EU Stress Test

Sizewell B

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Document Revision Record		
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Rev 000	First Issue	December 2011
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Contents

Glossary

AC	Alternating Current
AGR	Advanced Gas-cooled Reactor
ALARP	As Low As Reasonably Practicable
AOD	Above Ordnance Datum
ASME	American Society of Mechanical Engineers
CEGB	Central Electricity Generating Board
DC	Direct Current
EDF	Electricity de France
ENSREG	European Nuclear Safety Regulators' Group
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
LC	License Condition
ONR	Office for Nuclear Regulation
p.a.	Per Annum
PWR	Pressurised Water Reactor
SZB	Sizewell B
WANO	World Association of Nuclear Operators

Executive Summary

Sizewell B

Executive Summary

Introduction

In response to the 11 March 2011 Great East Japan Earthquake and the subsequent events at Fukushima Dai-ichi Nuclear Power Plant it was immediately clear to EDF Energy[1] that a thorough response was appropriate to assess and take corrective actions to address any identified issues discovered when reviewing the lessons learned from this event.

An internal review of our nuclear facilities and emergency response measures was initiated by the Board; this was then expanded to include the scope of a Significant Operating Experience Report issued by WANO, the World Association of Nuclear Operators, an international cross industry organisation which aims to help its members achieve the highest levels of operational safety and reliability.

On 12 March 2011, the Secretary of State for Energy and Climate Change, Chris Huhne, requested Mike Weightman, HM Chief Inspector of Nuclear Installations, to produce a report on the implications for the UK nuclear industry of the accident that took place at the Fukushima Dai-ichi nuclear power station, the interim findings of which were published in May 2011 with the final report published in September 2011. The report focuses on significant lessons for the safety of nuclear power stations operating in the UK and proposals to build new ones. It looks at the evidence and facts, as far as they were known at that time, to establish technically based issues that relate to possible improvements in safety and regulation in the UK. It also indicates some lessons for international arrangements for such systems.

In addition to this, the Council of the European Union declared that "the safety of all EU nuclear plants should be reviewed, on the basis of a comprehensive and transparent risk assessment ("stress tests")". On 25 May 2011 the European Commission and the European Nuclear Safety Regulators' Group produced a joint specification for a three stage process covering all 143 nuclear plants in the EU.

The "stress test" is 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 technical scope of the reassessment is concerned with an evaluation of the response of a nuclear power plant when facing a set of specific extreme situations.

An EU Stress Test report has been completed for each station and submitted to the Office for Nuclear Regulation (ONR), the UK independent nuclear industry regulator: This is the EU Stress Test report for Sizewell B.

This report is focused on the adequacy of design basis protection for infrequent external hazards. Infrequent external hazards are assessed as those with a frequency of occurrence of 1 in 10,000 per year. All references to design basis in this report should therefore be interpreted as meaning a hazard with this return frequency unless otherwise stated.

This EU Stress Test Report concludes that there are no significant shortfalls in the safety case for all the UK power stations operated by EDF Energy, and that it is safe to continue their operations. This conclusion is consistent with conclusion IR-1 from the ONR's Interim Report i.e. "In considering the direct causes of the Fukushima accident we see no reason for curtailing the operation of nuclear power plants or other nuclear facilities in the UK".

The EU Stress Test Reports also raise 'considerations': these are defined as 'Opportunities to further examine potential enhancements to plant, process or people for beyond design basis scenarios'.

An overview and summary of each EU Stress Test subject area is provided below.

Earthquakes

In the Office for Nuclear Regulation (ONR) Interim Report into the Japanese Earthquake and Tsunami, it is stated that "The extreme natural events that preceded the accident at Fukushima - the magnitude 9 earthquake and subsequent huge tsunami - are not credible in the UK. We are 1,000 miles from the nearest fault line[2] and we have safeguards in place that protect against even very remote hazards."

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[1] EDF Energy Nuclear Generation Group Ltd (NGGL) is part of EDF Energy. EDF Energy Nuclear Generation Ltd (NGL) is the licensed nuclear entity within NGGL. For the purposes of this document only the term EDF Energy will be used unless otherwise specified.

[2] Assumed to mean tectonic plate boundary

With the exception of Heysham 2 (HYB) and Torness (TOR), the Advanced Gas-Cooled Reactors (AGRs) were not originally designed to withstand earthquakes. Sizewell B, the Pressurised Water Reactor was based on the Standard Nuclear Power Plant (SNUPPS) design and the standard design included qualification against earthquake. However, for the pre-HYB/TOR AGRs, seismic safety cases were developed as part of the first Periodic Safety Review (PSR) in the late 1990s covering both the at-power and shutdown conditions as well as fuel handling operations.

Summary of findings for earthquakes at Sizewell B

Chapter 2 covers the definition of the design basis earthquake and the equipment which is expected to survive an infrequent earthquake, i.e. an event with a return frequency of 10^{-4} p.a. There are also discussions on the margin to failure of this equipment. It demonstrates that:

- The design basis earthquake corresponds to an infrequent event using an extensive study of historical earthquakes and local geology.
- The design basis earthquake is reviewed by the periodic safety review process, which concluded that it was still valid in the light of modern standards and data.
- Protection of plant from seismic effects is provided through a qualification process, which ensures the plant needed to safely shut down the reactor and provide post-trip cooling remains available following the infrequent seismic event.
- Suitable processing in place to ensure that the plant remains compliant with its licensing basis.
- No cliff-edge (i.e. a large change in impact for a small change in hazard) effects are expected for events up to twice as severe as the design basis.

The information presented in Chapter 2 of this report shows that the processes for ensuring robustness of the plant for seismic events are well developed and implemented and give appropriate consideration to the requirement for margins. They make appropriate use of international experience and standards both nuclear specific and discipline specific.

Furthermore they have been reviewed periodically in line with company process and regulatory expectations. The methodologies are internationally recognised and have been constructed with appropriate conservatisms, margins and sensitivity studies employed. Thus:

- The severity of the earthquake chosen for the design basis event is considered conservative;
- There is high confidence that the essential systems structures and components will remain functional in a design basis earthquake, and
- The essential systems structures and components are tolerant to more severe earthquakes.

The robustness of the plant against design basis earthquakes and beyond design basis earthquakes is considered to be appropriate. The areas for consideration are not considered to undermine the current operating basis of the station.

External Flooding

In the Office for Nuclear Regulation's (ONR) Interim and Final reports on the Japanese Earthquake and Tsunami Implications for the UK Nuclear Industry, the following is stated.

"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."

In line with the statement quoted above from the ONR report, the Stress Test focuses on the External Flooding hazard. Within EDF Energy Nuclear Generation, the External Flooding hazard is defined as 'Extreme rainfall, snowmelt, overtopping of sea defences or gross failure of reservoirs external to the licensed site which directly or indirectly could result in the risk of a radiological release'. The Internal Flooding hazard, which considers flooding from sources within the licensed site, such as failed pipework, tanks, etc. is considered by the station safety case but is beyond the scope of this report. Any further references to floods in this report concerns the external flooding hazard.

Summary of findings for external flooding at Sizewell B

Chapter 3 of this report assesses the margins of the existing design basis, as well as the extant flood protection in place at Sizewell B Nuclear Power Plant. It demonstrates that:

- Sufficient margin exists between the maximum design basis flood (7.6 m AOD) and the coast defences comprising a primary 10m AOD and a secondary 5m AOD raised embankment. The physical elevation of the main nuclear island is 6.4 m AOD);
- During extreme rainfall events it is demonstrated that essential function availability is maintained by the site drainage and the natural fall of the land away from the station;
- The information presented shows that the methodology used to calculate the design basis flood for Sizewell B has been constructed using independent expertise based on well regarded sources of information. The methodology has also been constructed with appropriate conservatisms, margins and sensitivity studies employed;
- The methodology for determining external flooding risk has been reviewed periodically in line with company process and regulatory expectations;
- Appropriate consideration has been given to the predicted impact of global warming on the risk of external flooding due to sea level rise and increasing wave heights. It has been demonstrated that appropriate margins will be maintained beyond the operating life of the station;
- Operating procedures and emergency activities identified for the management of actions in response to external flooding have been reviewed and their adequacy confirmed;
- For the purposes of beyond design basis risks management a number of physical plant modifications have been considered, primarily affording protection of external plant areas, and will be prioritised based on the benefit to robustness of essential plant and the potential risk to plant during implementation/operation.

The information presented in Chapter 3 of this report shows that the processes for ensuring robustness of the plant for flooding events are well developed and implemented and give appropriate consideration to the requirement for margins. They make appropriate use of international experience and standards both nuclear specific and discipline specific.

Furthermore they have been reviewed periodically in line with company process and regulatory expectations. The methodologies are internationally recognised and have been constructed with appropriate conservatisms, margins and sensitivity studies employed.

The robustness of the plant against design basis floods is considered to be appropriate; in considering the robustness to beyond design basis floods, several areas have been identified where enhancement could be considered.

The areas for consideration are not considered to undermine the current operating basis of the station.

Extreme Weather

In the Office for Nuclear Regulation Interim Report into the Japanese Earthquake and Tsunami, Recommendation 13 states that “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.” Recommendation 16 states that “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.”

EDF Energy considers a range of hazards, some of which are initiated or come about as a result of events on the site (internal hazards) and others that arise off-site or which relate to conditions which envelop the site (external hazards). Chapter 4 of this report considers those external hazards that are related to meteorological events other than external flooding. These are:

- Extreme Wind
- Extreme Ambient Temperatures (Including both seawater and air temperatures)
- Lightning
- Drought

In each case consideration is given to the adequacy of the existing design basis event, the inherent margins in the analysis and the potential for improvements in plant robustness. In addition, the tolerance of the plant to combinations of extreme external hazards is also considered.

The findings of this work are summarised below.

Summary of findings for extreme winds at Sizewell B

The bounding design basis hazard for extreme wind is defined as a wind speed of 60.2 m/s at a frequency of10^{-4} p.a.

The design basis for an infrequent extreme wind is based on demonstrating that buildings conform to relevant standards and codes for an event with a probability of 10^{-4} p.a. Equipment required to fulfil the essential safety functions is either located inside buildings which are qualified against infrequent wind, or qualified directly. This approach has been concluded to be adequately robust.

Summary of findings for extreme ambient temperatures at Sizewell B

The bounding design basis hazard for instantaneous high and low air temperature is defined as 36°C and -17°C respectively at a frequency of10^{-4}p.a.

The equivalent 12 hour average high and low air temperatures are defined as 29.5°C and -13°C respectively.

Summary of findings for extreme Seawater Temperature at Sizewell B

The bounding design basis hazard for high and low seawater temperature is defined as 26°C and 0°C respectively. The probabilities of exceeding these maxima and minima are calculated as $9x10^{-3}$p.a. and $3x10^{-2}$p.a. respectively.

The safety case for extreme air and sea temperatures demonstrates that most equipment is expected to remain functionally available or fail-safe when subjected to the high or low ambient temperatures considered in the design basis. Operator actions play a large part in ensuring that during extreme air temperature events sufficient safety related plant remains available. Seawater temperature is primarily a commercial concern and it is judged incredible that changes in temperature will impact nuclear safety.

Summary of findings for Snow at Sizewell B

The bounding design basis hazard for snowfall is defined as being a depth of 0.543 m at a frequency of10^{-4}p.a. This corresponds to a loading of 0.8 kN/m^2.

The reactor buildings and others containing essential equipment have been assessed against snow loading and demonstrate sufficient margin.

Summary of findings for Lightning at Sizewell B

The bounding design basis hazard for lightning is defined as being a current of 290 kA and a rate of current rise of 340 kA/ µs at a frequency of 10^{-4}p.a.

The assessment is judged to be conservative. At 10^{-6}p.a. level the peak current and rate of current rise are also conservatively assessed as 500 kA and 550 kA/µs respectively.

Summary of findings for Drought at Sizewell B

No numerical design basis hazard level has been defined for drought.

Drought was screened out by the hazard assessment on the following basis.

Industrial and domestic water will be provided by the townswater services system which receives water from the local water company.

The design provisions for discontinuation of off-site water supplies ensure that there is sufficient warning available to the operators to allow the appropriate actions to be taken. With regard to drought-induced changes to the site's water table, the impact upon building foundations would be within the design capacity and can therefore be screened out by virtue of effect.

External hazards due to drought, lightning and snow loading have been screened out by effect and as such it is deemed that adequate margins exist.

Loss of Power and Loss of Ultimate Heat Sink

Chapter 5 of this report focuses on prevention of severe damage to the reactor and to the irradiated fuel under potential loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances. The effects on both the reactor and fuel storage ponds are considered within this chapter.

The Stress-Test requires a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.

The Stress Test also requires a consideration of 'Loss of Ultimate Heat Sink'. Within this a number of scenarios are considered, the impact of the loss of the primary ultimate heat-sink (seawater) as well as, loss of primary ultimate heat-sink combined with loss of alternate heat-sinks (i.e. other cooling water supplies and heat-transfer routes to atmosphere). The Stress Test also required the combined consequences of station black out and loss of primary ultimate heat-sink.

The following scenarios are considered within Chapter 5 of this report:

- Loss of off-site power;
- Loss of all AC power;
- Loss of primary ultimate heat-sink;
- Loss of all ultimate heat-sinks;
- Loss of all AC power and all ultimate heat-sinks.

As Sizewell B has been designed to withstand both the loss of all AC power and all ultimate heat-sinks, none of the above events would lead to fuel damage. As such, it was deemed responsible as operators to consider beyond the design basis, and investigate the effect of the loss of DC power on top of the existing scenarios. This postulated event could lead to fuel damage, and therefore the on-site protection required was assessed.

Chapter 5 of this report concludes that even though the loss of all AC power and all ultimate heat-sinks is considered to be extremely unlikely, the effect on the safety of the plant would not lead to the loss of cooling, containment or criticality control.

The loss of DC power on-site, combined with the loss of all AC power and all ultimate heat-sinks (considered to be an event even more unlikely) could lead to a loss of cooling, and as such fuel damage could occur. The protection of safety related equipment is believed to be appropriately robust and diverse to prevent the occurrence of such a scenario. The provision of beyond design basis equipment and procedures (discussed further in Chapter 6 of this report) further strengthen the plant's ability to withstand such an event.

Severe Accident Management

In the ONR Interim Report into the Japanese Earthquake and Tsunami, Mike Weightman states:

"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, widespread on and off-site disruption, and the environment on-site associated with a severe accident."

"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."

"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."

This EU Stress Test report explores the organisation and management measures which are in place within EDF Energy to deal with severe accidents.

In a number of places, this EU Stress Test report refers to the need for ongoing development work. Some of this work had been previously identified and captured by normal company processes, whilst some is new work highlighted by the post-Fukushima review. In the latter group, there is some potential work packages referred to as 'Considerations'. These Considerations will be carefully reviewed following the completion of the Stress test reports and an appropriate programme of work formulated.

The Japanese event and findings from the stress test has provided EDF Energy with an opportunity to review its accident management capabilities. EDF Energy has concluded that it has robust arrangements for Emergency Response. However there are lessons we have learnt during this process which we will consider in order to improve our response.

These can be broadly categorised into three areas:

Facilities – this includes site resilience and multi site support

Technical – communications and supply chain

Procedures – emergency arrangements and procedures taking into account staff welfare

Training and Exercising encompasses all elements as it is only through these functions EDF Energy can ensure continuous improvement and oversight of our arrangements.

The provision of off-site equipment and support is a maintained and formal process within EDF Energy Nuclear Generation. Following the 2011 emergency in Japan it is recognised that it is possible that the equipment could be enhanced to provide further resilience to the emergency scheme.

