement risk reduction and mitigation measures in accordance with the ALARP Principle, pending finalisation of arrangements to remove the fuel.

6.25 At HMNB Clyde there are two floating jetties – the Explosives Handling Jetty (EHJ) at the Royal Naval Armaments Depot (RNAD) Coulport and the new Valiant Jetty at Faslane. As they are floating, these structures experience low seismic loads and their abilities to withstand high currents and extreme wind and waves becomes a dominant design consideration. DNSR is satisfied that the Valiant Jetty has been designed to modern standards, including the provision of margins against extreme weather.

6.26 DNSR considers that HMNB Clyde should provide clarification of the arguments on the withstand of the over-side services to extreme weather conditions at their facilities, particularly for over-side seawater supplies to a submarine on the Shiplift. Noting that the onboard systems will be virtually unaffected by extreme weather conditions and the availability of alternative systems to get water to the submarine inlets when raised out of the water, this is not believed to be a significant concern. Clarification will also be sought on the capability of the buildings with a nuclear function at HMNB Clyde to withstand beyond design basis extreme weather conditions with frequencies less than once in ten thousand years.

6.27 At Devonport, the Authorisee has identified a possible vulnerability where cables pass from the shore to a floating submarine as cable damage could occur in the event of an impact from wind blown debris. However, the over-side services follow diverse routes with always more than one connection between the shore and the submarine such that they are single failure proof. The threat has been recognised and considered within the facility safety case as well as during the stress test process. Similar arguments are applicable to a submarine docked in a dry dock; however, the connections to the submarine are generally better protected from the extremes of weather as they are under the submarine in the dock bottom. The available cooling systems for a submarine in a dry dock under maintenance will depend on the decay heat being produced by the shut down reactor, which will be significantly less than that for a reactor at power.

The management procedures for a docked submarine ensure there are always suitable, sufficient and justified reactor cooling systems available.

6.28 The buildings and civil engineering structures at Devonport with nuclear safety functions are generally of a very robust form designed to withstand once in ten thousand years extreme weather events. DNSR will seek clarification on the effects of lower frequency beyond design basis events.

6.29 The justification of dockside cranes under extreme weather conditions is dependent on the facility in question. Many cranes have been justified to safely withstand extreme weather conditions. On prediction or development of high wind conditions, in order to minimise risk, these cranes are removed from service and parked such that if they were to topple there would be no nuclear safety implications. An alternative approach, whereby authorisees increasingly use lighter cranes on docksides which would not damage a submarine's on board systems should they topple, is supported by DNSR .

6.30 At BAES Barrow, the time period when over-side services are provided to a submarine with a critical reactor is very short. During this period the submarine systems are fully intact such that there are large margins should over-side services be lost under severe weather conditions. BAES has not needed to provide information on the capability of its facilities to withstand extreme weather conditions as the nuclear safety case is based on the premise that the submarine is tolerant to any failures that might arise from severe weather conditions; DNSR is satisfied that this is an acceptable justification for withstand against extreme weather in this instance.

6.31 AWE has stated that the consequences of a seismic event bound those from extreme wind in potential to cause damage to their facilities. AWE recognises that lightning is a hazard to explosives and multiple defences are provided against this hazard. The move to the new facility currently under construction will ensure future activities fully meet modern standards including capability to withstand one in ten thousand year weather events, combinations of events, and more severe beyond design basis events.

Probabilistic Safety Assessment

6.32 The NRPA is responsible for the submarine PSA at both "Level 1" and "Level 2". Level 1 addresses the frequency of events which could, in extreme circumstances lead to core damage while Level 2 addresses extremely low probability events which could potentially result in a radioactive release. Submarine PSAs are produced for each class of submarine, cover all operating states and allow for submarines being at sea and in port.

6.33 The hazards addressed within the PSA include external submarine hazards, submarine internal hazards and NRP hazards. The dominant risks arise from the NRP hazards and the PSA has concentrated on modelling the associated fault sequences in most detail. The Level 1 and Level 2 PSAs conclude that the risks are extremely low and DNSR agrees with this assessment. However, the Fukushima event suggests that extreme natural hazards and other external (to the reactor) threats might need deeper consideration. DNSR will be seeking assurance that the lessons learnt from the Fukushima event are appropriately captured within future development of the PSA.

6.34 For the next generation of nuclear submarines DNSR will assess whether the modelling of beyond design basis external and internal submarine hazards is conducted appropriately. The information made available to DNSR by the Next Generation submarine project team indicates that a reasonable approach is being followed and DNSR will keep this under review.

6.35 PSA has been undertaken for all the major facilities at Devonport by combining site and NRP risk data. However, the scopes of the PSAs differ depending on the time when the PSAs were produced, with the older PSAs being less detailed. The risks from extreme natural hazards are evaluated, and these can be the dominant risks when the reactor is shut down. The risks are generally very low and are assessed as being tolerable and ALARP.

6.36 HMNB Clyde has stated that a PSA has been undertaken for all their shore based facilities that may hazard the NRP or weapons. All hazards within the design basis are stated to have been assessed deterministically and the risks demonstrated to be tolerable and ALARP.

6.37 PSA has been undertaken for all facilities at AWE that require a nuclear safety case and the radiological risks to the workers and public evaluated. The risks to the public are very low and the risks to the workers are currently higher but tolerable. The construction of new facilities at AWE will considerably reduce the current risks and is needed as part of the requirement to demonstrate that risks are ALARP.

Loss of Electrical Power and Loss of Ultimate Heat Sink

6.38 As noted previously, the autonomous nature of the NRP is such that there is no reactor safety need¹⁵ for submarines to be provided with shore supplied over-side services when in port. (See A11) The decay heat to be removed from a shut-down reactor is only a small proportion of the heat that must be removed from an operational NPP. Cooling of the reactor is normally accomplished by on board duty systems supplied by electrical power.

6.39 When at sea or alongside, the ultimate heat sink is sea water which is in plentiful supply. In the event that a submarine were to ground the reactor would be shut down and on board systems would provide the cooling needed to dissipate the decay heat from the reactor. The crew are fully trained for such a situation and this is regularly rehearsed as part of training exercises designed to stress the crew, as the exercises include multiple challenges that the crew must overcome.

6.40 There are multiple methods of cooling the reactor which have been designed to be resilient to a multitude of postulated accidents. In particular, a passive decay heat removal system which works by natural convection and is not reliant on electrical power to cool the core is installed on all RN submarines.

6.41 If onboard electrical or cooling water systems need to be removed for maintenance then this is strictly controlled by management arrangements. These arrangements are dependent on the decay heat generated by the reactor having dropped to a predefined level following shutdown of the reactor. Back up systems are present and if these were all to fail and the submarine were to be out of the water then alternative systems to control reactor temperature could be readily provided, since the heat that would be generated would be very low and alternative systems can be very simple with ample time for setting up.

Severe Accident Management

6.42 The EU Stress Test Specification at Appendix C notes under the 'General Aspects' heading that: "*The approach should be essentially deterministic: when analysing an extreme scenario, a progressive approach shall be followed, in which protective measures are sequentially assumed to be defeated*".

6.43 As discussed earlier (see paragraph 1.3 for example), an important part of the Stress Tests on Severe Accident Management is the sequential removal of protective measures combined with a "Creative Review" that considers the situation that would be expected to develop and how the Severe Accident Management arrangements would be expected to respond. The purpose is to determine whether there could be any improvements in the resilience of the accident management arrangements. From the "Creative Review", *Considerations* are to be identified that might improve resilience, which can then be evaluated at a later date. The process is complete when a "Creative Review" has been undertaken for scenarios with all protective measures removed and the unmitigated consequences have been fully realised with no potential to mitigate the release of radioactive materials. Although this is deemed not to be credible this is the deliberate intention within the Stress Tests to see if further improvements can be identified.

6.44 Although the approach taken by individual Authorisees to identify *Considerations* is not entirely common it is clear that no major shortcomings in severe accident arrangements have been identified, and there are a number of common themes in the different site responses that might be considered generically across the DNP.

6.45 Authorisees all refer to improvements either implemented or in the process of being implemented as part of their extant PRS processes. The PRS process is an essential part of continuous improvement and places Authorisees in a strong position to respond to any new re-evaluation of safety, such as that specified by the Stress Tests. Nevertheless, a "Creative Review" process (see paragraph 5.22) might identify new *Considerations* and DNSR intends to engage further with Authorisees on this issue.

6.46 DNSR considers that there is benefit in Authorisees sharing good practice identified through application of the Stress Tests. *Considerations* need to be shared so as to ensure consistency when there is similarity in emergency arrangements at different sites. The evaluation of some *Considerations* is not site specific and does not need to be evaluated individually by each site. DNSR will seek assurance that good practice identified with respect to Severe Accident Management is shared between Authorisees via appropriate forums (e.g. the Safety Directors Forum). Potential areas for further consideration are on-site and off-site resilience and integrity of emergency control rooms and communications.

¹⁵ Though for convenience of operations, shore supplies may be used

6.47 The NRP has multiple protective systems to guard against accidents and a highly trained and conditioned crew to cope with the unexpected. The arrangements provided by the NRPA in the event of sequential removal of protective measures have been derived following extensive and in-depth analysis. A submarine has high resilience because of its operational requirements¹⁶. DNSR will engage with site authorisees on whether further *Considerations* for improving Severe Accident Management need to be investigated.

AWE

6.48 AWE has reviewed their emergency arrangements and the majority of the potential improvements are ones previously identified as part of the PRS process. A further five *Considerations* have been identified from their 'Creative Challenge' process. DNSR is satisfied that the *Considerations* indicate that AWE has followed through a well thought out process in line with the Stress Tests.

6.49 However the Stress Tests are of limited applicability to the operations undertaken at AWE as there is no heat generating reactor to be continuously controlled. Work at AWE generally comprises a number of discrete activities undertaken within different areas of the AWE sites. Nuclear safety at AWE is demonstrated by strict working to procedures, using safe equipment, controlled materials and highly trained and skilled staff together with multiple justified LOD.

6.50 The occurrence of a major accident is considered incredible but the potential for immediate and significant off-site consequences is recognised in the philosophy for Emergency Response. A function of particular importance for the arrangements at AWE is the ability to prevent an unsafe situation developing, as well as responding to a severe accident. The use of containment and the ability to take an appropriate range of emergency measures in the event that containment is lost, or might be lost, is therefore an important aspect of the Emergency Response arrangements. In these respects DNSR considers that further thought should be given at the facility level to ensure that activities such as 'Making Safe' (providing additional hazard resistant barriers or removing temporary hazards) or providing emergency back-up support can be undertaken quickly and reliably should an extreme natural event occur or be forecast. DNSR believes that if this were carried out there could be the potential to identify more *Considerations*.

6.51 AWE has responded to the ONR Interim Recommendations. AWE is to review forums through which the public and other stakeholders are informed of the hazards, risks and emergency arrangements at AWE's sites. AWE is also to consider the site emergency arrangements during a severe flooding event and review its emergency training and exercise programme. DNSR supports these proposals.

Vulcan

6.52 The Vulcan NRTE report does not identify any *Considerations* arising from the Stress Tests but highlights actions already being taken which were previously identified via the PRS process.

6.53 It should be noted that the STF reactor has a short remaining life and plans are being progressed for removal of the stored fuel in the near future. Furthermore, this fuel is long cooled such that it could not feasibly give rise to the significant release which ultimately came from the Fukushima cooling ponds. In this context, Vulcan NRTE has argued that the risks associated with the current site activities are ALARP. Whilst acknowledging this argument, DNSR believes that in the spirit of the Stress Tests there is scope for "Creative Review" (see paragraph 5.22) as a normal part of the PRS process.

BAES Barrow

6.54 BAES has not needed to provide information on the capability of its facilities to withstand severe natural hazards. This is because the nuclear safety case is based on the premise that the submarine is tolerant to any failures of the facilities that could arise from severe natural hazards. When undertaking the Stress Tests four extreme scenarios have been identified, verging on the incredible, in order to test the self-sufficiency of the submarine and the resilience of the site arrangements to provide an appropriate response. Noting that the activities undertaken at BAES Barrow are very different to those at Fukushima or a civil NPP, DNSR believes that this is a reasonable approach meeting the spirit of the specification of the Stress Tests.

¹⁶ The precise details are classified information and cannot be discussed in this report.