Conclusion

This EU Stress Test Report concludes that there are no significant shortfalls in the safety case for all the UK power stations operated by EDF Energy, and that it is safe to continue their operations. This conclusion is consistent with conclusion IR-1 from the ONR's Interim Report i.e. "In considering the direct causes of the Fukushima accident we see no reason for curtailing the operation of nuclear power plants or other nuclear facilities in the UK".

Chapter 0 - Introduction

Sizewell B

0 Introduction

0.1 Background

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On 12 March 2011, the Secretary of State for Energy and Climate Change, Chris Huhne, requested Mike Weightman, HM Chief Inspector of Nuclear Installations, to produce a report on the implications for the UK nuclear industry of the accident that took place at the Fukushima Dai-ichi nuclear power station, the interim findings of which were published in May 2011 with the final report published in September 2011. The report focuses on significant lessons for the safety of nuclear power stations operating in the UK and proposals to build new ones. It looks at the evidence and facts, as far as they were known at that time, to establish technically based issues that relate to possible improvements in safety and regulation in the UK. It also indicates some lessons for international arrangements for such systems.

In addition to this, the Council of the European Union declared that “the safety of all EU nuclear plants should be reviewed, on the basis of a comprehensive and transparent risk assessment (“stress tests”)”. On 25 May 2011 the European Commission and the European Nuclear Safety Regulators' Group (ENSREG) produced a joint specification for a three stage process covering all 143 nuclear plants in the EU.

The “stress test” is defined as a targeted reassessment of the safety margins of nuclear power plants in the light of the events which occurred at Fukushima Dai-Ichi: extreme natural events challenging the plant safety functions and leading to a severe accident. The technical scope of the reassessment is concerned with an evaluation of the response of a nuclear power plant when facing a set of specific extreme situations.

A review of safety has been structured to address the needs of an internal EDF Energy review, the Weightman report and the “stress test”. An EU Stress Test report has been completed for each station and submitted to the Office for Nuclear Regulation (ONR), the UK independent nuclear industry regulator.

0.2 Scope of Stress Test

This Stress Test comprises an examination safety against the scope of the stress test. This includes a review of the definition and magnitude of the initiating event, the physical safety measures, operator training and the procedural arrangements that are claimed as a barrier to prevent or minimise the release of radioactive material and the arrangements for severe accident management.

The scope of this Stress Test covers the following plant areas, which are described in more detail in chapter 1:

- **the main reactor and associated structure**, which contains the majority of the nuclear material;
- **the fuel route,** where new fuel assemblies are loaded to the reactor and where used fuel assemblies are removed from the reactor and;
- **the fuel cooling ponds,** where fuel elements are stored.

As well as the existing safety justifications, this Stress Test considers the response of the plant and the claimed safety measures to challenges of a severity in excess of those already covered in the station safety cases. The nature of the challenges has been defined considering the issues that have been highlighted by the events that occurred at Fukushima Dai-Ichi, including combinations of initiating events and failures. These include the directly relevant hazards such as earthquake and flooding (from tsunamis and other sources) and other extreme weather conditions, potentially more relevant to the UK such as high winds and extreme ambient temperatures.

[3] EDF Energy Nuclear Generation Group Ltd (NGGL) is part of EDF Energy. EDF Energy Nuclear Generation Ltd (NGL) is the licensed nuclear entity within NGGL. For the purposes of this document only the term EDF Energy will be used unless otherwise specified.

In these extreme situations, sequential loss of the engineered 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 to the response of the installed lines of defence to a specific initiating event, the Stress Test also considers the effects of:

- Loss of electrical power, including station black out;
- Loss of the ultimate heat-sink;
- Combination of both station black-out and loss of ultimate heat-sink

In this report the station black-out scenario is defined as a loss of all station electrical supplies. This includes the loss of the grid electrical supply, the loss of the station on-site normal (ordinary) electrical supplies and on-site diverse (alternative) electrical supplies.

The loss of the ultimate heat-sink scenario is defined as the loss of all cooling water supply to the station; including the primary heat-sink (seawater) as well as the main and diverse (alternative) heat-sink supplies.

These scenarios are conservatively assessed without specifying the likelihood or nature of the initiating event or the probability that loss of all of these safety functions could occur.

The Stress Test also considers the arrangements for managing severe accidents if the engineered safety measures fail to prevent the loss of the essential safety functions.

Throughout the Stress Test considerations are raised. These are defined as 'Opportunities to further examine potential enhancements to plant, process or people for beyond design basis scenarios'.

0.3 EDF Energy's Nuclear Sites

EDF Energy is one of the UK's largest energy companies and the largest producer of low-carbon electricity, producing around one-sixth of the nation's electricity from its nuclear power stations, wind farms, coal and gas power stations and combined heat and power plants. The company supplies gas and electricity to more than 5.5 million business and residential customer accounts and is the biggest supplier of electricity by volume in Great Britain.

In its nuclear activities EDF Energy has partnered with Centrica, which has a 20% stake in the company's eight existing plants and in the project carrying out pre-development work for nuclear new build. EDF Energy has prepared this response to the Japan earthquake on behalf of the joint venture between the two companies.

EDF Energy Nuclear Generation Ltd is the nuclear licensee and operates 15 reactors on 8 sites in the UK: one Pressurised Water Reactor (PWR) at Sizewell in Suffolk and 14 Advanced Gas Cooled Reactors (AGRs) at sites at Hinkley Point in Somerset, Heysham in Lancashire, Torness in Lothian, Hunterston in Ayrshire, Hartlepool on Teesside and at Dungeness in Kent.

Table 0.1: EDF Energy power stations, type, capacity and significant dates.

Power Station	Type	Net MWe	Construction started	Connected to grid	Full operation	Accounting closure date
Dungeness B	AGR	1040	1965	1983	1985	2018
Hinkley Point B	AGR	820	1967	1976	1976	2016
Hunterston B	AGR	820	1967	1976	1976	2016
Hartlepool	AGR	1190	1968	1983	1989	2019
Heysham 1	AGR	1160	1970	1983	1989	2019
Heysham 2	AGR	1235	1980	1988	1989	2023
Torness	AGR	1230	1980	1988	1988	2023
Sizewell B	PWR	1188	1988	1995	1995	2035

Figure 0.1: Map of the UK showing EDF Energy nuclear power stations.

The stations were designed and licensed to operate against standards appropriate at that time. Throughout their respective lives the stations have been subject to regular, formal review of their basis of design in the form of safety case reviews. These reviews form an essential and mandatory part of the UK legislative framework for nuclear facilities (discussed below) and both the reviews and the identified improvement activities are discussed in more detail in chapters 2 to 6.

0.4 Background to UK Nuclear Safety Framework and EDF Energy's Arrangements

The UK Health and Safety at Work Act leads to legislation made under the Act that may be absolute or qualified by expressions such as the need for duty holders to ensure "reasonable practicability". (As Low As is Reasonably Practicable - ALARP). The term reasonably practicable allows for a cost benefit analysis to be used when determining the actions to be taken in response to an identified risk, or for a comparison to be carried out with "good practice" in similar circumstances. The preventative measures taken should however be commensurate with the magnitude of the risk. Both "practicable" and "reasonably practicable" are statutory criminal liabilities in health and safety legislation. HSE guidance has been published on how this should be interpreted and the use of Cost Benefit Analysis. Several important points should be noted:

- There should be a transparent bias on the side of health and safety. For duty holders, the test of 'gross disproportion' requires erring on the side of safety in the computation of health and safety costs and benefits.
- Whenever possible, standards should be improved or at least maintained, thus current good practice is used as a baseline - the working assumption being that the appropriate balance between costs and risks was struck when the good practice was formally adopted.
- Hazards are regulated through a safety case regime requiring an explicit demonstration in the safety case that control measures introduced conform to the ALARP principle.

Nuclear facilities in the UK are required to have a licence to operate issued under the Nuclear Installations Act 1965 as amended (NIA65). The licence is granted to a corporate body by the UK Health and Safety Executive (HSE) and specifies the activities that can be undertaken at the named site. As mentioned previously EDF Energy Nuclear Generation Ltd is the licensed entity for the sites operated in the UK by EDF Energy.

The licence allows for the regulation by the ONR, on behalf of the HSE, of the design, construction, operation and decommissioning of any nuclear installation for which a nuclear site licence is required under NIA65. Attached to each licence is a standard set of 36 conditions developed by the ONR. In the main they require the licensee to make and implement adequate arrangements to address the particular issues identified. The licence conditions are largely non-prescriptive and set goals that the licensee is responsible for achieving. EDF Energy has developed compliance principles for all 36 licence conditions and implements these through identified arrangements, which include both Company-wide and site-specific documents.

Licence Condition (LC) 14 requires arrangements for the production and assessment of safety cases consisting of documentation to justify safety during the design, construction, manufacture, commissioning, operation and decommissioning phases of the installation. The Safety Case covers all activities undertaken at each site, the hazards associated with these and the safety measures, whether engineered or procedural, necessary to protect against or mitigate these hazards. The Safety Case defines limits and conditions on plant operation within which the safety of the plant is demonstrated. By operating within these limits and conditions it is shown that the risks are adequately controlled and that safety significant issues have been addressed. The limits and conditions arising from the Safety Case form the operating rules for compliance with LC 23, and operating instructions are provided in accordance with LC 24 to ensure these operating rules are implemented, along with any other instructions necessary in the interests of safety.

LC 28 requires regular and systematic examination, inspection, maintenance and testing of the engineered safety systems claimed in the Safety Case to ensure that they remain available and fit for purpose, and a schedule of these requirements is provided for each site. Safety measures and other safety significant actions that require operator action must be carried out by suitably qualified and experienced persons in accordance with LC12 and, in conjunction with arrangements for training in accordance with LC 10, each site maintains records of staff qualification and authorisation.

LC 22 requires arrangements to control any modification carried out on any part of the existing plant or processes which may affect safety. Modifications to implement new plant or processes, or a change to existing plant or processes represent a change that affects the existing safety case. For all modifications, consideration of safety must be full and complete, including any necessary amendment of rules, instructions, plant procedures and training requirements to be undertaken prior to implementing the proposed change. Consideration of such changes is an essential element in the justification of the proposed modification. In accordance with LC 22, EDF Energy has implemented a modifications process; modifications are categorised based on the potential for nuclear safety risk, with additional approvals required as risk increases.

LC15 requires a periodic and systematic review and reassessment of safety cases. Arrangements for periodic review complement the continuous review and maintenance of the Safety Cases under LC22 and ensure that the cumulative effects of plant ageing, operating experience and plant modifications are considered in totality.

Periodic safety reviews discharge the requirements of LC15 and are retrospective (learning from experience) and prospective, in reviewing the impact of changes in safety standards, expected lifetimes, intended uses, functional requirements, interaction with other plant and possible contingency measures which may be required. The periodic safety reviews are designed to ensure that a thorough and comprehensive review is made of the safety case at regular intervals throughout a nuclear installation's life. The objectives of the periodic safety reviews are:

- to review the total current safety case for the nuclear installation and confirm that it is robust;
- to compare the safety case with modern standards, evaluate any deficiencies and implement any reasonably practicable improvements to enhance plant safety;
- to identify any ageing process which may limit the life of the installation;
- to revalidate the safety case until the next periodic safety review, subject to the outcome of routine regulation.

The first AGR periodic safety reviews were completed in 1996 for Hinkley Point B and Hunterston B, with other AGR following thereafter. These are referred to as periodic safety review 1 and marked the start of a cycle of periodic safety reviews for all of EDF Energy's nuclear power stations. Periodic safety review 1 for Sizewell B was completed in 2005.

The second wave of periodic safety reviews, referred to as periodic safety review 2, commenced in 2002 with a review process that was broadly similar to periodic safety review 1 but included strategic changes to reflect lessons learnt. SZB periodic safety review 2 is underway and is due for completion in 2015.

LC 11 requires the provision of arrangements for dealing with any accident or emergency arising on the site and their effects; arrangements for compliance with LC 11 are described in section 0.9.

0.5 Safety Case Methods and Principles

Sizewell B was designed to meet the requirements of the Company standard "PWR Design Safety Guidelines" and prior to initial operation the design was assessed against the NII's (now ONR) "Safety Assessment Principles" and the HSE's "Tolerability of Risk from Nuclear Power stations". For the first Periodic Safety Review (PSR) of Sizewell B a new document was produced which specified the "PWR Nuclear Safety Assessment Principles" for use in PSR. This document takes into account the relevant documentation issued by ONR and the "AGR Design Safety Guidelines", and as such forms a useful document to summarise the station designers' approach to nuclear safety. The principles contained within the "PWR Nuclear Safety Assessment Principles" are as follows:

Fundamental safety Principles

NSAP1.1 – Fundamental Safety Principles

Probabilistic Safety Principles

NSAP2.1 – Risk to the Public

Radiological safety principles

NSAP3.1 – Operational Dose Limits

NSAP3.2 – Doses to the Public

NSAP3.3 – Doses to Workers

Defence in Depth

NSAP4.1 – Prevention

NSAP4.2 – Hazard Protection

NSAP4.3 – Fault Mitigation

NSAP4.4 – General Requirements for Defence in Depth claims

NSAP4.5 – Single Failure Criterion

NSAP4.6 – Severe Accidents

NSAP4.7 – Emergency Arrangements

The next section of this chapter explains each principle in more detail.

0.5.1 The Fundamental Safety Principles

NSAP 1.1 establishes the basic nuclear safety objective which requires that the station should be capable of being operated whilst adequately safeguarding the health and safety of operators and of the general public. To achieve this objective, the following fundamental principles apply:

- No person shall receive doses of radiation in excess of the statutory dose limits as a result of normal operation
- The exposure of any person to radiation shall be kept as low as reasonably practicable (ALARP)
- The collective effective dose to operators and to the general public as a result of operation of the nuclear installation shall be kept as low as reasonably practicable
- All reasonably practicable steps shall be taken to prevent accidents
- All reasonably practicable steps shall be taken to minimise the radiological consequences of any accident

0.5.2 Probabilistic Principles

NSAP 2.1 sets numerical targets for the individual and societal risks from normal operation and faults. It requires that the practicability of reducing the risk arising from a single reactor need not be considered further provided that the risk of fatality to any identified individual member of the public is shown to less than 10^{-6}p.a. Risks to any identified individual member of the public of greater than 10^{-4}p.a. would only be considered to be acceptable in extraordinary circumstances. Risks between these limits shall be shown to be ALARP.

0.5.3 Radiological Safety Principles

There are 3 radiological safety principles as follows:
NSAP3.1 sets the normal operational dose limits for personnel working on the station and for members of the public. It notes that the company sets these dose limits to a lower level than the statutory limits.

NSAP3.2 sets the acceptable dose limits for members of the public under accident conditions. Ideally the dose to any identified individual member of the public should be shown to lie within the Broadly Acceptable Region, as defined by the frequency/effective dose relationship of Figure 1. However if it is not possible to demonstrate this, then the risk of fatality to any identified individual member of the public should be shown to be tolerable.

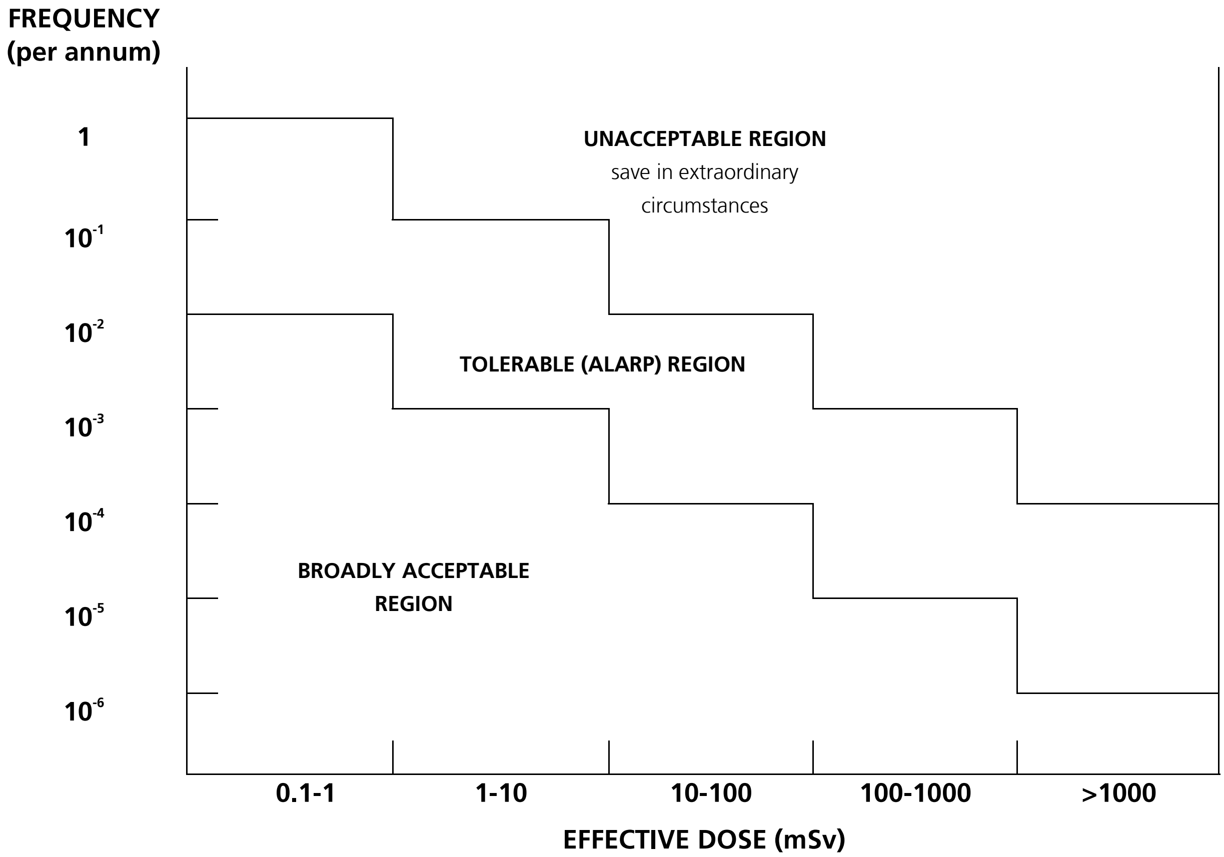

Figure 1 Frequency/Effective Dose Relationships

NSAP3.3 requires that the doses to workers under accident conditions is assessed and shown to be ALARP.

0.5.4 Defence in Depth

A key element to the safety provisions at Sizewell B is the concept of “Defence in Depth”, which ensures that there are overlapping provisions, so that if failure were to occur, it would be detected and compensated for or corrected by appropriate measures. The Safety Assessment Principles address the five levels of defence defined by the IAEA.

NSAP4.1 is concerned with fault avoidance which is the first level of “Defence in Depth” and addresses both plant based faults and hazards. It requires that all reasonably practicable steps should be taken to identify and avoid the occurrence of initiating events which have the potential to lead to public harm. It provides guidance on the practical measures that should be taken to meet this principle which range from the specification of functional requirements, the use of high standards of design and manufacture, provision of a programme of maintenance, testing and in-service inspection, and the provision of comprehensive Operating Procedures.

NSAP4.2 establishes the requirements for hazard protection that should be provided to ensure that the contribution to radiological risk from hazards is acceptably low. This is achieved by:

Taking appropriate measures to prevent Internal Hazards from occurring.

Ensuring, as far as is reasonably practicable, that a hazard will not cause a plant fault that places a demand on safeguards equipment.

Where such a fault cannot be prevented, ensuring that sufficient safeguards equipment survives the hazard to maintain the plant in a safe state reliably.

Ensuring that equipment required for this is qualified to withstand the hazard and to function in the post-hazard environment.

For natural hazards, and where adequate data exist, the magnitude of the hazard, which should be treated as a design basis event, should correspond to a severity consistent with a return frequency of 10^{-4} p.a. at the site. The continued validity of these data should be reviewed periodically.

It should be shown that there would not be a disproportionate increase in risk from a range of events, which are more severe than the design basis event.

Where it is not reasonably practicable to protect against a hazard, either because of its severity or its extreme low probability of occurrence, the risk associated with that hazard shall be considered in the assessment of overall station risk.

NSAP4.3 addresses fault mitigation and requires all reasonably practicable steps to be taken to minimise the radiological consequences of any accident, so that any initiating event which can affect the reactor or its support systems, and which potentially could lead to public harm, is protected by provisions which ensure, as far as is reasonably practicable, the maintenance of Nuclear Safety Functions. These provisions which contribute to fault mitigation should include:

- Provision, as appropriate, of segregated, diverse and redundant plant to perform safety functions. Diversity should be provided where the possibility of common cause failure threatens the achievement of the reliability required for the safety function.
- Provision, where appropriate, of multiple containment of radioactive substances. The failure of more than one barrier[4] should only be acceptable for low frequency faults/hazards and a minimum of one barrier shall remain intact for all Design Basis Faults.
- The qualification of safety components, systems and structures for the environmental conditions in which they are, or may be, required to function.

NSAP4.4 requires that safety systems which constitute part of a defence in depth provision are justified by appropriate means. The means of providing this justification include, as appropriate, transient analysis, seismic analysis, equipment testing, and human factors assessments.

NSAP4.5 defines the single failure criterion which is the primary deterministic means of ensuring that the safety systems which provide necessary safety functions, have adequate redundancy.

[4] The barriers for fission products contained in the fuel whilst in the reactor are:
1. the fuel matrix;
2. the fuel cladding;
3. the RCS pressure boundary;
4. the primary and secondary containment boundaries.

0.5.5 Severe Accident Mitigation

NSAP 4.6 requires that effectiveness of the containment is maintained under design basis fault conditions and, in addition, its effectiveness should be maintained for conditions outside the design basis, as far as reasonably practicable.

Although the main function of the primary and secondary containment boundaries is to assist in limiting the off-site release of radioactivity to an acceptable level in the event of a design basis fault, the capability of the containment is such that faults outside the design basis do not necessarily lead to a large uncontrolled release of radioactivity. Although such faults may lead to a damaged core, and may eventually lead to a core melt, the containment remains an effective barrier for cases in which it is not bypassed and in which its services remain effective. The aim of this level of defence is to address severe accidents in which the design basis may be exceeded and to ensure that radioactive releases are kept as low as reasonably practicable. The most important objective of this level is the protection of the confinement function. This may be achieved by complementary measures and procedures to prevent accident progression, and by mitigation of the consequences of severe accidents, in addition to accident management procedures.

0.5.6 Emergency Response

Emergency response is the final level of "Defence in Depth" and NSAP4.7 requires that comprehensive emergency arrangements are in place to deal with accidents or emergencies, which might arise on site in order to limit the on- and off-site consequences. These emergency arrangements shall include guidance on countermeasures off site and procedures for cooperation with the police and other authorities.

0.6 Specific Assessment and Design Against Hazards

Hazards are a particular subset of faults within the safety cases that are of particular interest as they have the potential to cause extensive harm in their own right as well as damaging or disabling multiple safety systems across the site. In some cases, such as seen at Fukushima, not only is the plant affected by the initial event (the seismic acceleration) but there are also consequential effects such as flooding from tsunamis. The NSAPs require consideration of hazards in our safety cases (NSAP4.2). The following definitions are used in relation to hazard identification:

- Natural hazard – Those hazards which occur at the site as a result of the geophysical location and prevailing meteorological conditions e.g. seismic, extreme wind.
- Man-made hazard – Those hazards which may affect a plant sited in a particular location, as a result of man's existence or utilisation of the area, e.g. fires, aircraft impacts.
- External hazard – An initiating event occurring outside of the site boundary with the potential to affect plant or buildings important to the safety of the reactor. These are generally site specific, e.g. seismic, extreme wind.
- Internal hazard – An initiating event occurring within the site boundary (including within buildings) with the potential to affect plant or buildings important to the safety of the reactor. These are generally plant and engineering design specific, e.g. fire, turbine disintegration.

The main reason for categorising the hazards in this way is that internal hazards are faults for which EDF Energy can have a direct influence in limiting the magnitude and frequency of the hazard by, for example, minimising quantities of flammable materials or ensuring hazardous equipment is suitably segregated. External hazards are those which initiate independently of EDF Energy's operations and to which EDF Energy have limited (such as industrial hazards and aircraft impact) or no (such as natural hazards) control over the magnitude or frequency of the hazard event.

The nature of the event at Fukushima Dai-Ichi and therefore focus of this Stress Test are the natural external hazards. Unlike other faults they cannot be prevented and so, as far as defence is depth is concerned, one of the barriers is not available. In addition the external hazards have the potential to affect multiple systems on the site and disrupt large areas in the locality of the site, which could hamper recovery operations, challenging the other levels of defence in depth.

Defence against hazards was built into the design of Sizewell B Power Station.

PSR1 evaluated the design basis, methodology and validity of all the hazards assessed as part of the Internal and External Assessment. PSR2 (which is currently being completed for Sizewell) is again reviewing the design basis, methodology and validity of the hazards. Issues like climate change are being captured as part of this process.

The major external natural hazards addressed as part of the design process at Sizewell B were:

- Seismic

- Wind
- Air and Sea Temperature
- Precipitation
- Seawater Flooding
- Lightning
- Water/pollution

These hazards were considered to be the major ones on the basis of either their expected frequency of their potential effect. For each of these hazards, a level of severity was defined, where appropriate, such that is extremely unlikely that the station will be exposed to more onerous conditions within its life. The level of this severity is defined as the 'design basis'. Design features were incorporated into the design of Sizewell to protect against these hazards. The design approach has ensured that the station may be safety brought to, and maintained at, a safe shutdown sate following any design basis hazard.

The NSAPs define the design basis for external hazards as an event with an annual probability of exceedance of 10^{-4}. The magnitude of the hazard is conservatively derived owing to the uncertainties that exist. For many external hazards the available historic data are sparse and require specialist interpretation to allow a probabilistic treatment and an extrapolation to an annual probability of exceedance of 10^{-4}. The methods used and their adequacy are discussed later in this report. The reasonable prediction of events less frequent than the design basis is difficult. We therefore demonstrate that there is no disproportionate increase in risk beyond this frequency, i.e. no "cliff-edge" effect where the consequence significantly increases with a slight increase in the challenge.

The equipment that is claimed to provide the essential safety function during and following the hazard is demonstrated to withstand the event through a process of substantiation. This can take many different forms but is essentially a thorough assessment of the ability of the claimed equipment or operator action to perform as required even when the plant has been affected by the external event. Qualification can be through protection from the challenge e.g. the equipment is located above the maximum flood level, the equipment is protected by buildings built to withstand the challenge, or demonstration that it can be exposed to the challenge and still function e.g. the maximum peak ground acceleration from the design basis earthquake.

0.7 Mission Time and Off-site Support

The EDF Energy safety cases demonstrate the capability of safety measures claimed to prevent or minimise the releases of radioactive materials. Many of these systems consume stocks such as fuel for diesel generators or water for cooling. It is a normal requirement within EDF Energy to have sufficient stocks of essential consumables on each site for independence from off-site support for at least 24 hours. This is usually referred to as the 'mission time'. There are longer claimed mission times for some equipment, for example, fuel stocks for the Essential Diesel Generators (refer to Section 1.3.4). Mission Times may also be longer for a shutdown reactor, but the cooling requirement during these periods is less onerous and the stocks requirements are considered to be bounded by the at-power requirements.

The minimum mission times for essential stocks are well established under the Sizewell B emergency arrangements and Sizewell B's approach to hazard protection has ensured that hazards will not affect operation of safety equipment within these periods.

Following an emergency, Station staff will continuously review stocks of essential consumables and make whatever arrangements for their supply/replenishment that are considered appropriate but will, in any event, have the capability to remain independent for at least the claimed periods and still safely manage the emergency. The mission times are key assumptions incorporated into the corresponding PSA modelling used to aid judgements made and support the risk levels claimed in the safety cases.

Beyond this period it is claimed that adequate arrangements can be established for any required essential supplies to be brought to site. If a significant incident occurs at any site the Central Emergency Support Centre is set up to manage off-site technical resources in conjunction with the on-site Emergency Control Centre and the Emergency Services. If required the Central Emergency Support Centre can contact specific suppliers, with which there are pre-existing arrangements, to deliver additional supplies to the site within the required time period.

It should also be noted that, with the exception of prolonged extreme weather conditions, the external hazards are either of short duration or episodic in nature. They are all expected to have diminished or ceased well within a period of 24 hours. The required stocks to support the 24 hour mission time and the viability of replenishing these stocks have been considered as part of this Stress Test and are discussed in chapter 6.

0.8 Beyond Design Basis Events and Accident Management

The design basis for Sizewell B is defined by reference to the "PWR Design Safety Guidelines" and other applicable standards in use at the time it was designed (refer to Section 0.5, above). The Design Basis includes all those events identified to occur with a frequency and a consequence within that for which the Guidelines require safety measures to address. The safety case demonstrates that the safety measures will perform their function against this defined basis with an appropriate reliability such that the overall risk from the site is acceptably low.

There are events beyond the design basis where the frequency of the events, either a single initiating event or a combination of faults, is such that the NSAPs do not require them to be specifically addressed. They are deemed to be sufficiently unlikely that the risk is acceptably low even if the unmitigated consequences were to occur. However, regardless of this, arrangements have been developed to ensure that the fault is managed and consequences are minimised even if these unlikely events occur.

Experience worldwide has shown that the less probable events which have occurred are often a combination of design fault, hardware failure and human error which have not been anticipated. Even if we could anticipate every possible combination of low frequency events, the vast number of these potential events would lead to an unmanageable number of event-based procedures and operating instructions. Such events have to be managed by assessment of the symptoms associated with the potential events.

For Sizewell B, guidance to reactor operators on the management of events at the edge of the design basis is provided in a series of documents. These documents are aimed at the prevention of an uncontrolled release and so are concerned with shutting the reactor down and maintaining adequate post-trip cooling. The documents are written in such a way that the operators can follow them without needing to know the exact state of the plant. This is useful for low frequency events as there could be unexpected combinations of unavailable plant and plant damage. Inherent in the design of Sizewell B is the provision of equipment and systems to deal with beyond design basis accident scenarios (for example the provision of a robust containment structure).

0.9 Emergency Response Arrangements

The key priority for EDF Energy is the safe, reliable generation of electricity. Generating safely means the prevention of accidents, and recognising the potential hazardous situations that might cause harm to the public, on-site staff, the environment, or the reputation of the company. Despite constant vigilance, and the safeguards incorporated into the design and operation of plant and systems and a positive accident prevention culture, accidents can still happen. Having well rehearsed emergency arrangements in a state of readiness gives another layer of protection by mitigating the effects of unforeseen events.