6.55 BAES has identified a total of thirty-four *Considerations* which it has listed under four headings, which are summarised below:

6.55.1 FURTHER ANALYSES: The purpose of the *Considerations* under this heading is to better define the effects on the reactor plant/nuclear fuel of almost incredible combinations of effects. Five *Considerations* are identified.

6.55.2 EMERGENCY PLANNING: The *Considerations* under this heading are based on the premise that it might be appropriate to strengthen the link between safety case accident sequences and emergency planning. Nine *Considerations* are identified.

6.55.3 POST ACCIDENT ENVIRONMENT: The *Considerations* under this heading relate to the need for potential environments, on and off site, to be recognised within the emergency arrangements and emergency plans. Twelve *Considerations* are identified.

6.55.4 SUPPORTING EQUIPMENT AND PROVISIONS: The *Considerations* under the final heading recognise the need for those tasked with responding to an emergency to be fully aware of the equipment and facilities available at Barrow. Eight *Considerations* are identified.

6.56 Some *Considerations* identified by BAES relate to gaining an improved understanding of the response of the submarine during beyond design basis accidents. NRPA has information of relevance to these *Considerations* and therefore BAES will need to consult with NRPA to establish whether there is a need to take them forward.

6.57 DNSR believes the number and scope of the *Considerations* identified by BAES to be indicative of a thorough "Creative Review". DNSR will seek assurance that the *Considerations* identified by BAES are shared with the other Authorisees.

6.58 Prior to undertaking the Stress Tests, BAES responded to the ONR Interim Recommendations. BAES response to the majority of the Interim Report recommendations was to state that they would be incorporated into the 2014 PRS. DNSR considers that BAES should give further consideration to the ONR Recommendations at the same time as addressing their own *Considerations*.

Devonport

6.59 As a result of undertaking the Stress Tests DRDL and HMNB Devonport have concluded that their facilities at the Devonport site are fully resilient with respect to design basis events (once in ten thousand year frequency of occurrence) and compliant with the UK regulatory framework. It is only when significantly more extreme beyond design basis events are considered that DRDL and HMNB Devonport believe that their facilities will come under strain. As part of the PRS process, detailed points arising from the Stress Tests are to be reviewed further. PRS improvements are undertaken as part of the process of continuous improvement. For instance, a building is shortly to be seismically upgraded to reduce the risk of collapse in the event of a large earthquake.

6.60 DRDL and HMNB Devonport have identified thirty-four *Considerations* under six headings, which are summarised below:

6.60.1 SEISMIC: Considerations relate to provision of equipment and services and to the withstand of support facilities. Nine *Considerations* are identified.

6.60.2 FLOODING: A number of *Considerations* have been identified relating to increased waterproofing of the site, particularly with respect to the electrical overside services. Twenty-two *Considerations* are identified.

6.60.3 EXTREME WEATHER: Considerations relate to impact on buildings and electrical supplies. Two *Considerations* are identified.

6.60.4 LOSS OF SITE ELECTRICS: The single *Consideration* identified is for investigating options for additional alternative generators.

6.60.5 LOSS OF ULTIMATE HEAT SINK: A single *Consideration* has been identified related to extending existing justifications for use in dry dock.

6.60.6 SEVERE ACCIDENT MANAGEMENT: Considerations relate to storage of equipment and communications systems. Three *Considerations* are identified.

6.61 HMNB Devonport and DRDL have responded separately to the ONR Interim Recommendations. However, their responses are very similar allowing for the different activities undertaken by the different organisations. More detailed information is provided in the Stress Tests report, which therefore needs to be referred to in order to fully understand how HMNB Devonport and DRDL have addressed the ONR Interim Recommendations. Both organisations note that the provision of certain responses is ongoing, with this dependent on advice to be developed within MoD forums. DNSR accepts this is an appropriate response at this time, but will be monitoring progress to gain assurance that there is satisfactory resolution of these issues.

Clyde

6.62 Generally the information provided by HMNB Clyde is a good summary of the technical justification of the facilities, although DNSR considers the Stress Tests information provided by the NRPA and DRDL / HMNB Devonport as important supplementary information. HMNB Clyde's ongoing PRS programme also gives DNSR confidence that all activities are undertaken safely with appropriate consideration given to extreme natural hazards and site resilience.

6.63 HMNB Clyde has identified a number of potential improvements. Proposed improvements that have been identified are summarised below:

- Undertake additional flooding studies and analyses.
- Undertake improvements to the flood resistance of the facilities that provide electrical overside services.
- Evaluate the potential for landslide generated waves on Gare Loch / Loch Long to affect the nuclear facilities.
- Undertake a site specific seismic hazard assessment.
- Monitor further developments on the effects of "Seaquake".
- Additional provision of either truck or barge mounted portable diesel alternator(s) and sea water pump(s).
- Provision of additional flexible lifting equipment such as a barge mounted derrick.
- Re-evaluation of the effects of blast pressures from accidental explosion of onsite gas mains and potential offsite accidents.
- Update past analysis on the effects of failure of a bulk nitrogen storage vessel onsite.
- Undertake communication upgrades.

6.64 DNSR will engage further with HMNB Clyde on supplementary information required to gain further assurance that HMNB Clyde's reviews of their facilities are of suitable and sufficient depth. Based on the information currently provided, DNSR believes that HMNB Clyde would benefit from sharing good practice identified through other Authorisees' assessments.

6.65 HMNB Clyde has provided a response to the ONR Interim Recommendations that makes reference to ongoing programmes of work; in particular it is noted that the PRS is in progress with findings to be reported in 2012. When undertaking a regulatory review of the HMNB Clyde PRS, DNSR will look for evidence the lessons from the events at Fukushima have been incorporated appropriately. HMNB Clyde notes, as do other Authorisees, that the provision of certain responses is ongoing, as this is dependent on advice to be developed within MoD forums.

NRPA

6.66 NRPA has carried out a substantial programme of work evaluating the implications of the Fukushima event, applying the stress test principles to the NRP at sea and alongside, both operating and shut-down. This is reported in a summary document to DNSR.

6.67 In relative terms the reactors used within submarines are smaller and have a much lower power rating than civil power reactors, and typically operate at a fraction of their maximum permitted operating power. A submarine, its highly trained crew and its onboard systems are by design able to operate in hostile environments and there are multiple protective systems to safeguard against accidents.

6.68 When undertaking submarine design, consideration is given to postulated extreme accident scenarios including multiple faults and loss of systems from damage. Generally, compared to civil NPP, the equipment on board a submarine is of higher resilience. Furthermore, the submarine reactor has extremely robust primary and secondary containment. The capability of a submarine to continue to operate as systems are progressively removed is militarily highly classified information (but is known to DNSR).

6.69 DNSR is satisfied that NRPA has effected a thorough review taking account of lessons identified to date from the Fukushima event. However, DNSR considers that the "stress test" approach, though similar in principle to Design Basis Analysis and which should yield the same outcome, is a useful discipline. DNSR will monitor closely the application of this approach in the assessment of the resilience of the next generation of submarine reactor designs.

6.70 As noted at paragraph 7.23 below, DNSR will be engaged in the updating of the HSE SAPs and the supporting TAGs. DNSR will seek to ensure that the factors of particular relevance to submarine reactors are adequately reflected within the HSE SAPs and TAGs. DNSR will give the NRPA early visibility of the thinking as it applies to the regulation of the submarine reactor plant design.

Navy Command

6.71 Navy Command is the duty holder for the Operational Berths used by Submarines. When at an operational berth there are no nuclear safety requirements placed on the services to the submarine because the onboard nuclear safety systems are fully available, as if the submarine were at sea. Nuclear safety is therefore demonstrated by the at sea case which is the responsibility of NRPA. There is a potential for the facilities at an Operational Berth to present additional hazards to the submarine compared to an at sea submarine. Navy Command therefore assesses each operational berth to check that there could be no adverse challenge to nuclear safety, and that off-site emergency arrangements are adequate.

6.72 DNSR generally views the information provided by Navy Command to be a sufficient response to the Stress Tests and ONR Interim Recommendations.

Transport

6.73 The transport of radioactive material is essentially regulated against IAEA Safety Standard TS-R-1 (currently 2009 Edition), 'Regulations for the Safe Transport of Radioactive Material'. The amount of radioactive material (i.e. activity not mass, and whether fissile material is involved) determines which category of Transport Container the package design must conform to. At a certain threshold (activity and all fissile package designs), the package design must be approved by the appropriate Competent Authority as satisfying the IAEA Regulations (below this threshold self certification can take place). It is the package design and not an individual package manufactured to that design which is approved by the Competent Authority; DNSR is the Competent Authority for such packages in the DNP. On satisfying the IAEA Regulations, a Certificate of Approval can be issued for the package design, covering allowable contents, handling, operational requirements and emergency arrangements etc. The owner, consignor, carrier of the package design must adhere to the approved QA programme (e.g. covering maintenance) and Certificate of Approval to ensure that the package design is being used as intended. As part of the approval process the package design must be proved to meet certain test conditions to simulate potential worst case effects of routine, normal and accident conditions of transport. For the packages containing significant quantities of activity and/or fissile material the tests to be satisfied are to ensure that, in particular, containment, adequate shielding and criticality safety are maintained. These tests cover severe impact, penetration, thermal (i.e. fire) and flooding. After the tests the package contents must remain in a safe state and meet the appropriate requirements of the IAEA Regulations. The impact/fire tests are particularly onerous and give confidence in the package withstand in extreme external events (e.g. earthquake, flooding, tsunami).

Nuclear Weapons

6.74 A modern-standards Operational Safety Case (OSC) has recently been produced for the transportation of Nuclear Weapons. Whilst producing the OSC, the Authorisee incorporated the recommendations from the ONR Report on the Fukushima accident.

6.75 The OSC includes a wide range of hazards to transport operations, both within the Design Basis (DB) and Beyond the Design Basis (BDB). The OSC was completed at a point when a PRS would have been required; therefore the management arrangements for delivering a Safe and Secure transport operation were also scrutinised. The Authorisee has reported that the OSC reviewed the dominant hazards presented to the

transport operation and has applied 'Stress Tests' (in that two orders of magnitude were added to these hazards) and the response was still well within safety margins.

6.76 Whilst the OSC considers the severe accident it does not consider the emergency response which is covered by the Authorisee's Nuclear Emergency Response Organisation (NERO). The transport operation has a number of layers of emergency response located at a wide variety of geographical areas. As the operation traverses the UK the effects of extreme conditions will vary greatly. All conditions, including weather conditions, which could have an effect on the safe and timely transportation of Nuclear Weapons are monitored and if criteria are not met the journey is postponed until favourable conditions return. The Severe Accident Response is regularly exercised and DNSR assessments have found the transport NERO arrangements to be satisfactory.

6.77 The Authorisee considers the overall transport operation for the movement of Nuclear Weapons to be tolerable and ALARP, even when considering the extreme conditions as seen in Fukushima. DNSR considers the measures put in place for the transport of Nuclear Weapons to be adequate.

Special Nuclear Material and Nuclear Fuel

6.78 The responses received by DNSR do not encompass transport of Special Nuclear Material (SNM) in the NWP or reactor fuel in the NNPP; nevertheless, some discussion is provided below.

6.79 Arrangements similar to those applied for NW apply to the transport of Special Nuclear Material in the NWP; packages are compliant with International Standards.

6.80 The large shielded flasks designed for transport of irradiated nuclear fuel are very robust and of massive weight/structure meaning that the effects of natural events (flooding, impact by super structure and any short lived intense fire (i.e. less than 30 minutes) will be mitigated by the package design. For packages not containing highly active nuclides but significant quantities of fissile material the package design need not include large amounts of shielding material such as steel/lead. Consequently these package designs are smaller and lower in mass; thus, there may be more potential for damage by impact (e.g. from a building structure crashing on to a package when on an unyielding surface). Nevertheless, for the package designs in question, there is confidence that extreme natural events will not compromise the containment/shielding/criticality safety aspects, noting that the ultimate radiological hazard from such packages is much lower (the package need maintain only one CSF, containment).

New Designs

6.81 The Next Generation Nuclear Propulsion Plant (NGNPP) design is not yet complete and its resilience is being assessed using a 'stress test' approach at appropriate points in the design process. This work is considering appropriate lessons learnt and is consistent with DNSR's expectations.