The Emergency Plan describes the principles of the emergency arrangements and implements the requirements of LC11. The plan also supports compliance with Regulation 7 of Radiation Emergency Preparedness and Public Information Regulations (REPPIR). The Site Emergency Plan together with the Site Emergency Handbook form the 'operators plan' as defined in REPPIR 2001. The plan and handbook are provided to the HSE as the operators plan for REPPIR compliance. REPPIR establishes a framework of emergency preparedness measures to ensure that members of the public are properly informed and prepared, in advance, about what to do in the unlikely event of a radiation emergency occurring, and provided with information if a radiation emergency actually occurs.

If an event should ever occur resulting in a release to the environment of significant quantities of radioactive material then, in addition to the operator, many off-site organisations would be involved and called upon to take actions to protect the public. These organisations include the Police and other Emergency Services, Local Authorities, Government Departments and Agencies, each of which has its own emergency responsibilities and procedures. These procedures are co-ordinated in the Off-Site Emergency Plan by the Local Authority, which fulfils the requirements under REPPIR.

Emergency exercises are used to demonstrate and test the adequacy of the Emergency Plan response for EDF Energy. These exercises demonstrate the on-site arrangements and off-site aspects of an emergency including central emergency support centre operations and exercising each strategic co-ordination centre, which is activated by the police and co-ordinates the off-site organisations. These exercises are witnessed by the ONR.

0.10 Mandatory Evaluations

As described in section 0.1 an internal review of our nuclear facilities and emergency response measures was initiated by the Board; this was then expanded to include the scope of a significant operating experience report issued by WANO, the World Association of Nuclear Operators, an international cross industry organisation which aims to help its members achieve the highest levels of operational safety and reliability. The primary output of these reviews was two separate Mandatory Evaluations from each of the sites, the scope and results of these initial reviews were used to inform the 'stress tests' and are presented below.

All required systems/ equipment for cooling of fuel both within the reactors and the fuel route plant areas were identified and thoroughly tested through visual walkdown and audit of compliance to the individual stations normal processes. In all cases the review concluded that the systems meet their safety function.

The next stage was to identify all equipment/systems and processes required to support mitigation of internal and external flooding events required by station design. Then thorough walkdowns of all systems, procedures, equipment and materials required to support this situation were completed.

Stations then identified all important equipment required to mitigate fire and flood events which could be impacted by a seismic incident across all reactors within the fleet. Walkdowns and comprehensive inspections were completed for all of the identified equipment and all station locations provided significant detailed information on susceptibility of claimed lines of protection in these situations. No shortfalls were identified in the support of current design basis assumptions. Further review beyond the design basis is presented in this report.

A comprehensive review of all equipment required to support the mitigation of severe accident situations was conducted across all 15 reactors within the EDF Energy fleet. Where feasible, testing of this equipment's readiness to respond in the event of a major incident was completed and all was found to be in a satisfactory state of readiness. Where testing was not possible due to normal plant operating conditions, walkdowns and visual inspections of equipment condition were completed and again all was found to be in a satisfactory state.

Procedures required to support mitigation of severe accident situations were identified and thoroughly reviewed across all facilities including central support functions. The findings from this review are detailed in Chapter 6.

All applicable agreements and contracts designed as contingencies to support severe accident mitigation were identified and comprehensively reviewed. Walkdowns of the key processes and equipment covered by these arrangements were completed (over and above those routine arrangements already in place for regular inspection/ maintenance of these arrangements). These support arrangements were found to be in line with current expectations and contract agreements.

Chapter 1 – General Data about Sizewell B

Sizewell B

1 General Data about Sizewell B

1.1 Brief Description of the site characteristics

General Location

Sizewell B is Britain's only pressurised water reactor. It is situated on the east coast, near the hamlet of Sizewell in Suffolk, around 35km north-east of Ipswich. The station is capable of producing enough electricity to supply a population of 1.5 million people, which is equivalent to the whole of East Anglia.

Sizewell B shares a site with Sizewell A of 97 Hectares. Sizewell B is built on a plateau at 6.4m Above Ordnance Datum (AOD). To the east of the site is a series of stable sand ridges known as the Bent Hills which slope down and run parallel to the seashore which at this point runs due north-south. The Bent Hills are 100m wide and have been remodelled and extended to form a continuous sea defence embankment 10m high along the eastern site boundary. The land to the north and east of the station is marshy and low lying. To the south lies the A station.

The nearest road and rail routes pass within 7.5km and 8km respectively and coastal shipping normally passes within around 6 to 15km from the site.

The land to the north and west of the site is low lying marshland. These marshlands present no flooding hazard to the site and there are no major water-retaining structures inland of the site which could collapse and result in a flooding hazard.

The coastline at the station is one of the most stable sections of the East Anglian coast. Provision is made for the continuous monitoring of erosion.

Based on investigations which have been carried out, the site is not subject to any geological hazards other than those that are conventionally dealt with by normal civil engineering procedures. Also, there is no evidence of any of the circumstances which could present geological hazards unacceptable to nuclear developments. There is also no evidence of tectonic deformation within the Sizewell site.

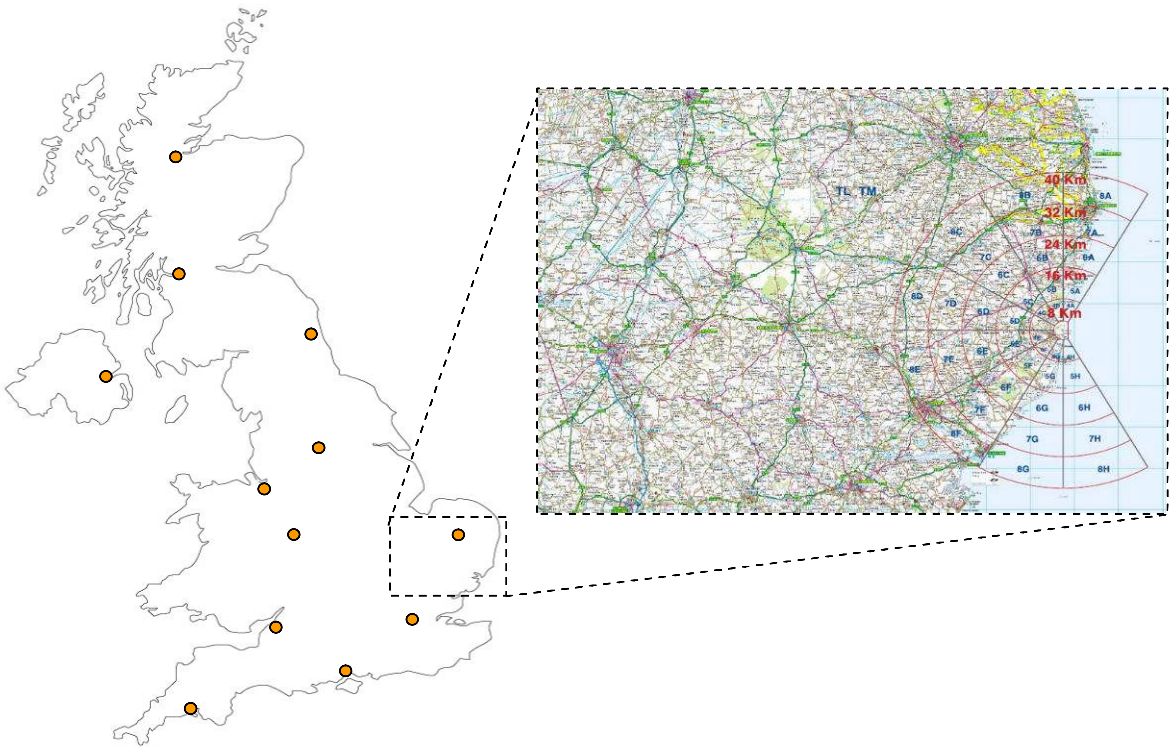

Figure 1.1: Location of Sizewell B Power Station

The Licence Holder

EDF Energy is one of the UK's largest energy companies and the largest producer of low-carbon electricity, producing around one-sixth of the nation's electricity from its nuclear power stations, wind farms, coal and gas power stations and combined heat and power plants. The company supplies gas and electricity to more than 5.5 million business and residential customer accounts and is the biggest supplier of electricity by volume in Great Britain.

In its nuclear activities EDF Energy has partnered with Centrica, which has a 20% stake in the company's eight existing plants and in the project carrying out pre-development work for nuclear new build. Centrica also has the option to take up to 20% stakes in each of the four planned plants. EDF Energy has prepared this response to the Japan earthquake on behalf of the joint venture between our two companies.

EDF Energy Nuclear Generation is the nuclear licensee and operates 15 reactors on 8 sites in the UK. 1 Pressurised Water Reactor (PWR) at Sizewell in Suffolk and 7 twin reactor advanced gas cooled reactors (AGR) at sites at Hinkley Point, Somerset, Heysham in Lancashire (2 sites), Torness and Hunterston in Scotland, Hartlepool on Teesside and at Dungeness in Kent.

The AGR stations were commissioned over the period 1976 to 1988 whilst the PWR at Sizewell was commissioned in 1995. The stations were designed and licensed to operate against standards appropriate at that time.

Throughout their respective lives the stations have been subject to regular, formal review of their basis of design in the form of safety case reviews. These reviews form an essential and mandatory part of the UK legislative framework for nuclear facilities and both the reviews and the improvement activities carried out as a result of them will be discussed in more detail in chapters 2, 3, 4, 5 and 6.

1.2 Main characteristics of the unit

Table 1.1 below provides information regarding the pressurised water reactor installed at Sizewell B.

Table 1.1: Details for Sizewell B Reactor

Reactor Type	Westinghouse standard four loop pressurised water reactor design
Process	PWR
Model	PWR
Vendor	Atomic Power Construction (APC)
Owner	EDF-Energy
Operator	EDF-Energy
Capacity Net	1188 MWe
Start Construction	18th July 1988
Criticality	31st January 1995
Grid Connection	14th February 1995
Accounting closure date	2035

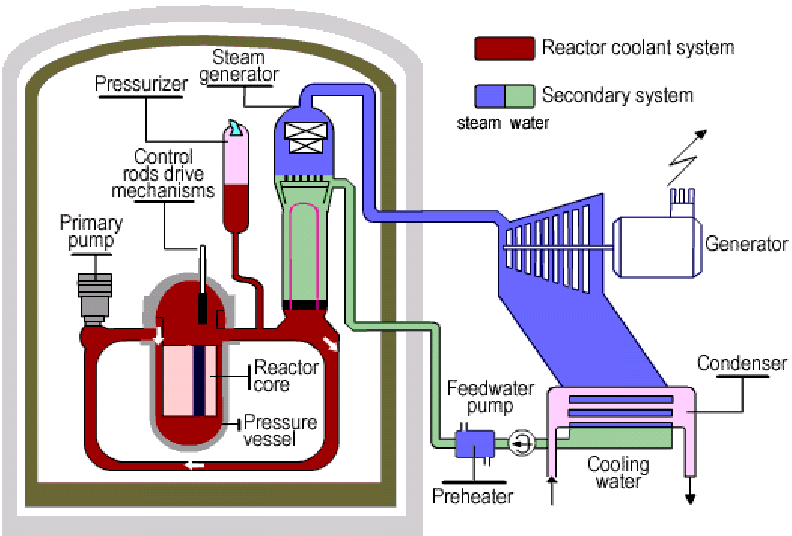

Figure 1.2: Basic Details of a PWR

Figure 1.2 above shows the basic details of the PWR. Sizewell B PWR has been developed from an American design known as the Standardised Nuclear Unit Power Plant System. At the heart of this design is a nuclear reactor which is part of the nuclear steam supply system and used to provide high pressure steam. The nuclear steam supply is of the four-loop type. Hot, pressurised water from the reactor is pumped via four pipe loops to four steam generators. The steam generators transfer the heat in the water they receive to a separate water/ steam circuit (the secondary circuit). This steam is then used to drive the turbo-generators which produce electricity.

1.3 Systems for providing or supporting main safety functions

Nearly 60% of the world's commercial reactors are Pressurised Water Reactors. Sizewell B Pressurised Water Reactor is a development of a Westinghouse Pressurised Water Reactor design known as the Standardised Nuclear Unit Power Plant System.

The Pressurised Water Reactor core consists mainly of fuel assemblies and control rods and is contained in a low alloy steel pressure vessel. Sizewell B's pressure vessel has an inside diameter of approximately 4.4m, a thickness of 0.21m and an overall height of 13.6m.

The Pressurised Water Reactor fuel is cooled by water which also acts as the moderator. The reactor operates at a pressure of 155bar. As for Advanced Gas-Cooled Reactors, Pressurised Water Reactors have separate reactor coolant system and secondary cooling system. The reactor coolant system is inside the containment. Sizewell B has four cooling loops connected to the reactor each containing a reactor coolant pump and a steam generator which provides steam to the turbine-generators. The fuel in a Pressurised Water Reactor is slightly enriched uranium dioxide which is contained within zirconium alloy cladding.

EDF Energy Nuclear Generation's Approach to Safety Assessment

The safety cases for the stations operated by EDF Energy Nuclear Generation Ltd are essentially deterministic. However the company takes the internationally accepted position in the assessment of safety that, where appropriate, Probabilistic Safety Analysis provides an accompanying role as an aid to judgement, in support of a deterministic approach. In this context a 'deterministic' approach is intended to mean both quantitative (but non-probabilistic) and qualitative assessments of the adequacy of the plant's safety systems. The Company's approach towards nuclear safety is based on the concept of defence in depth and focuses initially on three aspects of safety: prevention, protection and mitigation.

In light water reactor design four barriers exist;

1. The fuel matrix;
2. The fuel clad;
3. The primary circuit (pressure vessel); and
4. Containment.

The basic nuclear safety objective which has been adopted for the Sizewell B pressurised water reactor is that the station should be capable of being operated whilst safeguarding the health and safety of operators and of the general public. In pursuing a strategy designed to achieve this objective, the following fundamental principles have been adopted:

- No person shall receive doses of radiation in excess of the statutory dose limits as a result of normal operation;
- The exposure of any person to radiation shall be kept As Low As Reasonably Practicable (ALARP);
- The collective effective dose equivalent to operators and to the general public as a result of operation of the nuclear installation shall be kept as low as reasonably practicable;
- All reasonably practicable steps shall be taken to prevent accidents;
- All reasonably practicable steps shall be taken to minimise the radiological consequences of any accident;

These fundamental principles are also adopted by the ONR.

The main elements of the basic strategy by which EDF Energy ensures that the identified fundamental principles are met, are as follows:

- The design and operating approaches whereby radiation exposure to the operators and the public is maintained ALARP during normal operation and in any case within prescribed limits;
- The design, construction and operating approaches whereby faults are prevented from occurring as far as is reasonably practicable and, given the occurrence of a fault, the radiological consequences are rendered as small as is reasonably practicable with the aim of not exceeding certain design targets;
- The safety analysis approach whereby faults are systematically considered and adequate safety provisions are shown to exist in each case.

In applying the fundamental principles identified above and a strategy which is directed towards satisfying them, as set out in this chapter, EDF Energy judges that a proper balance will be achieved between the risk and benefit to the community.

The general design approach to nuclear safety is developed through consideration of Nuclear Electric's PWR design safety guidelines. These guidelines are a development and amplification of the Design Safety Criteria issued by the Health and Safety Department for internal use for application to all reactor types which they consider. The purpose of the design safety guideline is to provide guidance to designers on all significant nuclear safety matters.

The need to ensure that risk of harm resulting from operations at the power station is acceptably low, is recognised at all stages from initial design concept to final decommissioning.

1.3.1 Reactivity Control

Core reactivity control during normal operation and shut down in the event of a reactor trip is provided by the rod cluster control assemblies. In a reactor trip the rod cluster control assemblies fall under gravity into the core which shuts the primary nuclear reaction down.

In addition to the rod cluster control assemblies, an emergency boration system provides a diverse means of shutting down the reactor.

The Control Rods

There are 53 rod cluster control assemblies in the core. They are divided into two groups according to their function, namely;

- Control banks. These banks are allowed to enter the core sequentially according to a fixed programme and are used in normal operation. They are also used during reactor trip to help shut down the reactor.
- Shutdown banks. During normal power operation, they will be fully withdrawn, but during a reactor trip they will fall into the core to shut down the reactor.

Reactor Coolant System

The primary function of the reactor coolant system is to transfer the heat from the fuel to the steam generators. A second function is to contain any fission products that escape the fuel. The reactor coolant system is located inside the reactor building

Reactor Building System

The reactor building system comprises the reactor building primary containment shell and those structures located within the reactor building. The reactor building shell surrounds the reactor, primary coolant circuit, and parts of the secondary steam circuit. It takes the form of a substantial pressure-retaining structure which, in conjunction with the containment isolation system, provides a barrier having a very high standard of leak tightness.

A reactor building cooling system maintains the reactor building environment within suitable limits to maintain the integrity of internal structures. It is also a system which allows for monitoring of parameters such as temperature and humidity inside the reactor building.

Control of Reactivity

The reactor coolant system and associated systems provide the water used as a neutron moderator within the core. The reactor coolant system maintains a uniform distribution of soluble boron (a neutron absorber) within the water. Boron is used to balance changes in core reactivity and to permit power operation to take place at an appropriate temperature and rod insertion. Control rods are used to shutdown the reactor when required. A boronation system provides rapid boron injection if a situation arises whereby insufficient control rods enter the core. This system is capable of both shutting down the reactor and also has the capability of longer term hold-down if necessary.

Emergency Charging System

The emergency charging system provides automatic boronated water injection to the reactor coolant pumps and boronated water make-up to the reactor coolant system. The system is independent of both on-site and off-site AC power and is a system which provides diversity.

1.3.2 Heat transfer from reactor to the ultimate heat-sink

Post-Trip Cooling

Once the reactor is shut down decay heat removal can be provided by a number of systems as described below.

Assuming the reactor coolant system is intact, cooling can be provided by the following systems:

- Main feedwater system (not backed by emergency diesels).
- Motor driven auxiliary feedwater system consisting of two redundant trains, supplied by AC power backed by the emergency diesel generators.
- Turbine driven auxiliary feedwater system consisting of two redundant trains. The system is supplied by steam from the steam generators, therefore it has self-sustaining motive power derived from core decay heat.

If the reactor coolant system is not intact, i.e. there is a coolant leak, make-up water and decay heat removal would be provided by the emergency core cooling system. This consists of high head safety injection pumps, low head safety injection pumps and pressurised accumulators.

Heat-sink for the post-trip cooling systems at Sizewell B is provided by the essential service water system or the reserve ultimate heat-sink (air cooled). These systems are backed by the essential diesel generators.

Reactor Coolant System and Reactor Coolant Pressure Boundary

The heat from the reactor is transferred from the core to the steam system by the reactor coolant system. The system has connections with other heat removal systems and has the capability of removing residual heat during reactor cool down operations. The system is also capable of transferring heat to other cooling systems under both high and low pressure conditions.

Emergency Core Cooling System

The emergency core cooling system comprises equipment from a variety of systems and is specifically designed to mitigate the consequences of loss of coolant accidents and is designed to provide protection against a range of these accident types. The principal protection required following a loss of coolant accident is to ensure adequate shutdown margin and that the core is adequately cooled in order to limit fuel damage, minimise the release of fission products from the fuel cladding and prevent a loss of core geometry. The emergency core cooling system maintains this shutdown margin with reactor shutdown being initiated by other safety related systems.

Steam Generators

The steam generators form the interface between the radioactive coolant in the reactor coolant system and the feedwater in the secondary cooling system.

The steam generator uses high temperature pressurised water on the primary side as the heat source for producing essentially dry, saturated steam on the secondary side to drive the turbine generator. Heat from the reactor coolant is transferred through the tube walls to convert the secondary side feedwater into steam.

Main Feedwater System

The main feedwater system takes condensate from the deaerators and delivers it to the steam generators, via the high pressure heaters at the required pressure and temperature during normal operation, start-up and certain fault conditions.

The main feedwater system provides the means whereby feedwater is supplied to the steam generators for removal of core heat when the reactor coolant conditions are above the limit for operation of the residual heat removal system. The main feedwater system is able to discharge this function following a reactor trip. The main feedwater system provides the means of regulating the feed flow to the steam generators to prevent excessive cooldown, stratification or overfilling. In the limit, feed flow to the steam generators can be isolated.

Auxiliary Feedwater System

The auxiliary feedwater system is provided to supply feedwater for the steam generators when the main feedwater system is not available, to achieve heat removal and cooldown of the reactor coolant system to the point where the residual heat removal system is brought into service.

The system comprises two independent systems with motor and turbine driven pumps. These two systems have physical barriers segregating their pumps with townswater reservoir as the back-up supply to this system.

Residual Heat Removal System

The purpose of the residual heat removal system is to remove heat from the reactor during shutdown and cooldown. The system is also used for other duties. The residual heat removal system is a duplex system; this allows for some redundancy, although at reduced efficiency. Assuming both trains of the residual heat removal system are operating as designed, plant cool-down is completed within an economic time following shutdown of the reactor from full power operation.

Main Steam System

The main steam system conveys steam from the steam generators to the main turbine generators and the auxiliary steam system during power generation. The main steam system enables heat to be removed from the reactor during normal cooldown and certain post-fault operating conditions. Post reactor trip the main steam system supplies steam to the turbine-driven auxiliary feedwater pumps and emergency charging pumps as required.

The main steam system, in conjunction with the main feedwater system, enables removal of decay heat and cooldown of the reactor coolant system at an acceptable rate, by removing the steam generated by transfer of heat from the reactor coolant to the feedwater.

The steam is transported to the main turbine generators, or if the main turbine generators are unavailable, the steam is dumped to the main condensers, the atmosphere, or both via the main turbine bypass subsystem. If the main turbine generators and the main turbine bypass subsystem are unavailable, the steam is discharged to atmosphere through power-operated relief valves and/or through the main steam safety valves.

Fuel Handling

Spent fuel is removed from the reactor under water during a station refuelling outage. The fuel is transferred via a water-filled transfer canal to the fuel storage pond.

Criticality

The subcriticality of the fuel assemblies in the fuel storage racks is ensured under normal and fault conditions by the provision of two major neutron absorbers;

- Sheets containing boron fixed to the fuel assembly storage racks; and
- Boron dissolved in the water of the fuel storage pond.

The racks' lattice structure ensures that fuel assemblies are separated so as to maintain a suitable ratio of absorber to fuel.

Cooling System

The fuel handling facilities have dedicated cooling systems with routes for transferring heat to the ultimate heat-sink.

1.3.3 Heat transfer from the reactor containment to the ultimate heat-sink

The Sizewell B steel pressure vessel and steam generators are housed within a containment building which will limit the release of radioactivity should a fault occur. This is a large structure made of pre-stressed concrete able to withstand substantial overpressure. In the containment, heat is removed and pressure reduced by fan coolers and reactor building spray systems.

The reactor building cooling system provides an acceptable environment in the reactor building during both normal operating and fault conditions and works in conjunction with the reactor building spray system. The principal role of this system is to spray water into the reactor building atmosphere to reduce temperature and pressure, to remove fission products, and to promote mixing of the reactor building atmosphere following for example, a loss of cooling accident.

1.3.4 AC power supply

1.3.4.1 Off-site power supply and station earthing

Off-site power supply

The station's two main generators produce power at 23.5 kV. Each transmits power to the grid via a circuit-breaker and generator transformer, which step up the voltage from 23.5 kV to 400 kV. There are also two 400kV/11kV station transformers, which supply power to the station from the grid.

The Grid Interface System comprises the cables from the 400kV side of the generator and station transformers along with the isolators, switchgear and busbars in the grid substation up to the four overhead transmission line connections of the 400kV National Grid System.

The Sizewell B 400 kV substation has four circuits, constructed as two double circuit overhead lines, connecting the Sizewell substation to the Bramford substation. Two circuits are switched at Bramford and the remaining two bypass Bramford and are switched at Norwich and Pelham. Thus the Sizewell substation is directly connected to three separate points in the 400 kV system.

The function of the grid interface system is to:

- Provide connections between the 400kV grid substation and the generator transformers for the export of power:
- Provide connections between the 400kV grid substation and the station transformers for the import of power.

The auxiliary supplies to the Sizewell substation are provided from the Sizewell B power station main electrical system 3.3 kV auxiliary boards via two transformers. The connections are such that loss of one supply from the station will not jeopardise continued operation of the substation.

Under normal operating conditions, the load on each station transformer is 12 MVA. The station transformers are rated at 61 MVA, which is sufficient to meet the heaviest possible load requirement with an adequate safety margin. The 11 kV circuit breakers are rated at 3150A which is sufficient to switch maximum transformer output with an adequate safety margin.

The generator transformers normal load is 660MW and they are rated at 880 MVA.

Station earthing and lightning protection

The station earthing and lightning protection system ensures the safety of personnel and the protection of plant during an electrical fault or lightning discharge.

The station main earthing system is arranged as a buried earth ring interconnecting multiple earth electrodes and the various buildings and equipment on the site. Most of the principal buildings themselves have an internal earth ring connected at two or more widely separated points to the main station earthing ring. Within plant buildings the internal earth ring comprises aluminium conductors sheathed in extruded insulation.

For essential equipment, earthing is arranged so that the loss of earthing to one train of equipment by, for example, fire or missile damage, does not result in loss of system earth continuity to other trains of essential equipment required to maintain the plant in a safe state.

The lightning protection equipment protects buildings in which components or devices are housed by providing features such as air terminals and down conductors, to attract lightning and so prevent a lightning strike causing damage to the building. The lightning surge current would be discharged into the mass of earth through multiple, low impedance downcomers which are individually earthed and bonded to the station earth system. Electrical equipment and its cables are screened and isolated from the lightning protection equipment.

Where necessary, systems are provided with surge protection to protect them against surge voltages which would otherwise disrupt operation of the system or equipment which is electrically connected to it. Sensitive electronic equipment is protected from the effects of lightning by the following:

- Earthing cable armours at both ends and where they enter buildings;
- By surge protection on power supplies and on testing and field inputs to the reactor protection system;
- By the electrical isolation of communication routes between the reactor protection system and other systems.

1.3.4.2 Off-site power supply reliability

The off-site circuits are maintained by National Grid, who monitor and maintain reliability statistics regarding the loss of off-site circuits. The National Grid records show that there have been no loss of off-site power events at Sizewell B since first criticality.

1.3.4.2.1 Connections to the Off-Site Power Supply – Performance in Hazards

The four 400kV connections from the main generator transformers and station transformers are protected by concrete in special cable tunnels.

It is judged that the underground cable routes are robust against seismic and flooding events. The grid connection has no specific qualification against seismic events or extreme high winds. This is not a requirement of the safety case since it is assumed that grid supplies would be lost following such initiating events.

1.3.4.3 Power distribution inside the plant

Each generator connects via its circuit-breaker to a unit transformer which steps down the voltage from 23.5 kV to 11 kV to provide supplies to the station's two 11kV unit boards. Two 11kV station boards are also provided, connected via the station transformers to the 400 kV Sizewell substation bus-bars.

Power distribution inside the plant is carried out at lower voltages than the grid connections. Supplies at 11kV, 3.3kV and at lower voltages are provided on a unit and station basis as part of the 'main electrical system' as follows. Post reactor trip and in fault situations, the safeguards equipment claimed in the safety case is dependent on the 'essential electrical system' which is a four train system at 3.3kV system and lower voltages.

<u>Main power system 11KV</u>

The 11kV Main Power System is the core element in maintaining the reliability and integrity of the electrical supplies to the station. It receives power from the turbine generators, or the grid, via the 400kV Main Power System. The system is designed to maintain supplies automatically if an incoming supply fails.

The system distributes to the 3.3kV Main Power System and 3.3 kV Essential Power System switchboards, plus the turbine generator essential auxiliaries, the reactor coolant pumps, cooling water and feedwater pumps.

During normal operation of the system it is divided into two trains, each train comprising a unit switchboard supplied from its relative turbine generator and a station switchboard supplied from the 400kV Main Power System.

<u>Main power system 3.3KV</u>

The 3.3kV main power system comprises the 3.3kV unit and station auxiliary boards, the 11/3.3kV unit and station auxiliary transformers, and the incoming supplies from the 11kV boards to the transformers and all the associated cabling.

Power is received from the 11kV unit and station boards and fed to the unit and station auxiliary transformers. The power input is transformed down to 3.3kV for use on the unit and station auxiliary boards where it is made available for the 3.3kV/415V service transformers and individual 3.3kV non-safety classified loads.

The boards are arranged in pairs, each pair connected by a normally open circuit breaker. The circuit breakers are provided to connect the boards together should a board suffer an incoming power failure, thus sharing the available power for distribution to the 415V system.

Main power system 415V AC

The Main Power System distributes 415 V AC for application to a number of load control centres and motor control centres located at convenient positions around the plant. The 415 V is derived from the 3.3 kV supply provided by Main Power System 3.3kV. Most 415 V outputs are duplicated to provide a degree of redundancy and to ensure integrity of supplies under certain fault conditions.

Main power system 250 V D.C

The function of the 250V DC main power system is to provide a battery standby power supply to essential standby motor driven plant and the station siren system in the event of the loss of the normal station supplies coincident with a turbine trip, thus preventing any damage to the turbine.

The system comprises four batteries, four chargers and two switchboards.

Main power system 110VDC

The purpose of the 110 V DC Main Power System is to provide battery supported power and control supplies to the main station switchgear and control equipments so that station output can be maintained.

The system comprises two batteries, two chargers, two switchboards and distribution fuse boards.

Main power system 48V AC

The purpose of the 48 V DC main power system is to provide battery supported power to interposing relays for remote control of non essential switchgear, and supply the non essential equipment, sequence equipment and communications equipment.

Main uninteruptible power supplies system 110V AC

The function of the 110V AC uninterruptible power supply is to provide battery supported power at 110V AC to the data processing systems.

1.3.4.3.1 Main Electrical System – Cable and Equipment Locations

A separation group is a set of equipment and cables for which there are common requirements for power supply alignment and segregation from the equipment and cables in other separation groups. The cables of each separation group are physically separated from those of other groups. This is achieved generally by spatial separation but sometimes by the use of flame shields between cables.

Due to the sensitive nature of this information, details are not discussed further.

1.3.4.3.2 Main Electrical System – Performance in Hazards

There is no requirement for the main electrical system to be qualified to function during or after a safe shutdown earthquake, nor after a reactor trip associated with loss of off-site power.

1.3.4.4 Main ordinary on-site source for back-up power supply

Following a reactor trip, the preferred source of power for safety purposes is the off-site power system. Under fault conditions, power may not be available from the off-site system and a set of four essential diesel generators is provided (as part of the essential electrical system) which can supply power to those selected systems whose operation is necessary to achieve safe shutdown of the reactor. During the diesel generator starting period, battery-backed AC and DC systems are provided to maintain power to equipment which cannot tolerate a loss of power. In addition, two battery charging diesel generators provide AC power to keep batteries associated with nuclear safety adequately charged in case the essential diesels fail.