6.82 The unique design and utility of nuclear submarines makes them likely to be resilient against the stresses applied to the Fukushima plant, and provides a different environment to that experienced by land based civil plant. DNSR is, therefore, ensuring that the reactor plant Authorisee takes appropriate account of the submarine environment in its safety assessments.

7. Responses to ONR Recommendations

Recommendations Relevant to Authorisees

7.1 The information provided to DNSR by Authorisees in response to the Stress Tests has generally been more detailed than that provided in response to the ONR Interim Recommendations. Therefore the discussions in this report on the Stress Test assessments generally cover most of the issues relevant to the ONR Interim Recommendations. However, some further discussion of the Authorisees' responses to the ONR Interim Recommendations is provided below. Many of these Recommendations relate to long term objectives of ensuring that all potential lessons are learned and acted upon. Having reviewed Authorisees initial responses, DNSR is broadly satisfied with the proposed forward actions, and will monitor progress against these as part of its normal regulatory processes.

IR-1 to IR-4: General

7.2 The Authorisees' responses to the first four ONR Recommendations (IR-1 to IR-4 inclusive) were generally supportive of the initiatives proposed with regard to national and international arrangements and use of the Nuclear Emergency Planning Liaison Group to instigate a review of the UK arrangements. With respect to IR-4, DNSR recognises the need to protect MoD information due to UK national security considerations.

IR-8 to IR-25: Relevant to the Nuclear Industry

7.3 Recommendations IR-8/9 are concerned with off-site resilience in extreme conditions and whether sites are self-sufficient. DNSR has generally received comprehensive responses from the various Authorisees, who have examined reliability of power supplies, water supplies, impact on operations, the need for additional diesel generators and sustainability of operation of emergency control rooms.

7.4 Recommendation IR-10 is to initiate a review of flooding studies, including tsunamis, and the need for enhanced defences. The site Authorisees have presented flooding reviews as part of the Stress Tests and raised a number of *Considerations*. Further discussion is provided in paragraph 6.19 above.

7.5 Recommendation IR-11 is concerned with multiple reactor sites and in particular new sites. There are a number of sites in the DNP where more than one reactor may be present at a given time. The presence of multiple reactors on a single site is addressed by Authorisees within their site safety cases.

7.6 Recommendation IR-12 is concerned with the adequacy of any new spent fuel strategies. The Authorisees to whom this is relevant provided an adequate response.

7.7 Recommendation IR-13 is concerned with how the site and plant layout protects against extreme external events. The Authorisee responses generally provide adequate discussion of the protection measures in place and identify areas for further consideration where appropriate.

7.8 Recommendation IR-14 is concerned with the proximity of new spent fuel ponds to reactors. Vulcan is the only site where fuel is stored in close proximity to the reactor. No new spent fuel ponds are currently proposed for DNP sites.

7.9 Recommendation IR-15 is concerned with the provision of any new information on the performance of concrete and how it might impact on existing site structures. DNSR will seek to gain assurance that sites have the necessary processes in place to monitor developments on such issues arising from the Fukushima accident that have the potential to affect their site safety cases.

7.10 Recommendation IR-16 is concerned with not focusing on seismic and tsunami hazards only, but giving consideration to all extreme hazards. DNSR emphasised to Authorisees that in reviewing the lessons learnt from Japan, care should be taken not to focus too closely on the specifics of the problems at Fukushima. It is noted that the Stress Tests drive an approach where sequential loss of the lines of defence must be assumed; this is not limited to consideration of seismic and tsunami hazards.

7.11 Recommendation IR-17 is concerned with assuring robustness of National Grid power supplies. The Authorisee responses were supportive of initiatives to improve reliability of these essential supplies.

7.12 Recommendation IR-18 is concerned with the provision of additional, diverse robust long-term independent supplies when off-site supplies are lost. The site Authorisees have presented reviews of the diverse methods of providing reactor services as part of the Stress Tests with a number of *Considerations* raised. This is an area where DNSR considers that good practice needs to be shared between Authorisees; DNSR will consider specific site issues through normal regulatory/site business inspections.

7.13 Recommendation IR-19 is concerned with long-term supply of cooling to a site with widespread disruption. The Authorisee responses discuss the coolant supplies to facilities from existing options on sites and identify areas for further consideration where appropriate. If a submarine is berthed, its own systems and external loch or estuary supplies will keep the plant cool when required.

7.14 Recommendation IR-20 is concerned with contingency water supplies to make up any storage pond water losses following a major accident. MoD has facilities for storing fuel in ponds at Vulcan; see paragraph 6.55.

7.15 Recommendation IR-21 is concerned with ventilation and venting routes for combustible gases on nuclear facilities. This issue is particularly important following a severe accident when activity and hydrogen could potentially escape. DNSR will engage with NRPA on whether further *Considerations* for improving Severe Accident Management need to be investigated.

7.16 Recommendation IR-22 is concerned with provision of on-site emergency control, instrumentation and communications in the light of insights from Fukushima. This is an extensive topic area and is likely to involve co-ordination and co-operation with other Government organisations. DNSR will expect Authorisees to take cognisance of developments in what is considered relevant good practice in this area.

7.17 Recommendation IR-23 is concerned with robustness of off-site communications for severe accidents involving widespread disruption. The Authorisees have presented reviews of the diverse methods of communications as part of the Stress Tests, with a number of *Considerations* raised. This is an area where DNSR considers that good practice needs to be shared between Authorisees; DNSR will consider specific site issues through normal regulatory/site business inspections.

7.18 Recommendation IR-24 is concerned with severe accident contingency arrangements, training and organisational factors. Recommendation IR-25 is concerned with provision of appropriate analyses for long-term evaluation of severe accidents and the need for appropriate site supplies, equipment and logistics. DNSR considers that Authorisees should engage with the relevant emergency response forums to ensure that lessons learned in these areas are appropriately implemented; see also the discussion under IR-6/7 below.

Recommendations Relevant to the Regulator

7.19 ONR's Final Report (Reference 4) also raised a number of Recommendations relevant to the Regulator. DNSR's response to those Recommendations is discussed below.

IR-4: Openness and Transparency

7.20 DNSR notes the intention for ONR, the statutory regulatory body, to be open and transparent about its decision making, so that it can clearly demonstrate its independence and is trusted by the public and other stakeholders. DNSR is similarly independent and seeks to demonstrate this to maintain public confidence. In support of this aim, DNSR regulates nuclear safety jointly with ONR on several DNP sites and is always open and transparent to the extent that national security allows. When regulating defence nuclear safety DNSR adopts the same regulatory stance regardless of whether or not the safety arguments have a dependency on classified defence information. DNSR is therefore able to ensure effective regulation irrespective of national security or classification constraints.

7.21 DNSR's vision is "Demonstrably safe Defence Nuclear Programmes providing effective, available capability" and the mission statement is "To regulate nuclear and radiological safety of the Defence Nuclear Programmes so that they are managed with due regard for the protection of the workforce, the public and the environment".

7.22 The information in this report demonstrates DNSR's commitment to being open and transparent to the extent that national security allows. DNSR notes that AWE is to review forums through which the public and other stakeholders are informed of the hazards, risks and emergency arrangements at AWE's sites. DNSR will be encouraging other defence nuclear sites to undertake similar reviews.

IR-5: Safety Assessment Approach

7.23 Recommendation IR-5 is for ONR to undertake a formal review of the Safety Assessment Principles (SAPs) and underpinning Technical Assessment Guides (TAGs) to determine whether any additional guidance is necessary in the light of the Fukushima accident. DNSR engaged closely with ONR (then NII) to ensure the relevance of the current SAPs (2006 version) to activities and facilities in the DNP, and anticipates similar engagement for the next update of the SAPs. DNSR similarly engages with ONR on the production of ONR TAGs. Furthermore, DNSR intends to consider whether any updates are needed to the NWR SAPs and DNSR TAGs in the light of Fukushima when they are next reviewed.

IR-6/7: Emergency Response Arrangements and Exercises

7.24 Recommendations IR-6 and IR-7 relate to emergency response arrangements and exercises. DNSR has identified the Nuclear Emergency Arrangements Group (NEAG) as an existing forum for the coordination of any required activities for improvements in DNP emergency response arrangements arising from the post-Fukushima reviews. NEAG has subsequently agreed to take the lead for coordination of any arising 'pan-defence' issues, with individual duty holders leading for emergency arrangements issues particular to their site(s). The NEAG have reported that no significant pan-defence emergency arrangements issues have been identified to date, although two potential common areas might arise in the future:

- Potential requirements on the availability and provision of additional portable generators may result in sufficient pan-MOD demand that it warrants the NEAG's involvement to achieve a most cost-effective and cost-efficient solution.
- Further work on resilience at a national level (in response to the ONR Final Report) may see changes to the national expectation, particularly with regard to 'extendibility', that will warrant NEAG engagement.

7.25 With regard to wider considerations for UK nuclear emergency planning, MoD will be represented at the recently formed cross-government Nuclear Emergency Arrangements Board, chaired by the Department for Energy and Climate Change (DECC). MoD will also continue to interface with the Nuclear Emergency Arrangements Forum (NEAF), which has representation from ONR and UK Licensees.

7.26 DNSR understands that what is considered 'relevant good practice' with regards to emergency arrangements may change as a result of new reasoning on what is appropriate and proportionate. DNSR intends to be active in promoting the necessary discussions and gaining assurance that Authorisees appropriately respond to what will be a national debate. DNSR will expect Authorisees to progress any identified *Considerations* with respect to their own on-site and local off-site emergency arrangements. *Considerations* with respect to wider external support will expect to be progressed through the NEAG, which should be appropriately coordinated with work under the cross-government Nuclear Emergency Arrangements Board.

7.27 Recommendation IR-6 is for the regulator to consider to what extent long-term severe accidents can and should be covered by the programme of emergency exercises. DNSR recognises the potential benefits of longer duration exercises and will give further consideration to this, taking cognisance of developments in thinking from the aforementioned forums.

7.28 Recommendation IR-7 is for the regulator to review the arrangements for regulatory response to potential severe accidents to see whether more should be done to prepare. DNSR is currently giving consideration to an initiative to support this.

FR-10: Research

7.29 The ONR Final Report highlights a number of areas where it is considered that new research is needed. Recommendation FR-10 is for the regulator to expand its oversight of nuclear safety-related research, particularly that needed to take forward lessons from Fukushima. In the DNP, the primary responsibility for undertaking the necessary nuclear safety-related research lies with the Authorisees and in particular with the Design and Approving Authorities for NRP and NW. However, DNSR recognises the importance of gaining assurance that the necessary research to support existing and planned facilities is being undertaken. DNSR may consider its current oversight of nuclear safety-related research.

Way Forward

7.30 DNSR will continue to interact regularly with ONR to ensure there is appropriate consistency in regulation between the civil nuclear and defence nuclear sector with regard to implementation of lessons (whilst recognising that substantial differences exist between the civil and defence nuclear programmes). DNSR will be open and transparent to the extent that national security constraints allow. DNSR considers that it is likely that thinking will develop further with respect to emergency response arrangements and exercises, and will gain the necessary assurance that relevant good practice is taken on-board by Authorisees. DNSR will take forward these issues as part of normal regulatory business.

8. Conclusions

8.1 No major issues have arisen as a result of the Authorisee reviews in response to the ONR Interim Recommendations and the ENSREG Stress Tests. Generally the Authorisee submissions have drawn heavily on information already to be found in their safety cases; the Authorisees' PRS processes will ensure that the extant safety cases will continue to consider relevant lessons learnt and be the subject of a continuous improvement regime. The Authorisees have generally assembled the necessary information and reported their findings within the requested time-scales. The continued operation of the nuclear powered (including nuclear armed) submarine fleet, and land-based nuclear activities supporting the DNP in the UK, is supported by DNSR.

8.2 The important process of "Continuous Improvement" is formalised by the requirement to conduct PRS. As discussed in this report, a number of potential areas for improvement have been identified, which are to be addressed by future programmes of work. DNSR will be seeking assurance that Authorisees take cognisance of relevant developments in international research programmes and their outcomes, as nuclear safety enhancements and new insights in the areas of severe environmental hazards, emergency planning and severe accidents are likely to emerge.