Essential diesel generators

The essential diesel generator system consists of four separate diesel generator systems (trains), each capable of generating an output of 8MW at 3.3kV, which is supplied to the 3.3kV Essential Switchboards if normal station supplies are lost. They are capable of providing at least 10% of generated full load on gravity fed fuel if the fuel pumps fail. Each of the four trains is capable of supplying its selected loads independently of the other three systems.

Essential electrical system 3.3 KV

The function of the essential electrical system (3.3kV) is to receive power from either the 11 kV main electrical system or the essential diesel generator system and to supply power to safety related loads.

Following a loss of grid the 3.3 kV essential electrical system will continue to function, obtaining power from the essential diesel generators.

Essential electrical system 415V

The essential electrical system (415 V) supplies AC power to safety related loads. The system is designed to operate with power supplies from both on-site and off-site sources. The plant equipment is located geographically so that there is always sufficient plant functioning to allow safe shutdown of the reactor after a trip and to maintain full generating capacity during operation at power.

Essential electrical system 110VAC Uninterruptible Power Supply

The function of the 110 V AC essential uninterruptible power supply system is to provide battery supported power and control supplies to safety classified equipment so that sufficient equipment is operable at all times to ensure reactor safety.

Essential electrical system 110VDC

The function of the 110V DC essential electrical supply is to provide battery supported power and control supplies at 110V DC to safety related equipment in order that sufficient equipment is operable at all times to ensure reactor safety.

Essential electrical system 48VDC

The essential electrical system generates 48 V DC by rectification of the 415 V essential AC supply from the essential power system, with batteries for short term emergency back-up.

The function of the essential electrical system is to provide battery supported power and control supplies at 48V DC. The supply is fed to safety related equipment associated with essential systems and ensures that sufficient equipment is operable to maintain reactor safety at all times.

1.3.4.4.1 Primary On-Site Back-up Power Supplies – Cable and Equipment Locations

Power supply units are located in their own cells in pairs and are independent of each other. Diesel oil storage and transfer systems are separated from other power units physically as they are situated on the other side of the building. Generally, equipment is stored in a variety of locations to ensure that enough separation exists in order to maintain sufficient plant availability under fault conditions, for example flooding.

Further discussion of specific locations is not possible due to the sensitive nature of the information.

1.3.4.4.2 Primary On-Site Back-up Power Supplies – Performance in Hazards

The diesel engines will remain functional during and after a safe shutdown earthquake and will survive the effects of other natural phenomena including high winds, floods and extremes in ambient temperature.

Following a postulated internal hazard, such as fire, internal missiles, pipe break coincident with loss of grid, sufficient essential diesel generator system equipment will remain functional to allow a safe shutdown of the reactor.

Adequate independence of electrical supplies has been provided for those essential safety systems which include redundancy. Electrical systems which are themselves essential to safety are provided with redundancy and sufficient diversity of power supplies. Interactions between different trains of essential electrical equipment which are required to be independent, have been minimised.

1.3.4.4.3 Primary On-Site Back-up Power Supplies – Time Constraints

Each bulk fuel oil storage tank has a capacity based on the fuel consumption of one diesel engine operating continuously for a minimum of 80 hours. Therefore in combination with the day tanks, stocks are available to last a minimum of 88 hours for each diesel generator. These timescales conservatively assume that the diesel generators are required to operate continuously at full power. In reality fuel stocks would be expected to last a good deal longer.

1.3.4.5 Diverse permanently installed on-site sources for back-up power supply

Battery charging diesel generators 415V AC

The function of the battery charging diesel generator system is to provide supplies to all essential battery chargers, plus non-essential battery chargers for the main power system 110V d.c, and the main power system 48V DC, when no AC supply is available from the 3.3 kV Essential System via the 415V AC systems. The system may also be used to provide a supply route to the essential chargers during partial failures of the essential 3.3 kV system and essential 415 V AC system.

The battery charging diesel generator system is provided to act as a power source to maintain DC supplies for an extended period when all other sources of AC power are unavailable. It is required to restore charging supplies within the discharge period of the batteries.

The battery charging diesel generators have sufficient fuel to last at least 24 hours from the day tank. There is a bulk storage tank with sufficient capacity to last several days.

1.3.4.5.1 Diverse On-Site Back-up Power Supplies – Cable and Equipment Locations

The battery charging diesel generator system comprises two diesel generator sets, associated auxiliary equipment and two 415V switchboards. Each diesel is connected to its associated switchboard via a fuse-switch. The switchboards are interconnected via fuse-switch units. Supplies from the switchboards are taken to all the nominated battery chargers via fuse-switches.

These battery chargers are fitted with mechanically interlocked isolating switches, such that only either the preferred supply or the battery charging diesel generator system supply can be in service at any one time. The diesel generators are totally self-contained, being complete with air start systems, fuel oil tanks, and cooling system etc. Compressed air for starting is from two automatic compressors with separate reservoirs for each engine. The compressed air storage capacity ensures that the engines can be started and connected to the switchboards under 'black start' conditions without the requirement for any external services.

Fuel storage is sufficient to run the generators for a minimum period of twenty four hours. The tanks are situated high enough to ensure a gravity feed to the engine. Each diesel generator and the respective switchboards are located in separate rooms.

Further discussion of locations is not permitted due to sensitivity of information.

1.3.4.5.2 Diverse On-Site Back-up Power Supplies – Performance in Hazards

The battery charging diesel generator system is protected from most hazards by the building surrounding it.

1.3.4.5.3 Diverse On-Site Back-up Power Supplies – Time Constraints

The battery charging diesel generator system is rated to supply its nominated load for at least 24 hours, by gravity fed day tanks.

1.3.4.6 Further Available Back-up Power Supplies

There is a set of emergency equipment, including electrical generating equipment, that would support some safety functions but this is at present very limited in this scope. This equipment is located remotely off site and centrally within the UK on trailers to be transported to the affected site within hours following the declaration of an Off-Site Nuclear Emergency. Additional time would then be required to deploy this equipment.

1.3.5 Batteries for DC power supply

Main power system 250V D.C

The system comprises four similar main power system battery/charger units, each separately fed with 415V AC. The main power system will supply normal full load for several hours.

Main power system 110VDC

On losing a 415 V AC input the load is taken up, without interruption, by the appropriate battery. A fully charged battery gives up several hours of continuous operation during 415 V failure. This allows time for the essential diesel generators to start (to provide a standby supply) or for the normal supply to be reinstated. Reconnecting the 415 V supply immediately takes the load and places the battery back on charge.

Main power system 48V AC

The batteries are maintained fully charged by distributed battery units and will be connected to the load automatically in the event of 415 V failure.

Main uninterruptible power supplies system 110V AC

The system is capable of supporting the full system load for several minutes.

Essential electrical system 48V DC & 110V DC

The 110V DC essential power system comprises four trains of equipment each including one battery, one charger, one switchboard and associated distribution fuse-boards on each of the primary and secondary systems.

For the primary system the 48V DC essential power system comprises four trains of equipment each consisting of one battery, two chargers, one switchboard and one composite board containing multiple distribution fuse-boards. For the secondary system, there are again four trains of equipment each consisting of two distributed battery units permanently connected by an inter-connector cable. Each distributed battery unit is a self-contained battery charger and distribution fuse-board.

Following a loss of off-site power and during the brief change-over period from off-site to essential diesel generator supplies, the batteries supply all connected loads. The battery chargers remain connected to the essential AC system so that when AC supplies are restored, the battery chargers are immediately energised. All battery cells are of high performance recombination (sealed lead acid) type.

Essential uninterruptible power supply system 110V AC

The role of the essential uninterruptible power supply system is to provide 110 V AC single-phase instrumentation supplies to the reactor protection system and other essential systems such that sufficient equipment is operable at all times to prevent an unacceptable release of radioactivity to the environment. It comprises four separate trains of equipment with each train further subdivided into a primary system which provides supplies to the primary protection system and a secondary system which provides supplies to the secondary protection system.

1.3.5.1 Batteries - Cable and Equipment Locations

Switchgear is often located separately to the equipment it supplies and can often be found in different buildings. Separate trains are provided for systems and some systems also have secondary sets of equipment for back-up to the primary sets.

Information regarding location is sensitive and is not discussed further.

1.3.5.2 Batteries - Performance in Hazards

The following main power systems are not qualified for hazards and are not required for safe shutdown of the plant:

- Main Power System - 250V D.C;
- Main Power System - 110VDC;
- Main Uninterruptible Power System – 415V DC
- Main Power System - 48V AC.

Essential electrical systems

The 110 V AC essential electrical uninterruptible power supply system, 110V DC essential electrical system and the 48V DC essential electrical system is designed to survive external hazards such as earthquakes, high winds and floods with consideration given to extremes of ambient temperature.

1.3.5.3 Batteries - Time Constraints

Main power system - 250 V DC

Each battery, when fully charged, has a duration on normal load of several minutes, assuming the parallel battery is out of service. In normal circumstances supplies will be restored to the 415V AC plant protection boards within the period when the backup diesels are run up and loaded.

Main power system - 110V DC

Each battery, when fully charged, has a duration of several hours.

Main power system - 48V AC

Each battery, when fully charged, has a duration of several hours.

Main uninterruptible power supplies system 110V AC

In the event of loss of the 415V AC plant protection board, the battery will maintain the DC input to the inverter for a minimum of 30 minutes and thus maintain the supply to the main uninterruptible power supply board.

Essential electrical system 110V AC uninterruptible power supplies

When off-site and on-site AC sources are lost the batteries are rated to supply the system load for several hours.

Essential electrical system 110V DC

The batteries will supply all required connected loads for several hours after loss of AC power, when charging supplies from the battery charging diesels are available if required.

Essential electrical system 48V DC

The batteries will supply all required connected loads for several hours after loss of AC power, when charging supplies from the battery charging diesels are available if required.

1.3.5.4 Alternative possibilities for recharging each battery bank

The battery charging diesel generator system is supplied to ensure that should the normal charging route to the essential batteries be lost, recharging by the battery charging diesel generator system will fulfil this function within the period of capability of the batteries.

1.4 Significant differences between units

There is only one unit at Sizewell B.

1.5 Scope and main results of Probabilistic Safety Analysis

1.5.1 Probabilistic safety analysis

The probabilistic safety analysis is used primarily to advise our judgement of risk, while also performing a diverse check on the existing deterministic safety case. Some more recent safety cases have used probabilistic safety analysis extensively for qualitatively demonstrating plant interactions and functions as well as assessing 'single plant failure' vulnerabilities as well as quantitatively to assess risk margins & robustness of the reliability of plant - in support of 'as low as reasonably ALARP arguments in particular.

Probabilistic safety analysis is a structured and comprehensive analytical methodology which is used in the assessment of safety critical systems. It allows the evaluations of identified risks to the essential safety systems present within a nuclear reactor. It models identified potential outcomes using a systematic process, including identification of complex interactions between nuclear safety systems, and thus provides a logical, consistent method for evaluating the consequences of failures.

The probabilistic safety analysis does not invent new faults in addition to those identified through deterministic safety cases on the station fault schedule. Instead the probabilistic safety analysis gives further insight to the complex nature of some faults, identification of vulnerabilities to single failures and enables risk estimation that accounts for both the fault frequencies as well as the radiological consequences for those faults (Dose bands).

The probabilistic safety analysis also identifies the most significant faults, and the most important plant, components and operator actions to protect against them. This allows targeted training and plant improvements to be implemented, therefore achieving the greatest risk reduction for effort expended, supporting the as low as reasonably practicable solution.

Chapter 2 - Earthquakes

Sizewell B

2 Earthquakes

In the Office for Nuclear Regulation (ONR) Interim Report into the Japanese Earthquake and Tsunami, it is stated that "The extreme natural events that preceded the accident at Fukushima - the magnitude 9 earthquake and subsequent huge tsunami - are not credible in the UK. We are 1,000 miles from the nearest fault line and we have safeguards in place that protect against even very remote hazards.

Sizewell B, a Pressurised Water Reactor, was based on the standard nuclear power plant design, this design included qualification against earthquake. As the design is based upon an American design, modified to meet UK requirements, both American and UK safety guidelines and requirements have been addressed. In licensing the design for operation in the UK the design was assessed against the original CEGB design safety criteria and guidelines and modified as appropriate through the licensing process.

In a number of places, this document refers to the need for ongoing development work. Some of this work had been previously identified and captured by normal company processes, whilst some is new work highlighted by the post-Fukushima review. In the latter group, there are some potential work packages referred to as 'Considerations'. These Considerations will be carefully reviewed following the completion of the Stress Test reports and an appropriate programme of work formulated.

2.1 Design basis

2.1.1 Earthquake against which the plant is designed

2.1.1.1 Characteristics of the design basis earthquake

The level of earthquake used for design purposes is referred to as the safe shutdown earthquake which is the principal design hazard. For Sizewell B this earthquake has been defined as having a peak horizontal ground acceleration of 0.14g. This ground acceleration relates to a probability of exceedance of 10^{-4} p.a., which means that there is less than a one in ten thousand chance that a more severe earthquake will affect the power station in any calendar year.

The design intent was that Sizewell B could be replicated at a range of UK sites and the original approach was to design the structures and equipment to a peak ground acceleration of 0.25g. During the course of the Sizewell B project the development of the station design and the introduction of revised Sizewell B site specific soil properties resulted in the revision of the safe shutdown earthquake specification from 0.25g to 0.14g. However in practice, a large majority of the Sizewell B structures and equipment have actually been designed to a peak ground acceleration of 0.25g.

As well as the revision of the safe shutdown earthquake, during the course of the Sizewell B project, certain preliminary design data was superseded by confirmed design data. This resulted in the seismic loading data package being changed on several occasions. When the final seismic design floor response spectra became available a reconciliation exercise was undertaken to ensure that the seismic qualification of equipment carried out using early revisions of the loading data remained valid.

In association with this reconciliation exercise and to reflect uncertainty in the calculation of the relationship between peak ground acceleration and probability of exceedance, assessments against a higher level of earthquake were conducted. These were based on a 0.2g peak ground acceleration seismic event. The results of the study showed that sufficient margins existed within the procedures used to qualify the equipment to enable seismic qualification to be claimed in all cases for a 0.2g seismic event.

Earthquakes of a lower magnitude are expected to occur more frequently than the safe shutdown earthquake. To protect against such events an operational shutdown earthquake has been defined. The operational shutdown earthquake is based on a peak ground acceleration of 0.05g. The design allows for the operational shutdown earthquake to occur five times within the lifetime of the plant. The operational shutdown earthquake has been considered in structural design and account has been taken of it in the qualification of equipment to ensure adequate fatigue life when subjected to repeated lower levels of seismic loading.

According to a Tokyo Electric Power Company (TEPCO) report, the maximum recorded peak ground acceleration at Fukushima Dai-ichi plant was equivalent to 0.561g at Unit 2: this compares with infrequent seismic hazards at UK stations of no more than 0.23g. It should be noted that the same report indicates that the reactors shutdown and post-trip cooling was initiated subsequent to the earthquake. The tsunami was the cause of the majority of the plant failures.

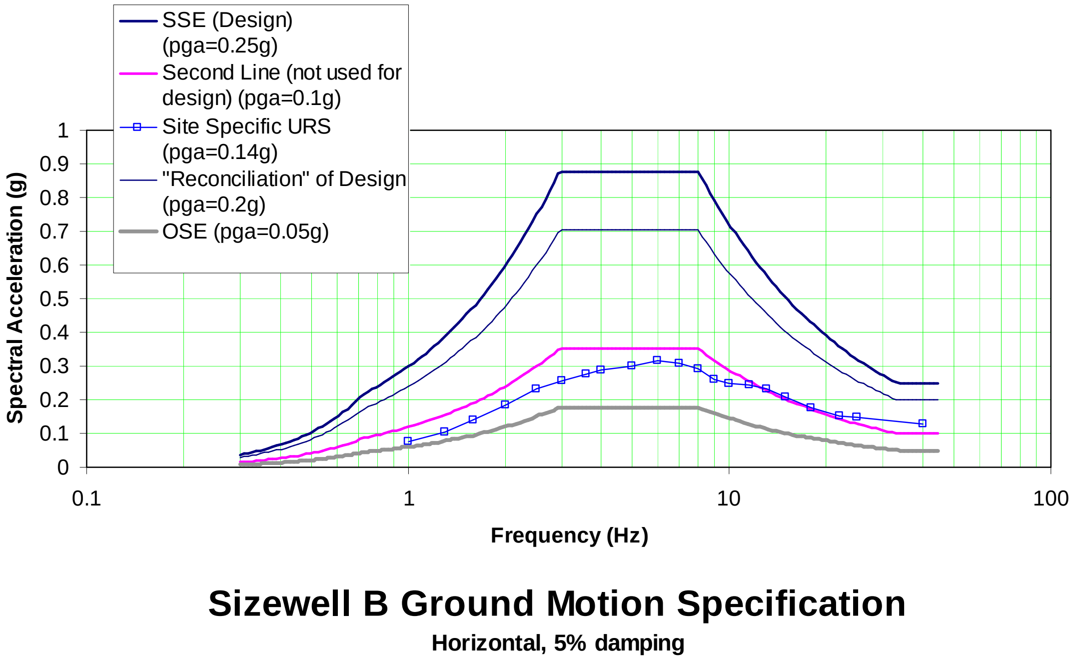

Figure 2.1: Sizewell B Bottom Line Seismic Spectrum

At Sizewell B the zero period acceleration for the design basis earthquake is 0.14g.

The uniform risk spectrum is obtained from site-specific evaluation and generally presents a more onerous requirement than the 0.1g Principia Mechanica Ltd (PML) [1981] spectra adopted in accordance with IAEA guidelines. However, as can be seen in Figure 2.1 above, as a result of the hazard for Sizewell B being relatively low in UK terms, the horizontal spectral accelerations (uniform risk spectrum) below about 2Hz are lower than those associated with the soft site PML [1981] spectrum anchored to 0.1g peak ground acceleration.

2.1.1.2 Methodology used to evaluate the design basis earthquake

Seismic Hazard Assessment Methodology

The methodology for assessing the seismic hazard at each site was developed in the early 1980's by a group known as the seismic hazard working party. The seismic hazard working party was chaired and co-ordinated by Central Electricity Generating Board staff, but included individuals drawn from external consulting companies with a specialised knowledge of the relevant disciplines (historians, geologists, seismologists, engineering seismologists etc).

The principle objective was to evaluate the level of ground motion corresponding to various probabilities of exceedance per year. Initially the methodology was only used to calculate peak accelerations with the specified probability of exceedance, but this was soon extended to produce ground response spectra which have a uniform probability of exceedance across the entire frequency range of the spectrum. These spectra are know in the UK as the uniform risk spectra and are used to define the infrequent seismic hazard at the reactor sites.

The methodology is developed in four stages which are as follows:

1) Compilation of a seismic source model in which seismic source zones and specific faults surrounding the sites are represented. The model takes in to account a variety of data sources.

2) Specifying parameters describing factors such as the rates of activity in these zones, source depths and attenuation parameters. These are specified conservatively.

3) Computation of the hazard level at the site. The approach is a probabilistic one and takes full account of uncertainties in the model parameters in order to provide appropriate safety margins.

4) Sensitivity studies to confirm that the results are not unduly sensitive to model or parameter variations, in order to ensure that appropriate margins to safety are present.

The Seismic and Geotechnical Database section 1.3 provides further details of the Seismic Hazard Assessment Methodology, which is applicable to all EDF Energy's Nuclear Generation sites in the UK.

Historical Data

According to the British Geological Survey (Natural Environment Research Council), over 80% of large earthquakes occur around the edges of the Pacific Ocean, known as the 'Ring of Fire', where the Pacific plate is being subducted beneath the surrounding plates.

Significant historical earthquakes in the UK are shown in the Table 2.1 below:

Table 2.1: Recent Significant Historical UK Earthquakes

Date	Region	Magnitude	Comment
27 June 1906	Swansea	5.2 ML	
07 June 1931	North Sea (Dogger Bank)	6.1 ML	
10 August 1974	Kintail, Western Scotland	4.4 ML	
26 December 1979	Longtown, Cumbria (Carlisle)	4.7 ML	
19 July 1984	Lleyn Penin, North West Wales	5.4 ML	
2 April 1990	Bishop's Castle, Shropshire	5.1 ML	
26 December 2006	Dumfries	3.6 ML	
28 April 2007	Folkestone, Kent	4.3 ML	PEAK GROUND ACCELERATION of 0.1g at 10 Hz
27 February 2008	Market Rasen, Lincolnshire	5.2 ML	
14 July 2011	English Channel 85km South-East of Portsmouth	3.9 ML	

NB. ML (Local Magnitude): A logarithmic scale, based on the original Richter magnitude scale, used to express the total amount of energy released by an earthquake. This is the magnitude scale used by British Geological Survey when describing UK earthquakes. The scale is logarithmic in order to cover a large range of earthquake energies. Due to this, it should be noted that a magnitude 6 ML is around 30 times larger, in terms of energy, than a magnitude 5 ML.

Review of Local Seismic Events

A review of seismic hazards for Sizewell B was completed during the design phase and covered known earthquakes (from historical or instrumental data) up to the 31st December 1989. By taking advantage of neighbouring investigations the area of study was able to cover an area of 50,000km^2 - this measured 200km from East to West and 250km from North to South.

The requirements of IAEA stipulate a region of interest of a radius of 150km.

These reviews concluded that the events that were considered did not give cause to reconsider the validity of the design basis earthquakes.

The report demonstrated that there had been 24 felt (macroseismic) or recorded instrumentally between 1165 and 1989. It was noted that after 1800 when the frequency of recording of regional earthquakes increased in East Anglia, that it was much lower than the national trend, the report remarks that this strongly indicates that the Sizewell region experiences a level of seismicity which is genuinely lower than the national average.

Geological Information on Site

The solid geology stratigraphy of the Sizewell site is tabulated below:

Table 2.2: Solid Geology Stratigraphy

Stratum	**Elevation of top of stratum (m OD)**
Crag Deposits	+6.5 to -10.2
London Clay	-41.2 to -48.0
Lower London Tertiaries (Reading, Woolwich and Thanet beds)	-55.0 to -61.0
Upper Chalk	-77.5 to -83.2

NB: The Upper Chalk has been proven to a level of about -150 m Ordnance Datum (OD).

Over the northern part of the site the Crag Deposits are overlain by weak alluvial clays and peats up to about 7 m thick and a layer of sand fill generally between four and seven metres thick. It is in this area that elevations of the top of the Crag as low as the limiting value quoted above (-10.2 m OD) are encountered.

Major non-conformities exist between the Crag Deposits and the London Clay and between the Lower London Tertiaries and the Chalk.

The sequence between the Upper Chalk and the pre-Permian basement under the site is not known with precision. However, information from deep boreholes at Harwich and Lowestoft together with limited geophysical data, indicate a regional trend leading to the conclusion that the pre-Permian rocks at Sizewell are at about -400 m OD. A large number of on-site geotechnical investigations have confirmed and refined the anticipated sequence to a maximum borehole depth slightly in excess of 150 m.

Boreholes, in situ sampling and testing, geophysical tests and laboratory tests were carried out; the conclusions of the geological and seismological studies of the Sizewell region showed that East Anglia is an area with a long history of seismic events demonstrating consistent low seismicity throughout the historical period, sitting on a crustal block that has suffered only limited deformation in the past 450 million years. This platform is bounded by zones of more pronounced deformation: to the north-east, the edge of the North Sea Basin, and to the south, the Variscan Front. Both of these boundaries are incorporated into the final seismic source model which is used to compute the ground motion hazard.

There is no evidence from any of the boreholes of any tectonic deformation within the Sizewell site. Minor displacement features have been observed in boreholes at the extreme north-east corner of the site, but they do not pass downwards into the underlying chalk. Hence, they are not the direct result of tectonic displacement.

Regional structure

From the investigations which have provided the geological database for the Sizewell site, it is apparent that the site is not subject to any geological hazards other than those which are conventionally dealt with by normal civil engineering design procedures. There is no evidence of any of the circumstances which can present geological hazards unacceptable to nuclear developments. For example, there is no evidence of any swallow holes in the chalk which could give rise to sudden collapse of the overlying ground.

The conclusions of the geological and seismological studies of the Sizewell region are as follows:

(a) East Anglia is an area with a long history of seismic events demonstrating consistent low seismicity throughout the historical period.

(b) The Sizewell region lies within the Anglo-Brabant Platform, a crustal block that has suffered only limited deformation in the past 450 million years. This platform is bounded by zones of more pronounced deformation: to the north-east, the edge of the North Sea Basin, and to the south, the Variscan Front. Both of these boundaries are incorporated into the final seismic source model which is used to compute the ground motion hazard.

(c) The possibility of post-Crag faulting has been the subject of detailed examination. All of the claims for postulated faults affecting the Crag on land have been critically evaluated and, although the significance (or even the very existence) of all such faults is questionable, their implications have nevertheless been accommodated in the magnitude-frequency relationship attributed to the local area zone source in the seismic source model.

Seismic Source Model and Sensitivity Studies

Analysis of the final source model gives an expected hazard curve passing through a peak ground acceleration value of 0.136 g at 10^{-4} p.a. exceedance level. Sensitivity tests show that this result is stable in the face of realistic variations in the model. At this same probability level, the expected peak ground acceleration derived using the uniform risk spectra soft-site zero period attenuation relationship is 0.13 g. The level of earthquake adopted for design purposes is 0.14g and demonstrates conservatism. To reflect uncertainty in the calculation of the relationship between peak ground acceleration and probability of exceedance, assessments against a higher level of earthquake were conducted for equipment for structures, and sufficient margins were demonstrated to exist.

Ground motion spectra

Strong motion accelerometer recordings are extremely rare for intraplate events even on a worldwide basis. During design a specific study was therefore commissioned into the likely characteristics of the type of earthquakes experienced in the UK. The methodology for this study was as follows:

- List important parameters defining characteristics of UK events;
- Estimate the relevant limits of these parameters;
- From a comprehensive library of worldwide strong motion records, select those which fall within the postulated limits;
- Generate a spectrum which conservatively represents the features of all the selected records;
- Generate typical artificial time histories based on the spectrum.

A further degree of refinement was introduced in that the data were categorised to produce different spectra for hard, medium and soft sites. On the basis of this categorisation, it becomes necessary for any specific site in the UK to determine whether the ground motion spectra for hard, medium or soft ground should be applied.

The study also made comment on the ratio of vertical to horizontal peak accelerations and concluded that a figure of 2/3 was judged to be conservative.

As noted above, an alternative representation of seismic ground motion has been developed to provide uniform risk spectra, characterised by equal exceedance probability across the frequency range. Hard, medium and soft ground databases of strong-motion records were carefully selected and processed, and regression analyses performed on the response spectra to generate spectral attenuation relations, for both horizontal and vertical motion, in the frequency range of 1 Hz to 40 Hz. The availability of these attenuation relations, coupled with the Sizewell seismic source model, has allowed site-specific uniform risk spectra to be constructed for Sizewell.

Safety Margins in the derivation of design basis earthquakes

The methodology used to derive the design basis earthquakes has made use of expert opinion and uses models that have consensus support from a wide range of external consultants with specialist knowledge of the relevant disciplines. Additionally it has made use of sensitivity studies which demonstrate the absence of cliff edge effects and generally tended to reduce the predicted level of ground motion.

The frequent event design basis earthquake is 0.1g peak ground acceleration, in accordance with IAEA guidance and Sizewell B results show that sufficient margins exist within the procedures used to qualify the equipment, to enable seismic qualification to be claimed in all cases for a 0.2g seismic event. This shows a clear margin and is therefore a pessimistic representation of a frequent event and demonstrates that plant has been seismically qualified to the more onerous 10^{-4} p.a. uniform risk spectrum.

A review of historical events of relevance to Sizewell B and within the IAEA stipulated region of 150km has taken place as part of the periodic review process. It has been concluded that the events considered did not have a significant effect on the assessment of the seismic hazard. The events subsequent to this review have been considered and it is judged that they do not alter the outcome of the earlier review. It is also noted that the original seismic hazard models only considered events with a surface wave magnitude (MS) of greater than 4.0. When the surface wave magnitude scale was formulated it was intended to give similar values as the local magnitude scale. The Sizewell review states that "from the experience of the UK catalogue, the MS value is consistently lower than the ML value". This is supported by the estimates of the MS values for the events considered in each of the reviews that found that the MS values were either similar or less than the ML values. Therefore the corresponding threshold would be 4.0 ML or higher. The use of the ML value can be considered conservative in comparison to the MS value.

2.1.1.3 Conclusion on the adequacy of the design basis for the earthquake

The information presented in the preceding sections shows that the methodology used to calculate the design basis earthquakes for Sizewell B has been constructed using independent expertise based on well regarded sources of information. Furthermore it has been reviewed periodically in line with company process and regulatory expectations. The methodology has been constructed with appropriate conservatisms, margins and sensitivity studies employed.

Conclusion SZB 2.1: The methodology used for calculating design basis earthquakes is robust, has appropriate conservatisms, margins and sensitivity studies employed and has been periodically reviewed.

2.1.2 Provisions to protect the plant against the design basis earthquake

The safety case addresses the qualification of systems, structures and components whose functionality is important in terms of lines of protection. In addition the safety case addresses interaction threats from plant which is not seismically qualified, consequential hazards and the operator actions required by the safety case. This is discussed further in the following sections.

2.1.2.1 Identification of systems, structures and components that are required for achieving safe shutdown state and are most endangered during an earthquake. Evaluation of their robustness in connection with design basis earthquake and assessment of potential safety margin

Hazards, by their nature, have the potential to cause widespread damage to equipment and structures and hence could result in single or multiple plant faults. The following section describes the overall approach which has been taken to provide protection against hazards at Sizewell B. The second part of the section is where the evaluation of robustness of the plant is described. As can be seen a very comprehensive method was used to ensure that all relevant structures and components required for safety were identified and seismically qualified to ensure that not only would they function, but that related plant which might not be required for safety would not affect the function of the safety qualified plant in a seismic event.

In analysing the design basis earthquake, the comprehensive analysis undertaken took into account the different plant operating states as well as the impact on the fuel route. These were all analysed probabilistically within the living probabilistic safety analysis in order that the risks from all sources of potential radioactivity could be evaluated in a holistic approach. The following sections are therefore not always broken down into at power, shutdown and fuel route as with the AGRs but are assessed together with the risks appropriately identified.

The design approach adopted to protect the power station from the effects of earthquake-induced loading comprises the following five main phases:

- To define the safe shutdown earthquake as the level of earthquake used for design.
- To identify the seismic category of a structure, building or equipment item by examining its role in the safety argument, both during and following the safe shutdown earthquake. See section below.
- To verify the structural integrity of buildings, which have been allocated a seismic category relevant to attaining a safe shutdown of the station, they were seismically analysed, details of which are included in the safety case.
- To define the maximum seismic loading which seismically classified structures and equipment are required to withstand. This loading was specified in terms of floor response spectra at each floor elevation throughout the power plant buildings. The floor response spectra was derived from a finite element analysis of the building which included

the effects of soil structure interaction. The analysis methods and validation studies carried out to confirm these loadings are described in the safety case.