8.3 With regard to the application of the Stress Tests to the arrangements for severe accident management, there has been some variability between Authorisees as to what is considered credible and the depth to which "Creative Review" has been undertaken. DNSR considers that it would be beneficial for Authorisees to share good practice identified through the assessments; as a result, there is potential for more *Considerations* to be identified in addition to those already presented.

8.4 Nuclear Operators and Regulators internationally are examining accepted good practice regarding their emergency arrangements. DNSR intends to be active in promoting the necessary discussions and gaining assurance that DNP Authorisees are represented adequately at appropriate fora to contribute to the debate and for the findings and way forward to be decided, following discussion and deliberations within the NEAG.

8.5 DNSR will ensure that the factors of particular relevance to submarine reactors are adequately reflected in the updating of the HSE SAPs and the supporting TAGs. DNSR will be seeking assurance that the lessons learnt from the Fukushima event are appropriately captured within future improvement of the PSA. For the next generation of nuclear submarines DNSR will assess whether the modelling of beyond design basis external and internal submarine hazards is conducted appropriately. The information made available to DNSR by the Next Generation submarine project team indicates that a reasonable approach is being followed and DNSR will keep this under review.(6.34).

8.6 DNSR Inspectors continuously monitor Authorisees (including Design and Approving Authorities) by undertaking inspections and assessments in accordance with regularly reviewed intervention strategies. The intervention strategies will be updated to include the need for Authorisees to sentence and address their *Considerations*, implementing those agreed as reasonably practicable from the Stress Tests and those appropriate from ONR Recommendations. Furthermore, at various points throughout section 6, the need for additional information is identified. DNSR will engage with authorisees to progress both these as part of normal regulatory processes. DNSR will also monitor how *Considerations* are addressed to check whether it is consistent with developments in UK civil and international practices.

8.7 Further to the above, the key conclusions of this report are tabulated below.

Conclusion 1	All areas of the DNP have been subjected to assessments based on the European Stress Test and the ONR Recommendations. The continued operation of the nuclear powered (including nuclear armed) submarine fleet, and land-based nuclear activities supporting the DNP in the UK, is supported by DNSR.
Conclusion 2	DNSR will continue to engage with Authorisees to gain the necessary assurance that Periodic Reviews of Safety are undertaken in an adequately thorough and timely manner to support the implementation of lessons from the Fukushima accident.
Conclusion 3	Regulation of the design of future reactors, military and civil, must incorporate any appropriate lessons from the Fukushima accident which might affect Reactor Design.
Conclusion 4	DNSR has identified a number of areas where the provision of further information or clarification is needed; DNSR will engage further with Authorisees in these areas.

Table 1 – Key Conclusions

9. References

- 1 ONR HM Chief Inspector of Nuclear Installations: “Japanese earthquake and tsunami: Implications for the UK nuclear industry, Interim Report”, dated May 2011. (Link(c))
- 2 ENSREG Stress Test Specifications. (Link(d))
- 3 HSE Safety Assessment Principles for Nuclear Facilities, 2006 Edition, Revision 1 dated January 2008. (Link(e))
- 4 ONR HM Chief Inspector of Nuclear Installations: “Japanese earthquake and tsunami: Implications for the UK nuclear industry, Final Report”, dated September 2011. (Link(f))
- 5 Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety: The Accident at TEPCO’s Fukushima Nuclear Power Stations Nuclear Emergency Response Headquarters Government of Japan, dated 7 June 2011. (Link(j))
- 6 IAEA Mission Report: “IAEA International Fact Finding Expert Mission of the Fukushima Dai-Ichi NPP Accident Following the Great East Japan Earthquake and Tsunami”, dated 16 June 2011. (Link(i))
- 7 INPO Report 11-005 Revision 0: “Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station”, dated 11 November 2011. (Link(k))
- 8 ONR Report: “European Council ‘Stress Tests’ for UK nuclear power plants, National Final Report”, December 2011. (Link(g))
- 9 ONR Report: “Stress tests for UK Non Nuclear Power Plants, Progress Report”, December 2011. (Link(h))
- 10 Principia, Seismic Ground Motions for UK Design, Report prepared for British Nuclear Fuels Limited and Central Electricity Generating Board, April 1981.
- 11 Kerridge D: The threat posed by tsunami to the UK, June 2005, Study commissioned by Defra Flood Management. (Link(l))
- 12 HR Wallingford: Tsunamis – Assessing the Hazard for the UK and Irish Coasts, June 2006 (Link(m))

10. Web-links

A list of URLs for website links in this report is provided below:

- (a) http://en.wikipedia.org/wiki/2011_Japanese_nuclear_accidents
- (b) http://en.wikipedia.org/wiki/Evangelos_Florakis_Naval_Base_explosion
- (c) www.hse.gov.uk/nuclear/fukushima/interim-report.pdf
- (d) www.ensreg.eu/sites/default/files/EU%20Stress%20tests%20specifications_0.pdf
- (e) www.hse.gov.uk/nuclear/saps/saps2006.pdf
- (f) www.hse.gov.uk/nuclear/fukushima/final-report.pdf
- (g) www.hse.gov.uk/nuclear/fukushima/stress-tests-301211.pdf
- (h) www.hse.gov.uk/nuclear/fukushima/stress-tests-061211.pdf
- (i) www-pub.iaea.org/MTCD/Meetings/PDFplus/2011/cn200/documentation/cn200_Final-Fukushima-Mission_Report.pdf
- (j) www.iaea.org/newscenter/focus/fukushima/japan-report/
- (k) www.nei.org/resourcesandstats/documentlibrary/safetyandsecurity/reports/special-report-on-the-nuclear-accident-at-the-fukushima-daiichi-nuclear-power-station
- (l) <http://archive.defra.gov.uk/environment/flooding/documents/risk/tsunami05.pdf>
- (m) <http://archive.defra.gov.uk/environment/flooding/documents/risk/tsunami06.pdf>
- (n) www.mod.uk/DefenceInternet/MicroSite/DES/WhatWeDo/SDP/

Appendix A – UK Defence Nuclear Programme Arrangements

A.1 The phrase Defence Nuclear Programme (DNP) is used herein to cover the totality of both the Nuclear Weapons Programme (NWP) and the Naval Nuclear Propulsion Programme (NNPP). There are a number of important differences between the civil nuclear programmes and the DNP. Submarines and nuclear weapons are both transportable and for operational reasons are required to be very robust, since their normal design requirements call for safe operation in hostile military environments.

The Nuclear Weapons Programme

A.2 The NWP comprises four lifecycle phases: development, manufacture, assembly and disassembly at the Atomic Weapons Establishment (AWE); transport between AWE and HMNB Clyde; storage and in-service support at Clyde and deployment on Vanguard Class submarines. The Strategic Weapons Project Team (within Defence Equipment & Support at Abbey Wood) is the Approving Authority for NW and design is undertaken by AWE.

AWE

A.3 AWE provides and maintains the warheads for the UK's nuclear deterrent and undertakes its activities at Aldermaston and Burghfield in Berkshire. Besides undertaking the assembly and disassembly of warheads AWE undertakes activities involving toxic and hazardous substances, including radioactive and explosive materials. The main radioactive materials handled and processed on the AWE sites are plutonium, highly enriched uranium, depleted uranium and tritium. They are usually either in solid form, machined swarf or oxide powders for the metals and in gaseous form for tritium.

A.4 All nuclear activities at AWE are Licensed by ONR. Activities where nuclear materials are combined with explosive materials are jointly regulated (Licensed and Authorised) by ONR and DNSR.

A.5 See paragraphs A.30 below for Transport and A.26 for HMNB Clyde.

The Naval Nuclear Propulsion Programme

A.6 The NNPP essentially comprises all activities and operations required in support of the propulsion plant used within the UK's Nuclear Powered Warships (NPW)¹⁷, from initial design, testing and build of the reactor and fuel, through operation, maintenance and repair, to final decommissioning and disposal. Before discussing the various organisations and sites which provide support to the NRP, it is considered useful to present a brief discussion of the NRP itself, both when at sea, and alongside.

NRP at Sea

A.7 A UK nuclear powered submarine is an autonomous unit that is designed to operate for prolonged periods at sea with no external support and, as noted earlier, is required to perform all of its functions in a potentially hostile military and marine environment. As an example, the NRP is designed to withstand the effects of blast and shock loading from underwater explosions external to the submarine, with the justifications underwritten by both testing and actual experience from military action. The equipment used within the NRP has a level of demonstrated robustness significantly in excess of that found in commercial NPP, which would be extremely unlikely to meet naval shock requirements. The NRP also features a number of diverse and redundant systems, each of which has been designed taking into account the required autonomous operation. The submarine crew also has well developed emergency arrangements, that are maintained in a high state of readiness through continuous assessment and exercises.

A.8 The key safety issues for the NRP are essentially no different to those for civil plant, and include: control of reactivity; control of core temperature; and control of radiation exposure and control of release of radioactive material. When at sea:

A.8.1 Reactivity is controlled via withdrawal or insertion of the control rods.

A.8.2 Following shutdown, core temperature is controlled by the provision of multiple, self sufficient and diverse Decay Heat Removal (DHR) systems within the NRP design, including a passive system

¹⁷ The NPW propulsion plant is variously referred to as the Naval Reactor Plant (NRP) and / or the Nuclear Steam Raising Plant (NSRP).

that is rated to dissipate heat loads associated with a shutdown from full power. Under normal circumstances, the ultimate heat sink is seawater, which is in plentiful supply for a floating submarine. The design of the plant allows for long timescales to initiate back-up systems in the event that the duty system fails. The systems are internal to the pressure hull and distributed across watertight compartments. Ultimately cooling is able to be provided by natural circulation, without power, utilising only short lengths of pipe and an emergency cooling tank that utilises seawater.

A.8.3 Control of radiation exposure and control of release of radioactive material is ensured by the provision of multiple barriers (including fuel clad, primary circuit, primary and secondary containment) between the reactor fuel or radioactive material and the operator. In addition the internal steel bulkheads and hull of a submarine provide a substantial containment, noting that a submarine is designed to be both watertight and capable of withstanding substantial water pressure, with this tested during normal operations. The presence of openings in barriers (for example, access hatches) is strictly controlled including a requirement for rapid closure by the crew – this is a matter of routine for a submarine crew when for reasons of ship safety it is necessary to maintain watertight compartments.

A.9 In relative terms the reactors used within submarines are smaller and have a much lower power rating than civil power reactors, and typically operate at a fraction of their maximum permitted operating power. Fundamentally a submarine and its onboard systems are by design able to operate in hostile conditions, for which the crew are highly trained and conditioned.

A.10 The navy has multiple secure hardened systems for communicating with a submarine anywhere in the world and is able to rapidly draw on the flexible resources of the UK military should a situation develop with a submarine requiring external assistance, including in the very unlikely event of a reactor accident. The on-board personnel with responsibility for the reactor are trained to the highest standards of plant operation and supervision, with their abilities being tested and monitored through rigorous qualification processes and continuation training, including simulator and formal assessment regimes. The crew participate in substantial confirmatory exercises to evaluate their ability, under stress, to make the right decisions and to implement the appropriate actions.

NRP Alongside

A.11 When alongside the NRP has no direct reliance upon shore supplies for critical (power) operations or following shutdown. However, when berthed it is often advantageous for certain services to be provided from the shore (referred to as over-side services). This leads to reduced work for the crew and reduced operating of onboard equipment, and can enhance safety as a result of the additional redundancy and diversity that the over-side services provide. When berthed and receiving over-side services the ability to switch back to the on-board systems is always present, unless there is a fully managed and controlled process in place to undertake maintenance / tests on the submarine systems. All submarine maintenance / repairs are strictly managed and controlled. The key safety issues are essentially the same as when a submarine is at sea, with additional features, as follows:

A.11.1 Reactivity is controlled via withdrawal and insertion of control rods. For some periods alongside, additional measures are available, such as control rod locking measures and/or provision of boronated water.

A.11.2 Cooling water for core temperature control can be provided by over-side services, in addition to the usual on-board systems and seawater. The time taken for a shut down submarine reactor to reach a state where natural heat losses are sufficient to cool the reactor is much shorter than a civil power reactor. If any significant nuclear work is undertaken on a submarine the task is delayed until the natural heat loss is sufficient to keep the reactor cool without the functioning of any additional cooling system (that is, the energy from the decay heat is insufficient to boil water at atmospheric pressure – also referred to as “Cold Shutdown” state and achievement of “Thermal Roll-Over”). Even then additional cooling systems are normally provided as for operational reasons it is beneficial to keep the reactor at a constant low controlled temperature.

A.11.3 In the unlikely event of a severe accident, the control of radiation exposure and control of release of radioactive material is ensured by the provision of multiple barriers between the reactor fuel or radioactive substances and the operator.

A.12 NRPA is responsible for providing the various defence sites with the information that they need to support and maintain the NRP whilst a submarine is at a shore support facility, including information on the limits and conditions to be applied for nuclear safety criteria to be fully met. Mature interface arrangements

exist to ensure information transfer is appropriately managed. Nevertheless, the site Authorisee has direct responsibility for on-the-day safety of activities on the authorised site.

NNPP Organisations

A.13 Organisations involved in different phases of the NNPP include:

A.13.1 **NRP approval and design:** NRPA is the Approving Authority for the NRP and Rolls Royce Marine Power Operations Ltd (RRMPOL) at Derby is the designer (see also paragraph A.12 above).

A.13.2 **Fuel manufacture:** Submarine nuclear fuel is produced at Nuclear Fuel Production Plant (NFPP) operated by RRMPOL; the raw material is sourced from AWE.

A.13.3 **Testing:** The Shore Test Facility (STF) at the Vulcan Naval Reactor Test Establishment (NRTE) in Dounreay provides important technical and safety performance information to support operating submarines.

A.13.4 **Build of the reactor:** Construction of the NRP is undertaken by BAE Systems (BAES) at Barrow-in-Furness (a licensed and authorised site).

A.13.5 **Operation:** Navy Command Headquarters (NCHQ¹⁸) directs operational command of the submarine at sea.

A.13.6 **Support, maintenance and repair:** Support and first line maintenance is undertaken whilst submarines are at HMNBs Devonport and Clyde, with more significant repairs and major long overhaul periods being undertaken by DRDL.

A.13.7 **Decommissioning and disposal:** The plans are currently under development¹⁹, but some out of service submarines are stored at Rosyth (de-fuelled NRPs only) and Devonport (both fuelled and de-fuelled NRPs) pending final disposal.

A.14 From the above, it can be seen that the major sites / facilities supporting the NNPP are:

- Rolls Royce, Derby;
- Vulcan NRTE;
- BAES Barrow;
- Devonport (DRDL Babcock and HMNB Devonport);
- HMNB Clyde²⁰ (Coulport and Faslane).

The following discussions provide a brief description of these sites / facilities, highlighting the more significant features of each:

Rolls Royce Marine Power

A.15 Rolls Royce Marine Power operates two nuclear licensed sites in support of the NNPP; the Neptune zero-power test reactor used in the research and design of naval reactor fuels, and the Nuclear Fuel Production Plant for assembly of the NNPP fuel elements.

A.16 Rolls Royce Marine Power is also the designer of the NRP having the role of NRP Technical Authority (NRP TA) providing support to NRPA.

Vulcan NRTE

A.17 Vulcan NRTE is located on the north coast of Scotland adjacent to the Dounreay Licensed Site, and provides a full-scale land-based prototype NRP, to aid plant design, research and development, operation and evaluation. The nuclear facilities at Vulcan NRTE comprise the following:

¹⁸ NCHQ was previously known as Fleet

¹⁹ See MoD Internet Microsite "Submarine Dismantling Project" (Link(n))

²⁰ The HMNB Clyde Authorised Site also includes defined Authorised activities (Laid Up Submarine (LUSM) activities) at Rosyth Royal Dockyard.

A.17.1 A pressurised water reactor is located within the Shore Test Facility (STF) building. This reactor serves as a prototype core testing and performance facility for the type of NRP fitted in Vanguard Class and Astute Class submarines. The heart of the plant is the primary circuit, which houses the reactor core and interfaces with a number of primary systems that provide the normal operating and safety functions required by the plant. The reactor plant replicates that in a submarine almost exactly. This is achieved by having the reactor plant installed in what is essentially a submarine hull with the fore and aft ends missing. This part of the submarine, including the reactor compartment and adjacent equipment areas is immersed within a large tank of water.

A.17.2 There is a decommissioned reactor referred to as DSMP1, which was the prototype for the NRP installed in previous classes of submarine (Resolution, Swiftsure and the current Trafalgar Class). This reactor has been de-fuelled, and is awaiting dismantling.

A.17.3 There are two fuel storage ponds that are sunk into the ground. One is present in the STF building and the other is located in the adjacent DSMP1 building.

A.17.4 Finally site support systems provide the essential nuclear safety services including ventilation, drainage, process gases, craneage, electrical supplies, communications and environmental monitoring.

A.18 Vulcan NRTE is an Authorised Site regulated by DNSR. The Site Authorisee is the Naval Superintendent.

BAE Systems

A.19 BAE Systems (BAES) is contracted by the MoD to build and commission nuclear submarines, including the reactor used for propulsion. The site at Barrow-in-Furness includes the Devonshire Dock Hall, a large facility that was used to construct the Vanguard Class submarines and where currently the Astute Class submarines are being constructed. Although there may be a number of individual submarines at the site, in different stages of build, and the Site Safety Case allows nuclear fuel for a number of cores to be on site at any one time, only one reactor core is permitted in any one facility on the site at any one time. Nuclear activities start when the first containers of nuclear fuel are delivered to the site and finishes when the submarine departs with the nuclear fuel present in the reactor. The fuel is in a relatively benign state during the submarine construction process with little potential to react in any adverse manner until the reactor is initially taken critical. Initial criticality occurs once a submarine is fully constructed and all of the onboard systems required under normal and accident conditions have been fully tested. A rigorous safety clearance process is conducted before DNSR permissions initial criticality.

A.20 During the short period of critical reactor operations at BAES (a few weeks every 18 months to 2 years), there is a dependency on the site arrangements and facilities. BAES have produced Operational Safety Cases (OSCs) to demonstrate and justify that the facilities, equipment and procedures are 'Fit for Purpose' (including suitable and sufficient back-up equipment to resolve possible unplanned occurrences) and that in the event of either an extreme natural or manmade hazard, nuclear safety would not be undermined.

A.21 Nuclear activities at BAES are regulated by both ONR with emphasis on licensable activities and DNSR with emphasis on activities exempted from licensing.

DRDL and HMNB Devonport

A.22 The Devonport site at Plymouth on the south coast of England consists of two parts: DRDL and HMNB Devonport. DRDL is the site licence company for that part of the site owned and operated by the Marine and Technology Division of Babcock International Group. DRDL is contracted by MoD to refit and maintain the Royal Navy's nuclear powered submarines. The Naval Base is the base port for the UK's fleet of Trafalgar Class submarines, providing facilities for operational maintenance, together with the shore support services required by the submarine and crew, and is managed by MoD under the control of the Naval Base Commander. A number of redundant submarines are currently stored afloat at Devonport awaiting defuel and dismantling.

A.23 The key facilities operated by DRDL comprise a number of graving docks ("dry docks") for the refit, repair and maintenance of the NRP and general submarine systems. By the nature of these docks, when work is being undertaken on the submarines, the docks are pumped dry, and the submarines supported on a system of cradles. These cradles have been assessed and shown to withstand the effects of the Design Basis Earthquake for the site (as have the Caissons which seal the docks and prevent water from entering).

Management arrangements are used to ensure that the configuration of the submarine and its systems meet strict requirements before being allowed to enter any of the docks, including placing limits on the allowable decay heat, so as to minimise reliance on DHR systems. For certain activities whilst in dock, additional DHR systems are provided, together with additional means of ensuring reactivity control.

A.24 At the Naval Base, a more limited range of specific submarine activities is undertaken at alongside wharves, together with provision of a wide range of submarine support services.

A.25 DRDL is regulated by both ONR with emphasis on licensable activities and DNSR with emphasis on activities exempted from licensing; HMNB Devonport is Authorised and regulated by DNSR.

HMNB Clyde

A.26 HMNB Clyde is an operational Naval Base on the west coast of Scotland comprising facilities at both Faslane and RNAD Coulport for the berthing and maintenance of nuclear powered submarines when not at sea. The facilities at RNAD Coulport are primarily provided for weapons support activities, whereas the facilities at Faslane provide shore support services required by submarines and crew. The facilities with nuclear safety functions at Faslane comprise jetties, cranes and shore supplied services together with a Shiplift used to raise a submarine out of the water for maintenance and inspections.

A.27 The Coulport jetty facility is to a large extent isolated from the effects of earthquakes, as is the Valiant Jetty at Faslane, which is currently being commissioned in support of the berthing of Astute Class submarines. For such floating structures, the effects of tidal and wave loading becomes more significant, and both of these facilities have been robustly assessed for these load effects.

A.28 The additional hazards associated with lifting a submarine out of the water using the Faslane Shiplift (for example, due to potential mechanical or control system failure) have also been carefully addressed. Multiple systems are provided to control the lift which would halt the operation if any fault or departure from the expected lift profile were detected. Stability of the submarine has been demonstrated under highly unlikely fault conditions such as failure of a pair of the platform main support beams. When raised on the Shiplift, the submarine is no longer in its natural seawater heat sink, requiring the provision of over-side water services. The reliability of these systems has been substantiated, and management arrangements ensure that the configuration of the submarine and its systems meet strict requirements before lifting is permitted. In the unlikely event that the over-side seawater supplies should fail, the submarine could revert to the standard onboard back-up systems, noting that the reactor will always be shut down with very limited decay heat to be removed.

A.29 HMNB Clyde is an Authorised Site regulated by DNSR.

Transport Activities

A.30 DNSR regulates the transport of defence nuclear material, which is exempt from the relevant UK legislation, using equivalent provisions, including acting as the Competent Authority for the approval of packages to be used for such transport.

A.31 Nuclear material in the DNP needing to undergo transport operations includes packages for nuclear weapons, Special Nuclear Material, and reactor fuel and components.

Appendix B – ONR Report Recommendations

B.1 The Recommendations in the ONR Final Report (September 2011) are re-produced below. Authorisees were asked in July 2011 to respond to the recommendations in the ONR Interim Report (May 2011). The Interim Report Recommendations are denoted *IR-*; the additional 12 Recommendations from the Final Report are denoted *FR-*.

General	
International Arrangements for Response	<p>Recommendation IR-1: The Government should approach IAEA, in co-operation with others, to ensure that improved arrangements are in place for the dissemination of timely authoritative information relevant to a nuclear event anywhere in the world.</p> <p><i>This information should include:</i></p> <ul style="list-style-type: none"> a) <i>basic data about the reactor design including reactor type, containment, thermal power, protection systems, operating history and condition of any nuclear materials such as spent fuel stored on the site should be held permanently in a central library maintained on behalf of the international community; and</i> b) <i>data on accident progression and the prognosis for future accident development. The operator would provide such information as is available to its national authorities. International mechanisms for communicating this information between national governments should be strengthened. To ensure that priority is given to relevant information, international agreement should be sought on the type of information that needs to be provided.</i>
Global Nuclear Safety	<p>Recommendation FR-9: The UK Government, nuclear industry and ONR should support international efforts to improve the process of review and implementation of IAEA and other relevant nuclear safety standards and initiatives in the light of the Fukushima-1 (Fukushima Dai-ichi) accident.</p>

General	
National Emergency Response Arrangements	<p>Recommendation IR-2: The Government should consider carrying out a review of the Japanese response to the emergency to identify any lessons for UK public contingency planning for widespread emergencies, taking account of any social, cultural and organisational differences.</p> <p>Recommendation IR-3: The Nuclear Emergency Planning Liaison Group should instigate a review of the UK’s national nuclear emergency arrangements in light of the experience of dealing with the prolonged Japanese event.</p> <p><i>This information should include the practicability and effectiveness of the arrangements for extending countermeasures beyond the Detailed Emergency Planning Zone (DEPZ) in the event of more serious accidents.</i></p> <p>Recommendation FR-6: The nuclear industry with others should review available techniques for estimating radioactive source terms and undertake research to test the practicability of providing real-time information on the basic characteristics of radioactive releases to the environment to the responsible off-site authorities, taking account of the range of conditions that may exist on and off the site.</p> <p>Recommendation FR-7: The Government should review the adequacy of arrangements for environmental dose measurements and for predicting dispersion and public doses and environmental impacts, and to ensure that adequate up to date information is available to support decisions on emergency countermeasures.</p>
Planning Controls	<p>Recommendation FR-5: The relevant Government departments in England, Wales and Scotland should examine the adequacy of the existing system of planning controls for commercial and residential developments off the nuclear licensed site.</p>
Openness and Transparency	<p>Recommendation IR-4: Both the UK nuclear industry and ONR should consider ways of enhancing the drive to ensure more open, transparent and trusted communications, and relationships, with the public and other stakeholders.</p> <p>Recommendation FR-8: The Government should consider ensuring that the legislation for the new statutory body requires ONR to be open and transparent about its decision-making, so that it may clearly demonstrate to stakeholders its effective independence from bodies or organisations concerned with the promotion or utilisation of nuclear energy.</p>

Relevant to the Regulator	
Safety Assessment Approach	<p>Recommendation IR-5: Once further detailed information is available and studies are completed, ONR should undertake a formal review of the Safety Assessment Principles to determine whether any additional guidance is necessary in the light of the Fukushima accident, particularly for “cliff-edge” effects.</p> <p><i>The review of ONR’s Safety Assessment Principles (SAP should also cover ONR’s Technical Assessment Guides (TAG), including external hazards.</i></p>

Relevant to the Regulator	
Emergency Response Arrangements and Exercises	<p>Recommendation IR-6: ONR should consider to what extent long-term severe accidents can and should be covered by the programme of emergency exercises overseen by the regulator.</p> <p><i>This should include:</i></p> <ul style="list-style-type: none"> a) <i>evaluation of how changes to exercise scenarios supported by longer exercise duration will permit exercising in real time such matters as hand-over arrangements, etc.;</i> b) <i>how automatic decisions taken to protect the public can be confirmed and supported by plant damage control data; and</i> c) <i>recommendations on what should be included in an appropriate UK exercise programme for testing nuclear emergency plans, with relevant guidance provided to Radiation (Emergency Preparedness and Public Information) Regulations 2001 (REPPiR) duty holders.</i> <p>Recommendation IR-7: ONR should review the arrangements for regulatory response to potential severe accidents in the UK to see whether more should be done to prepare for such very remote events.</p> <p><i>This should include:</i></p> <ul style="list-style-type: none"> a) <i>enhancing access during an accident to relevant, current plant data on the status of critical safety functions, i.e. the control of criticality, cooling and containment, and releases of radioactivity to the environment, as it would greatly improve ONR's capability to provide independent advice to the authorities in the event of a severe accident; and</i> b) <i>review of the basic plant data needed by ONR – this has much in common with what we suggest should be held by an international organisation under Recommendation IR-1.</i>
Research	<p>Recommendation FR-10: ONR should expand its oversight of nuclear safety-related research to provide a strategic oversight of its availability in the UK as well as the availability of national expertise, in particular that needed to take forward lessons from Fukushima. Part of this will be to ensure that ONR has access to sufficient relevant expertise to fulfil its duties in relation to a major incident anywhere in the world.</p>

Relevant to the Nuclear Industry	
Off-site Infrastructure Resilience	<p>Recommendation IR-8: The UK nuclear industry should review the dependency of nuclear safety on off-site infrastructure in extreme conditions, and consider whether enhancements are necessary to sites' self sufficiency given for the reliability of the grid under such extreme circumstances.</p> <p><i>This should include:</i></p> <ul style="list-style-type: none"> a) essential supplies such as food, water, conventional fuels, compressed gases and staff, as well as the safe off-site storage of any equipment that may be needed to support the site response to an accident; and b) timescales required to transfer supplies or equipment to site. <p>Recommendation IR-9: Once further relevant information becomes available, the UK nuclear industry should review what lessons can be learnt from the comparison of the events at the Fukushima-1 (Fukushima Dai-ichi) and Fukushima-2 (Fukushima Dai-ni) sites.</p>
Impact of Natural Hazards	<p>Recommendation IR-10: The UK nuclear industry should initiate a review of flooding studies, including from tsunamis, in light of the Japanese experience, to confirm the design basis and margins for flooding at UK nuclear sites, and whether there is a need to improve further site-specific flood risk assessments as part of the periodic safety review programme, and for any new reactors. This should include sea-level protection.</p>
Multi-reactor Sites	<p>Recommendation IR-11: The UK nuclear industry should ensure that safety cases for new sites for multiple reactors adequately demonstrate the capability for dealing with multiple serious concurrent events induced by extreme off-site hazards.</p>
Spent Fuel Strategies	<p>Recommendation IR-12: The UK nuclear industry should ensure the adequacy of any new spent fuel strategies compared with the expectations in the Safety Assessment Principles of passive safety and good engineering practice.</p> <p><i>Existing licensees are expected to review their current spent fuel strategies as part of their periodic review processes and make any reasonably practicable improvements, noting that any intended changes need to take account of wider strategic factors including the implications for the nuclear fuel cycle.</i></p>
Site and Plant Layout	<p>Recommendation IR-13: The UK nuclear industry should review the plant and site layouts of existing plants and any proposed new designs to ensure that safety systems and their essential supplies and controls have adequate robustness against severe flooding and other extreme external events.</p> <p><i>This recommendation is related to Recommendation IR-25 and should be considered along with the provisions put in place under that recommendation. It should include, for example, the operator's capability to undertake repairs and the availability of spare parts and components.</i></p>

Relevant to the Nuclear Industry	
Fuel Pond Design	<p>Recommendation IR-14: The UK nuclear industry should ensure that the design of new spent fuel ponds close to reactors minimises the need for bottom penetrations and lines that are prone to siphoning faults. Any that are necessary should be as robust to faults as are the ponds themselves.</p>
Seismic Resilience	<p>Recommendation IR-15: Once detailed information becomes available on the performance of concrete, other structures and equipment, the UK nuclear industry should consider any implications for improved understanding of the relevant design and analyses.</p> <p><i>The industry focus on this recommendation should be on future studies regarding the continuing validation of methodologies for analysing the seismic performance of structures, systems and components important to safety. This should include concrete structures and those fabricated from other materials.</i></p>
Extreme External Events	<p>Recommendation IR-16: When considering the recommendations in this report the UK nuclear industry should consider them in the light of all extreme hazards, particularly for plant layout and design of safety-related plant.</p> <p>Recommendation FR-2: The UK nuclear industry should ensure that structures, systems and components needed for managing and controlling actions in response to an accident, including plant control rooms, on-site emergency control centres and off-site emergency centres, are adequately protected against hazards that could affect several simultaneously.</p> <p>Recommendation FR-3: Structures, systems and components needed for managing and controlling actions in response to an accident, including plant control rooms, on-site emergency control centres and off-site emergency centres, should be capable of operating adequately in the conditions, and for the duration, for which they could be needed, including possible severe accident conditions.</p>
Off-site Electricity Supplies	<p>Recommendation IR-17: The UK nuclear industry should undertake further work with the National Grid to establish the robustness and potential unavailability of off-site electrical supplies under severe hazard conditions.</p>
On-site Electricity Supplies	<p>Recommendation IR-18: The UK nuclear industry should review any need for the provision of additional, diverse means of providing robust sufficiently long-term independent electrical supplies on sites, reflecting the loss of availability of off-site electrical supplies under severe conditions.</p> <p><i>This should be considered along with Recommendation IR-8 within the wider context of “on-site resilience”.</i></p>
Cooling Supplies	<p>Recommendation IR-19: The UK nuclear industry should review the need for, and if required, the ability to provide longer term coolant supplies to nuclear sites in the UK in the event of a severe off-site disruption, considering whether further on-site supplies or greater off-site capability is needed. This relates to both carbon dioxide and fresh water supplies, and for existing and proposed new plants.</p> <p>Recommendation IR-20: The UK nuclear industry should review the site contingency plans for pond water make up under severe accident conditions to see whether they can and should be enhanced given the experience at Fukushima.</p>

Relevant to the Nuclear Industry	
Combustible Gases	<p>Recommendation IR-21: The UK nuclear industry should review the ventilation and venting routes for nuclear facilities where significant concentrations of combustible gases may be flowing or accumulating to determine whether more should be done to protect them.</p>
Emergency Control Centres, Instrumentation and Communications	<p>Recommendation IR-22: The UK nuclear industry should review the provision on-site of emergency control, instrumentation and communications in light of the circumstances of the Fukushima accident including long timescales, wide spread on and off-site disruption, and the environment on-site associated with a severe accident.</p> <p><i>In particular, the review should consider that the Fukushima-1 site was equipped with a seismically robust building housing the site emergency response centre which had: adequate provisions to ensure its habitability in the event of a radiological release; and communication facilities with on-site plant control rooms and external agencies, such as TEPCO headquarters in Tokyo.</i></p> <p>Recommendation IR-23: The UK nuclear industry, in conjunction with other organisations as necessary, should review the robustness of necessary off-site communications for severe accidents involving widespread disruption.</p> <p><i>In addition to impacting communications, it is possible that external events could also affect off-site centres used to support at site in an emergency. Alternative locations should be available and they should be capable of being commissioned in an appropriate timescale.</i></p>

Relevant to the Nuclear Industry	
Human Capabilities and Capacities	<p>Recommendation IR-24: The UK nuclear industry should review existing severe accident contingency arrangements and training, giving particular consideration to the physical, organisational, behavioural, emotional and cultural aspects for workers having to take actions on-site, especially over long periods. This should take account of the impact of using contractors for some aspects on-site such as maintenance and their possible response.</p> <p><i>This is a wide ranging recommendation and there are a number of aspects that need to be included:</i></p> <ul style="list-style-type: none"> <i>a) the reviews need to acknowledge design differences between individual nuclear facilities and consider whether corporate Severe Accident Guidelines need to be customised;</i> <i>b) adequacy of trained personnel numbers for long-term emergencies, particularly for multi-unit sites, and taking into account the potential impact of infrastructure damage and societal issues on the ability to mobilise large numbers of personnel;</i> <i>c) the time windows for availability of off-site support may be challenged hence the role of on-site personnel may change, which has implications for procedures and training;</i> <i>d) the review of Severe Accident Management Guidelines (SAMG) should consider not only critical safety functions prioritisation, but also whether and how SAMGs support any dynamic reprioritisation based on emerging information;</i> <i>e) consideration should also be given to operator support requirements relating to tactical and strategic decision making;.and</i> <i>f) in addition to the acute phase of a severe accident, consideration also needs to be given to stabilisation, recovery and clean-up, and the personnel involved from the many organisations involved.</i> <p>Recommendation FR-11: The UK nuclear industry should continue to promote sustained high levels of safety culture amongst all its employees, making use of the National Skills Academy for Nuclear and other schemes that promote “nuclear professionalism”.</p>

Relevant to the Nuclear Industry

Safety Case

Recommendation IR-25: The UK nuclear industry should review, and if necessary extend, analysis of accident sequences for long-term severe accidents. This should identify appropriate repair and recovery strategies to the point at which a stable state is achieved, identifying any enhanced requirements for central stocks of equipment and logistical support.

Recommendation IR-25 is linked with Recommendation IR-13. Combining these two recommendations means that we would expect industry to:

- a) identify potential strategies and contingency measures for dealing with situations in which the main lines of defence are lost. Considerations might include, for example, the operator’s capability to undertake repairs and the availability of spares (capability includes the availability of personnel trained in the use of emergency equipment along with necessary supporting resources);*
- b) consider the optimum location for emergency equipment, so as to limit the likelihood of it being damaged by any external event or the effects of a severe nuclear accident;*
- c) consider the impact of potential initiating events on the utilisation of such equipment;*
- d) consider the need for remotely controlled equipment including valves;and*
- e) consider in the layout of the site effective segregation and bunding of areas where radioactive liquors from accident management may accumulate.*

Regarding other aspects of Recommendation IR-25, the industry needs to:

- f) ensure it has the capability to analyse severe accidents to properly inform and support on-site severe accident management actions and off-site emergency planning. Further research and modelling development may be required;*
- g) ensure that sufficient severe accident analysis has been performed for all facilities with the potential for accidents with significant off-site consequences, in order to identify severe accident management and contingency measures. Such measures must be implemented where reasonably practicable and staff trained in their use; and*
- h) examine how the continued availability of sufficient on-site personnel can be ensured in severe accident situations, as well as considering how account can be taken of acute and chronic stress at both an individual and team level (this is linked to Recommendation IR-24).*

Recommendation FR-1: All nuclear site licensees should give appropriate and consistent priority to completing Periodic Safety Reviews (PSR) to the required standards and timescales, and to implementing identified reasonably practicable plant improvements.

Recommendation FR-4: The nuclear industry should ensure that adequate Level 2 Probabilistic Safety Analyses (PSA) are provided for all nuclear facilities that could have accidents with significant off-site consequences and use the results to inform further consideration of severe accident management measures. The PSAs should consider a full range of external events including “beyond design basis” events and extended mission times.

Way Forward	
Way forward	<p>Recommendation IR-26: A response to the various recommendations in the interim report should be made available within one month of it being published. These should include appropriate plans for addressing the recommendations. Any responses provided will be compiled on the ONR website.</p> <p><i>This recommendation was met in full by all of those on whom the recommendations fell, and is therefore discharged.</i></p> <p>Recommendation FR-12: Reports on the progress that has been made in responding to the recommendations in this report should be made available to ONR by June 2012. These should include the status of the plans, together with details of improvements that have been implemented by that time.</p>

Appendix C – ENSREG Stress Test Specifications

C.1 The text presented below is a verbatim reproduction of the ENSREG Stress Test specification document.

EU “Stress tests” Specifications

Introduction

Considering the accident at the Fukushima nuclear power plant in Japan, the EC of March 24th and 25th declared that “the safety of all EU nuclear plants should be reviewed, on the basis of a comprehensive and transparent risk assessment (“stress tests”); the European Nuclear Safety Regulatory Group (ENSREG) and the Commission are invited to develop as soon as possible the scope and modalities of these tests in a coordinated framework in the light of the lessons learned from the accident in Japan and with the full involvement of Member States, making full use of available expertise (notably from the Western European Nuclear Regulators Association); the assessments will be conducted by independent national authorities and through peer review; their outcome and any necessary subsequent measures that will be taken should be shared with the Commission and within ENSREG and should be made public; the European Council will assess initial findings by the end of 2011, on the basis of a report from the Commission”.

On the basis of the proposals made by WENRA at their plenary meeting on the 12-13 of May, the European Commission and ENSREG members decided to agree upon “an initial independent regulatory technical definition of a “stress test” and how it should be applied to nuclear facilities across Europe”. This is the purpose of this document.

Definition of the “stress tests”

For now we define a “stress test” as a targeted reassessment of the safety margins of nuclear power plants in the light of the events which occurred at Fukushima: extreme natural events challenging the plant safety functions and leading to a severe accident.

This reassessment will consist:

- In an evaluation of the response of a nuclear power plant when facing a set of extreme situations envisaged under the following section “technical scope” and
- In a verification of the preventive and mitigative measures chosen following a defence-in-depth logic: initiating events, consequential loss of safety functions, severe accident management.

In these extreme situations, sequential loss of the lines of defence is assumed, in a deterministic approach, irrespective of the probability of this loss. In particular, it has to be kept in mind that loss of safety functions and severe accident situations can occur only when several design provisions have failed. In addition, measures to manage these situations will be supposed to be progressively defeated.

For a given plant, the reassessment will report on the response of the plant and on the effectiveness of the preventive measures, noting any potential weak point and cliff-edge effect, for each of the considered extreme situations. A cliff-edge effect could be, for instance, exceeding a point where significant flooding of plant area starts after water overtopping a protection dike or exhaustion of the capacity of the batteries in the event of a station blackout. This is to evaluate the robustness of the defence-in-depth approach, the adequacy of current accident management measures and to identify the potential for safety improvements, both technical and organisational (such as procedures, human resources, emergency response organisation or use of external resources).

By their nature, the stress tests will tend to focus on measures that could be taken after a postulated loss of the safety systems that are installed to provide protection against accidents considered in the design. Adequate performance of those systems has been assessed in connection with plant licensing. Assumptions concerning their performance are re-assessed in the stress tests and they should be shown as provisions in place. It is recognised that all measures taken to protect reactor core or spent fuel integrity or to protect the reactor containment integrity constitute an essential part of the defence-in-depth, as it is always better to prevent accidents from happening than to deal with the consequences of an occurred accident.

Process to perform the “stress tests” and their dissemination

The licensees have the prime responsibility for safety. Hence, it is up to the licensees to perform the reassessments, and to the regulatory bodies to independently review them.

The timeframe is as follows:

The national regulator will initiate the process at the latest on June 1 by sending requirements to the licensees.

Progress report	Final report	
Licensee report	August 15	October 31
National report	September 15	December 31

- The final national reports will be subjected to the peer review process described below.
- The European Commission, with the support of ENSREG, will present a progress report to the EU Council for the meeting scheduled on 9th December 2011 and a consolidated report to the EU Council for the meeting scheduled for June 2012.

Due to the timeframe of the stress test process, some of the engineering studies supporting the licensees’ assessment may not be available for scenarios not included in the current design. In such cases engineering judgment is used.

During the regulatory reviews, interactions between European regulators will be necessary and could be managed through ENSREG. Regulatory reviews should be peer reviewed by other regulators. ENSREG will put at the disposal of all peer reviews the expertise necessary to ensure consistency of peer reviews across the EU and its neighbours.

Peer review process

In order to enhance credibility and accountability of the process the EU Council asked that the national reports should be subjected to a peer review process. The main purpose of the national reports will be to draw conclusions from the licensees’ assessment using the agreed methodology. The peer teams will review the fourteen national reports of Member States that presently operate nuclear power plants and of those neighbouring countries that accept to be part of the process.

- **Team composition.** ENSREG and the Commission shall agree on team composition. The team should be kept to a working size of seven people, one of whom should act as a chairperson and a second one as rapporteur. Two members of each team will be permanent members with the task to ensure overall consistency. The Commission will be part of the team. Members of the team whose national facilities are under review will not be part of that specific review. The country subject to review has to agree on the team composition. The team may be extended to experts from third countries.
- **Methodology.** In order to guarantee the rigor and the objectivity of any peer review, the national regulator under review should give the peer review team access to all necessary information, subject to the required security clearance procedures, staff and facilities to enable the team, within the limited time available.
- **Timing.** Reviews should start immediately when final national reports become available. The peer reviews shall be completed by the end of April 2012.

Transparency

National regulatory authorities shall be guided by the "principles for openness and transparency" as adopted by ENSREG in February 2011. These principles shall also apply to the EU "stress tests".

The reports should be made available to the public in accordance with national legislation and international obligations, provided that this does not jeopardize other interests such as, inter alia, security, recognized in national legislation or international obligations.

The peer will review the conclusions of each national report and its compliance with the methodology agreed. Results of peer reviews will be made public.

Results of the reviews should be discussed both in national and European public seminars, to which other stakeholders (from non nuclear field, from non governmental organizations, etc) would be invited.

Full transparency but also an opportunity for public involvement will contribute to the EU "stress tests" being acknowledged by European citizens.

Technical scope of the "stress tests"

The existing safety analysis for nuclear power plants in European countries covers a large variety of situations. The technical scope of the stress tests has been defined considering the issues that have been highlighted by the events that occurred at Fukushima, including combination of initiating events and failures. The focus will be placed on the following issues:

a) Initiating events

- Earthquake
- Flooding

b) Consequence of loss of safety functions from any initiating event conceivable at the plant site

- Loss of electrical power, including Station Blackout (SBO)
- Loss of the ultimate heat sink (UHS)
- Combination of both

c) Severe accident management issues

- Means to protect from and to manage loss of core cooling function
- Means to protect from and to manage loss of cooling function in the fuel storage pool
- Means to protect from and to manage loss of containment integrity

b) and c) are not limited to earthquake and tsunami as in Fukushima: flooding will be included regardless of its origin. Furthermore, bad weather conditions will be added.

Furthermore, the assessment of consequences of loss of safety functions is relevant also if the situation is provoked by indirect initiating events, for instance large disturbance from the electrical power grid impacting AC power distribution systems or forest fire, airplane crash.

The review of the severe accident management issues focuses on the licensee's provisions but it may also comprise relevant planned off-site support for maintaining the safety functions of the plant. Although the experience feedback from the Fukushima accident may include the emergency preparedness measures managed by the relevant off-site services for public protection (fire-fighters, police, health services....), this topic is out of the scope of these stress tests.

The next sections of this document set out:

- General information required from the licensees;
- Issues to be considered by the licensees for each considered extreme situation.

General aspects

Format of the report

The licensee shall provide one document for each site, even if there are several units on the same site. Sites where all NPPs are definitively shutdown but where spent fuel storages are still in operation shall also be considered.

In a first part, the site characteristics shall be briefly described:

- location (sea, river);
- number of units;
- license holder

The main characteristics of each unit shall be reflected, in particular:

- reactor type;
- thermal power;
- date of first criticality;
- presence of spent fuel storage (or shared storage).

Safety significant differences between units shall be highlighted.

The scope and main results of Probabilistic Safety Assessments shall be provided.

In a second part, each extreme situation shall be assessed following the indications given below.

Hypothesis

For existing plants, the reassessments shall refer to the plant as it is currently built and operated on June 30, 2011. For plants under construction, the reassessments shall refer to the licensed design.

The approach should be essentially deterministic: when analysing an extreme scenario, a progressive approach shall be followed, in which protective measures are sequentially assumed to be defeated.

The plant conditions should represent the most unfavourable operational states that are permitted under plant technical specifications (limited conditions for operations). All operational states should be considered. For severe accident scenarios, consideration of non-classified equipment as well as realistic assessment is possible.

All reactors and spent fuel storages shall be supposed to be affected at the same time.

Possibility of degraded conditions of the site surrounding area shall be taken into account.

Consideration should be given to:

- automatic actions;
- operators actions specified in emergency operating procedures;
- any other planned measures of prevention, recovery and mitigation of accidents;

Information to be included

Three main aspects need to be reported:

- Provisions taken in the design basis of the plant and plant conformance to its design requirements.
- Robustness of the plant beyond its design basis. For this purpose, the robustness (available design margins, diversity, redundancy, structural protection, physical separation, etc) of the safety-relevant systems, structures and components and the effectiveness of the defence-in-depth concept have to be assessed. Regarding the robustness of the installations and measures, one focus of the review is on identification of a step change in the event sequence (cliff-edge effect²¹) and, if necessary, consideration of measures for its avoidance.
- Any potential for modifications likely to improve the considered level of defence-in-depth, in terms of improving the resistance of components or of strengthening the independence with other levels of defence.

In addition, the licensee may wish to describe protective measures aimed at avoiding the extreme scenarios that are envisaged in the stress tests in order to provide context for the stress tests. The analysis should be complemented, where necessary, by results of dedicated plant walk down.

To this aim, the licensee shall identify:

- The means to maintain the three fundamental safety functions (control of reactivity, fuel cooling, confinement of radioactivity) and support functions (power supply, cooling through ultimate heat sink), taking into account the probable damage done by the initiating event and any means not credited in the safety demonstration for plant licensing.
- Possibility of mobile external means and the conditions of their use.
- Any existing procedure to use means from one reactor to help another reactor.
- Dependence of one reactor on the functions of other reactors on the same site.

As for severe accident management, the licensee shall identify, where relevant:

- The time before damage to the fuel becomes unavoidable. For PWR and BWR, if the core is in the reactor vessel, indicate time before water level reaches the top of the core, and time before fuel degradation (fast cladding oxidation with hydrogen production)
- If the fuel is in the spent fuel pool, the time before pool boiling, time up to when adequate shielding against radiation is maintained, time before water level reaches the top of the fuel elements, time before fuel degradation starts;

Supporting documentation

Documents referenced by the licensee shall be characterised either as:

²¹ Example : exhaustion of the capacity of the batteries in the event of a station blackout

- Validated in the licensing process.
- Not validated in the licensing process but gone through licensee's quality assurance program.
- Not one of the above.

Earthquake

I. Design basis

- a) Earthquake against which the plant is designed:
- Level of the design basis earthquake (DBE) expressed in terms of peak ground acceleration (PGA) and reasons for the choice. Also indicate the DBE taken into account in the original licensing basis if different.
 - Methodology to evaluate the DBE (return period, past events considered and reasons for choice, margins added...), validity of data in time.
 - Conclusion on the adequacy of the design basis.
- b) Provisions to protect the plant against the DBE
- Identification of the key structures, systems and components (SSCs) which are needed for achieving safe shutdown state and are supposed to remain available after the earthquake.
 - Main operating provisions (including emergency operating procedure, mobile equipment...) to prevent reactor core or spent fuel damage after the earthquake.
 - Were indirect effects of the earthquake taken into account, including:
 1. Failure of SSCs that are not designed to withstand the DBE and that, in losing their integrity could cause a consequential damage of SSCs that need to remain available (e.g. leaks or ruptures of non seismic pipework on the site or in the buildings as sources of flooding and their potential consequences);
 2. Loss of external power supply;
 3. Situation outside the plant, including preventing or delaying access of personnel and equipment to the site.
- c) Plant compliance with its current licensing basis:
- Licensee's general process to ensure compliance (e.g. , periodic maintenance, inspections, testing).
 - Licensee' process to ensure that off-site mobile equipment/supplies considered in emergency procedures are available and remain fit for duty.
 - Any known deviation, and consequences of these deviations in terms of safety; planning of remediation actions.
 - Specific compliance check already initiated by the licensee following Fukushima NPP accident.

II. Evaluation of the margins

- d) Based on available information (which could include seismic PSA, seismic margin assessment or other seismic engineering studies to support engineering judgement), give an evaluation of the range of earthquake severity above which loss of fundamental safety functions or severe damage to the fuel (in vessel or in fuel storage) becomes unavoidable.
- Indicate which are the weak points and specify any cliff edge effects according to earthquake severity.
 - Indicate if any provisions can be envisaged to prevent these cliff edge effects or to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).
- e) Based on available information (which could include seismic PSA, seismic margin assessment or other seismic engineering studies to support engineering judgement), what is the range of earthquake severity the plant can withstand without losing confinement integrity.
- f) Earthquake exceeding DBE and consequent flooding exceeding DBF
- Indicate whether, taking into account plant location and plant design, such situation can be physically possible. To this aim, identify in particular if severe damages to structures that are outside or inside the plant (such as dams, dikes, plant buildings and structures) could have an impact of plant safety.
 - Indicate which are the weak points and failure modes leading to unsafe plant conditions and specify any cliff edge effects. Identify which buildings and equipment will be impacted.

- Indicate if any provisions can be envisaged to prevent these cliff edge effects or to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).

Flooding

I. Design basis

- a) Flooding against which the plant is designed:
- Level of the design basis flood (DBF) and reasons for choice. Also indicate the DBF taken into account in the original licensing basis if different;
 - Methodology to evaluate the DBF (return period, past events considered and reasons for choice, margins added...). Sources of flooding (tsunami, tidal, storm surge, breaking of dam...), validity of data in time;
 - Conclusion on the adequacy of the design basis.
- b) Provisions to protect the plant against the DBF
- Identification of the key SSCs which are needed for achieving safe shutdown state and are supposed to remain available after the flooding, including:
 - o Provisions to maintain the water intake function.
 - o Provisions to maintain emergency electrical power supply.
 - Identification of the main design provisions to protect the site against flooding (platform level, dike...) and the associated surveillance programme if any.
 - Main operating provisions (including emergency operating procedure, mobile equipment, flood monitoring, alerting systems...) to warn of, then to mitigate the effects of the flooding, and the associated surveillance programme if any.
 - Were other effects linked to the flooding itself or to the phenomena that originated the flooding (such as very bad weather conditions) taken into account, including:
 - o Loss of external power supply.
 - o Situation outside the plant, including preventing or delaying access of personnel and equipment to the site.
- c) Plant compliance with its current licensing basis:
- Licensee's general process to ensure compliance (e.g., periodic maintenance, inspections, testing).
 - Licensee's process to ensure that off-site mobile equipment/supplies considered in emergency procedures are available and remain fit for duty.
 - Any known deviation and consequences of these deviations in terms of safety; planning of remediation actions.
 - Specific compliance check already initiated by the licensee following Fukushima NPP accident.

II. Evaluation of the margins

- d) Based on available information (including engineering studies to support engineering judgement), what is the level of flooding that the plant can withstand without severe damage to the fuel (core or fuel storage)?
- Depending on the time between warning and flooding, indicate whether additional protective measures can be envisaged / implemented.
 - Indicate which are the weak points and specify any cliff edge effects. Identify which buildings and which equipment will be flooded first.
 - Indicate if any provisions can be envisaged to prevent these cliff edge effects or to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).

Loss of electrical power and loss of the ultimate heat sink

Electrical AC power sources are:

- o off-site power sources (electrical grid);
- o plant generator;
- o ordinary back-up generators (diesel generator, gas turbine...);
- o in some cases other diverse back-up sources.

Sequential loss of these sources has to be considered (see a) and b) below).

The ultimate heat sink (UHS) is a medium to which the residual heat from the reactor is transferred. In some cases, the plant has the primary UHS, such as the sea or a river, which is supplemented by an alternate UHS, for example a lake, a water table or the atmosphere. Sequential loss of these sinks has to be considered (see c) below).

a) Loss of off-site power (LOOP²²)

- Describe how this situation is taken into account in the design and describe which internal backup power sources are designed to cope with this situation.
- Indicate for how long the on-site power sources can operate without any external support.
- Specify which provisions are needed to prolong the time of on-site power supply (refuelling of diesel generators...).
- Indicate any envisaged provisions to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).

For clarity, systems such as steam driven pumps, systems with stored energy in gas tanks etc. are considered to function as long as they are not dependent of the electric power sources assumed to be lost and if they are designed to withstand the initiating event (e.g. earthquake).

b) Loss of off-site power and of on-site backup power sources (SBO). Two situations have to be considered:

- LOOP + Loss of the ordinary back-up source;
- LOOP + Loss of the ordinary back-up sources + loss of any other diverse back- up sources.

For each of these situations:

- Provide information on the battery capacity and duration.
- Provide information on design provisions for these situations.
- Indicate for how long the site can withstand a SBO without any external support before severe damage to the fuel becomes unavoidable.
- Specify which (external) actions are foreseen to prevent fuel degradation:
 - o equipment already present on site, e.g. equipment from another reactor;
 - o assuming that all reactors on the same site are equally damaged, equipment available off-site;
 - o near-by power stations (e.g. hydropower, gas turbine) that can be aligned to provide power via a dedicated direct connection;
 - o time necessary to have each of the above systems operating;
 - o availability of competent human resources to make the exceptional connections;
 - o identification of cliff edge effects and when they occur.
- Indicate if any provisions can be envisaged to prevent these cliff edge effects or to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).

c) Loss of primary ultimate heat sink (UHS²³)

- Provide a description of design provisions to prevent the loss of the UHS (e.g. various water intakes for primary UHS at different locations, use of alternative UHS, ...)

Two situations have to be considered:

- Loss of primary ultimate heat sink (UHS), i.e. access to water from the river or the sea;
- Loss of primary ultimate heat sink (UHS) and the alternate UHS.

For each of these situations:

- Indicate for how long the site can withstand the situation without any external support before damage to the fuel becomes unavoidable.
- Provide information on design provisions for these situations.
- Specify which external actions are foreseen to prevent fuel degradation:
 - o equipment already present on site, e.g. equipment from another reactor;
 - o assuming that all reactors on the same site are equally damaged, equipment available off-site;
 - o time necessary to have these systems operating;
 - o availability of competent human resources;
 - o identification of cliff edge effects and when they occur.

²² All offsite electric power supply to the site is lost. The offsite power should be assumed to be lost for several days. The site is isolated from delivery of heavy material for 72 hours by road, rail or waterways. Portable light equipment can arrive to the site from other locations after the first 24 hours.

²³ The connection with the primary ultimate heat sink for all safety and non safety functions is lost. The site is isolated from delivery of heavy material for 72 hours by road, rail or waterways. Portable light equipment can arrive to the site from other locations after the first 24 hours.

- Indicate if any provisions can be envisaged to prevent these cliff edge effects or to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).
- d) Loss of the primary UHS with SBO
- Indicate for how long the site can withstand a loss of “main” UHS + SBO without any external support before severe damage to the fuel becomes unavoidable
 - Specify which external actions are foreseen to prevent fuel degradation:
 - o equipment already present on site, e.g. equipment from another reactor;
 - o assuming that all reactors on the same site are equally damaged, equipment available off site;
 - o availability of human resources;
 - o time necessary to have these systems operating;
 - o identification of when the main cliff edge effects occur.
 - Indicate if any provisions can be envisaged to prevent these cliff edge effects or to increase robustness of the plant (modifications of hardware, modification of procedures, organisational provisions...).

Severe accident management

This chapter deals mostly with mitigation issues. Even if the probability of the event is very low, the means to protect containment from loads that could threaten its integrity should be assessed. Severe accident management, as forming the last line of defence-in-depth for the operator, should be consistent with the measures used for preventing the core damage and with the overall safety approach of the plant.

- a) Describe the accident management measures currently in place at the various stages of a scenario of loss of the core cooling function:
- before occurrence of fuel damage in the reactor pressure vessel/a number of pressure tubes;
 - o last resorts to prevent fuel damage
 - o elimination of possibility for fuel damage in high pressure
 - after occurrence of fuel damage in the reactor pressure vessel/a number of pressure tubes;
 - after failure of the reactor pressure vessel/a number of pressure tubes.
- b) Describe the accident management measures and plant design features for protecting integrity of the containment function after occurrence of fuel damage:
- prevention of H₂ deflagration or H₂ detonation (inerting, recombiners, or igniters), also taking into account venting processes;
 - prevention of over-pressurization of the containment; if for the protection of the containment a release to the environment is needed, it should be assessed, whether this release needs to be filtered. In this case, availability of the means for estimation of the amount of radioactive material released into the environment should also be described;
 - prevention of re-criticality;
 - prevention of basemat melt through;
 - need for and supply of electrical AC and DC power and compressed air to equipment used for protecting containment integrity.
- c) Describe the accident management measures currently in place to mitigate the consequences of loss of containment integrity.
- d) Describe the accident management measures currently in place at the various stages of a scenario of loss of cooling function in the fuel storage (the following indications relate to a fuel pool):
- before/after losing adequate shielding against radiation;
 - before/after occurrence of uncover of the top of fuel in the fuel pool;
 - before/after occurrence of fuel degradation (fast cladding oxidation with hydrogen production) in the fuel pool.

For a) b) c) and d), at each stage:

- identify any cliff edge effect and evaluate the time before it;
- assess the adequacy of the existing management measures, including the procedural guidance to cope with a severe accident, and evaluate the potential for additional measures. In particular, the licensee is asked to consider:
 - o the suitability and availability of the required instrumentation;
 - o the habitability and accessibility of the vital areas of the plant (the control room, emergency response facilities, local control and sampling points, repair possibilities);
 - o potential H₂ accumulations in other buildings than containment ;

The following aspects have to be addressed:

- Organisation of the licensee to manage the situation, including:
 - o staffing, resources and shift management;
 - o use of off-site technical support for accident and protection management (and contingencies if this becomes unavailable);
 - o procedures, training and exercises;
- Possibility to use existing equipment;
- Provisions to use mobile devices (availability of such devices, time to bring them on site and put them in operation, accessibility to site);
- Provisions for and management of supplies (fuel for diesel generators, water...);
- Management of radioactive releases, provisions to limit them; Management of workers' doses, provisions to limit them;
- Communication and information systems (internal, external).
- Long-term post-accident activities.

The envisaged accident management measures shall be evaluated considering what the situation could be on a site:

- Extensive destruction of infrastructure around the plant including the communication;
- Facilities (making technical and personnel support from outside more difficult);
- Impairment of work performance (including impact on the accessibility and habitability of the main and secondary control rooms, and the plant emergency/crisis centre) due to high local dose rates, radioactive;
- Contamination and destruction of some facilities on site;
- Feasibility and effectiveness of accident management measures under the conditions of ^{external} hazards (earthquakes, floods);
- Unavailability of power supply;
- Potential failure of instrumentation;
- Potential effects from the other neighbouring plants at site.

The licensee shall identify which conditions would prevent staff from working in the main or secondary control room as well as in the plant emergency/crisis centre and what measures could avoid such conditions to occur.