In determining the systems structures and components which are required for achieving a safe shutdown state and which may be threatened during an earthquake it is important first to identify the equipment important to safety.

Mechanical and electrical equipment and civil structures are allocated to one of three safety categories; these are defined as follows:

Safety Category 1

Equipment which forms the principal means of ensuring nuclear safety. (The term safety classified is commonly applied to such equipment).

Safety Category 2

Equipment which, although not safety classified, makes a significant contribution to ensuring nuclear safety. (This category is not used for civil structures.)

Safety Category 3

All remaining equipment.

Definition of Safety Classes

Mechanical equipment in safety category 1 is further subdivided into safety classes 1, 2 and 3 in accordance with ANSI N18.2 'Nuclear Safety Criteria for the design of stationary PWR plants'. This can be summarised as follows:

Safety Class 1 - Applies to;

- components whose failure could cause a loss of coolant accident greater than the capability of the normal make-up system.

Safety Class 2 - Applies to;

- other reactor coolant pressure boundary components;
- systems necessary to directly remove residual heat from the reactor;
- safety systems necessary to circulate reactor coolant;
- systems used to control radioactivity release and hydrogen within the reactor building.

Safety Class 3 - Applies to;

- Components required to control activity release outside the reactor building;
- Systems required to remove decay heat from spent fuel;
- Systems which support other safety systems;
- Other safety category 1 equipment not defined above.

Having defined which safety class the equipment belongs to, the seismic category of a structure or item of equipment is determined by examining its safety role during and following a safe shutdown earthquake and all equipment allocated to one of five seismic categories as follows:

Seismic Category 1

The subset of safety category 1 structures and equipment which form the principal means of ensuring nuclear safety either during or following an safe shutdown earthquake, is allocated to seismic category 1.

This equipment has been qualified to withstand the effects of an safe shutdown earthquake; that is to remain structurally intact, leaktight in the case of fluid containing equipment, and functionally operable to the extent required by its safety role.

The following sub-categories of seismic category 1 are used where appropriate to define the extent of functional operability required:

- YK - Seismic category 1 equipment that must remain functionally operable during and following the safe shutdown earthquake;
- YA - Seismic category 1 equipment that must be functionally operable following the safe shutdown earthquake and must not operate spuriously in a manner detrimental to safety during an safe shutdown earthquake;
- YB - Seismic category 1 equipment that must not operate spuriously in a manner detrimental to safety during and following an safe shutdown earthquake;
- YC - Seismic category 1 equipment whose operational failure in any mode is not detrimental to safety.

Seismic Category 2

Other equipment which has been assessed as making a significant contribution to ensuring reactor safety following a safe shutdown earthquake and which is in either safety category 1 or 2 is allocated to seismic category 2.

This equipment is established to have a capability to withstand earthquake-induced effects to the extent required by its contribution to ensuring nuclear safety. Such capability has been demonstrated with a level of assurance commensurate with the significance of the contribution.

Seismic Category D

Supports of equipment containing gaseous Radwaste are allocated to seismic category D.

Supports of gaseous Radwaste equipment have been designed and constructed to provide reasonable assurance that following an safe shutdown earthquake, the equipment does not release its inventory to the environment.

This seismic category originated in the US and has been retained for continuity; however, in practice the equipment is designed to seismic category 2 requirements.

Seismic Category S

Equipment and structures which themselves are not required to remain operable or intact either during or following a safe shutdown earthquake, but whose failure could prevent seismic category 1 equipment from functioning as required, are allocated to seismic category S. Equipment and structures allocated to this seismic category have been designed, constructed and qualified where appropriate to prevent the identified threat.

Seismic Category N

All equipment and structures which are not allocated to one of the seismic categories described above are allocated to seismic category N.

Seismic Design/Qualification

All seismic category 1 and S equipment is qualified either by analysis or test, or a combination of the two, to ensure that it can perform its safety function following a safe shutdown earthquake. Equipment assigned to seismic category 2 or D has been designed to withstand earthquake-induced effects at a level of assurance commensurate with their contribution to safety.

In developing the hazard assessment methodology the following process was used. After the design of the station was essentially complete, a review process was undertaken to assess the compliance of the design with the principles and criteria and that any exceptions to these were justified as being acceptable

In addition a seismic review was undertaken as part of the design phase to confirm that no *seismic category 1* plant could be unacceptably affected by the failure (or other effect), due to a seismic event, of plant of a *seismic category 2 or N*. The analysis examined all locations within *safety classified* buildings and was carried out on a room-by-room basis. All potential post-seismic failures were identified and their consequences assessed. Where potentially unacceptable interactions were found the situation was resolved either by:

- modifying the design (e.g. by relocating or rerouting plant to remove the interaction); or
- by placing a barrier between the source of the interaction and the target; or
- by placing a `catcher' beneath the source to prevent significant movement); or
- by carrying out further analysis to demonstrate that the target would safely withstand the interaction; or
- by making the hazard `source' seismic category S to ensure that it does not fail in an unacceptable manner.

It is important to note that for Sizewell, qualified plant is qualified for both the operational shutdown earthquake and safe shutdown earthquake seismic event, thus giving adequate lines of protection for both events.

Requirements for Safe Shutdown

Following a plant fault or hazard it is necessary that:

- The short-term consequences of the event are adequately limited;
- The plant is taken to an appropriate safe stable shutdown state;
- The plant is maintained safely at the chosen shutdown state for as long as is required; for example, to rectify the fault.

Reactor Trip

Depending on the severity of the disturbance, the reactor may automatically trip or (in the case of an operational shutdown earthquake) may require a trip to be manually initiated. Normal post-trip procedures can then be used to bring the plant to a safe shutdown state.

In the case of a safe shutdown earthquake, there may be a partial or complete loss of the grid (the plant has been designed and is appropriately protected to deal with this). Seismic monitoring covers 3 areas, namely the containment base slab, the containment operating level and free field. All are alarmed for the operational shutdown earthquake and safe shutdown earthquake.

Reactor Shutdown

As previously discussed, following a plant fault or hazard, it is necessary to take the plant to an appropriate safe stable shutdown state. A safe shutdown state is one at which systems conditions are stable, that is, conditions are steady or slowly varying and are capable of adequate control, and the following safety objectives are met:

- Control of reactivity;
- Decay heat removal;
- Control of radioactive release;
- Maintenance of plant within safe limits;
- Support of safeguards system operation.

The required plant systems and seismic category of the systems to meet the above safety objectives are appropriately classified to ensure that a safe shutdown is achievable.

Protection Against an Operational Shutdown Earthquake

Earthquakes of a lower magnitude are expected to occur more frequently than the safe shutdown earthquake. To protect against such events an operational shutdown earthquake has been defined with a peak ground acceleration of 0.05 g. The operational shutdown earthquake has been considered in structural design and account has been taken of it in the qualification of equipment to ensure adequate fatigue life when subjected to repeated lower levels of seismic loading. Five operational shutdown earthquake events are assumed to occur in the station lifetime. The operational shutdown earthquake is also used to define the minimum level of seismic event following which the plant must be shut down for seismic evaluation/inspection purposes.

Shutdown Reactor

For a shutdown reactor, the appropriate plant state documentation would be used to ensure cooling, containment and control of the plant is appropriately maintained. As with the systems used to maintain cooling, containment and control of the plant when the hazard occurs at power, the systems required for a shutdown are appropriately qualified.

PWR Fuel Route Plant Areas

Following any seismic event any fuel assemblies being moved would be placed in a safe state, and then all fuel handling operations would be suspended. A safe state is considered an approved storage location, such as the vessel, fuel storage rack etc., that allows a safe level of water above the fuel assembly.

The fuel storage facility is designed to remain functional and maintain its structural integrity after a safe shutdown earthquake. The systems used to maintain adequate water inventory in the fuel storage pond are *seismic category 1;* that is, the pond and adjacent bays and their associated transfer gates when in position in the pond/bay transfer slots. Seismic analysis shows that during a seismic event the fuel storage racks will not overturn but may slide or rock on the pond floor. The maximum displacement of the racks horizontally does not result in the racks impacting the fuel storage pond walls.

The fuel storage facility is designed to prevent the loss of cooling water from the pond that could result in the stored fuel becoming uncovered or prevent cooling capability. Analysis has been carried out to ensure that fuel damage will not occur following the loss of pond cooling because evaporative losses from the fuel storage pond can be made up from three separate supplies, one of which is seismically qualified.

All components in the fuel storage facility that are necessary to adequately cool the irradiated fuel are seismic category 1. These components are qualified to perform the safety functions required of them both during and after a seismic event.

Robustness of the Plant Areas

The experiences at Fukushima Daiichi outline the significance of the plant experiencing events more severe than were considered within the design basis. The EDF Energy PWR Nuclear Safety Assessment Principles state that "all reasonably practicable hazard protection should be provided to ensure that the contribution to radiological risk from hazards is acceptably low."

The principle also states that "for natural hazards, and where adequate data exist, the magnitude of the hazard, which should be treated as a design basis event, should correspond to a severity consistent with a return frequency of 10^{-4} p.a. at the site. The continued validity of these data should be reviewed periodically."

The section 2.1.1.3 outlined that conservatisms and margins exist in the calculation of the design basis earthquake. This section outlines the additional robustness judged to exist by previous reviews of the safety case and an assessment of this robustness in the light of the events in Japan.

Safety Case Robustness

The design intent was that Sizewell B could be replicated at a range of UK sites and the original approach was to design the structures and equipment to a peak ground acceleration of 0.25 g. Where appropriate, the soil dynamic properties existing at that time were adopted. Thus, a large majority of the Sizewell B structures and equipment have actually been designed to a peak ground acceleration of 0.25 g. Later in the design process, a wider use of soil structure interaction methodology, revised Sizewell B site specific soil properties, and a site specific safe shutdown earthquake of 0.14g (estimated to have a return frequency of 10^{-4} p.a.) was adopted. With this final combination of parameters, the design was demonstrated to be robust in a seismic reconciliation exercise using as-built information. To reflect uncertainty in the calculation of the relationship between peak ground acceleration and probability of exceedance, assessments against a higher level of earthquake were conducted. These were based upon a 0.2 peak ground acceleration seismic event, to demonstrate that there was in fact a significant seismic withstand capability for events having a horizontal ground acceleration in excess of 0.14g. The study included a range of equipment and structures for which the existing seismic qualification loading showed potentially the smallest margins in relation to the final seismic design floor response spectra. It also included selected items of plant, significant to safety.

The intent of this study was to provide additional assurance of the robustness of the seismic safety case for Sizewell B. In practice, as has been mentioned above, a large majority of the Sizewell B structures and equipment have actually been designed to a peak ground acceleration of 0.25g and thus have large margins. That being said, during the early part of the design process it was necessary to use certain preliminary design data, but as the overall design developed and more information and data became available, confirmed design data became available. It was therefore necessary to reconcile the earlier design work in the light of both the confirmed design data and currently acceptable methodologies (Reconciliation Strategy). This ensured that the final design met the seismic design and qualification requirements.

Seismic Qualification Methods

Having identified which components and systems are important to safety in seismic hazards it is important to correctly qualify them in terms of seismic capability. Three methods of seismic qualification are used within EDF Energy.

2.1.2.1.1 Evaluation of their robustness in connection with design basis earthquake and assessment of potential safety margin

The information presented in the preceding sections shows that the processes for ensuring robustness of the plant for seismic events are well developed and implemented and give appropriate consideration to the requirement for margins. They make appropriate use of international experience and standards for both nuclear specific and discipline specific topics. Furthermore they have been reviewed periodically in line with company processes and regulatory expectations. The methodologies are internationally recognised and have been constructed with appropriate conservatisms, margins and sensitivity studies employed.

Conclusion SZB 2.2: The methodologies used for ensuring robustness of the plant have appropriate conservatisms, margins; make appropriate use of international experience and standards and have been periodically reviewed.

2.1.2.2 Main operating contingencies in case of damage that could be caused by an earthquake and could threaten achieving safe shutdown state.

The operators at Fukushima Dai-ichi were hampered in their recovery actions by the situation on and around the site. This was initially as a result of the inundation but also once the waters had receded as a result of debris, radiation levels and conventional hazards as a result of the event.

The EDF Energy Nuclear Safety Assessment Principles require that the functional capability claimed of an operator, which constitutes a line of protection is justified by appropriate means as follows:

- The claims made in the safety case should be supported by appropriate human factors assessments to demonstrate the capability demanded.
- The human factors assessments should include, as appropriate, task analysis, the state of supporting procedures, training, environmental issues (such as the state of emergency lighting), and administrative controls.

For earthquakes of magnitude less than the operational shutdown earthquake, no operator action is required and it would be expected that the station would run through the event. For earthquakes of higher magnitudes, the operators will follow the appropriate station operating instructions.

Mobile equipment on site is not required following either an operational shutdown earthquake or a safe shutdown earthquake.

2.1.2.3 Protection against indirect effects of the earthquake

2.1.2.3.1 Assessment of potential failures of heavy structures, pressure retaining devices, rotating equipment, or systems containing large amount of liquid that are not designed to withstand design basis earthquake and that might threaten heat transfer to ultimate heat-sink by mechanical interaction or through internal flood

Mechanical Interaction

During an earthquake there is possibility of interaction between buildings due to coupling through the soil medium, which may modify the building response significantly compared with the assumption that a building can be regarded as being isolated. Models of the main buildings were used to investigate the effect of introducing an adjacent building in comparison with the case where a single isolated building was considered. The effects of building-building interaction were found to be relatively small, a conclusion which has been supported by seismic analysis codes and standards.

As described earlier, equipment and structures which themselves are not required to remain operable or intact either during or following a safe shutdown earthquake, but whose failure could prevent seismic category 1 equipment from functioning as required, are allocated to seismic category S. Equipment and structures allocated to this seismic category have been designed, constructed and qualified where appropriate to prevent damage due to mechanical interaction.

Pressurised Component Failure Caused by Seismic

A seismic event has the potential to cause the failure of a pressurised component. During design it was therefore assumed that any pipework not seismically qualified would fail and as such, appropriate protection has been designed and engineered.

Conclusion SZB 2.3: Potential failures of systems, structures and components have been considered as part of the safety case and appropriate qualification has been carried out as a required.

2.1.2.3.2 Loss of external power supply that could impair the impact of seismically induced internal damage at the plant

Loss of external power as a result of a seismic event was considered during the design process and as such there are appropriate levels of qualification and protection to ensure that a loss of off-site power will not prevent the plant from reaching a safe state following an earthquake (operational shutdown earthquake or safe shutdown earthquake).

Appropriate levels of supplies are available on-site to bring the plant to a safe shutdown without assistance required off-site.

Conclusion SZB 2.4: Consequential loss of grid has been considered as part of the safety case. Electrical supplies to essential safety related equipment are provided by back-up power supplies designed to withstand the design basis earthquake.

2.1.2.3.3 Situation outside the plant, including preventing or delaying access of personnel and equipment to the site

Suffolk Community Risk Register May 2011

The Local Resilience Forums are the local authority body in the UK with responsibility for providing emergency response in the community. The review of emergency arrangements is contained in chapter 6 This assessment aligns with our own in that we would expect difficulty with access to and from site for a period, although it should be noted that the magnitude of this impact would be very much less than that seen in Japan. The local resilience forum for Suffolk has not identified seismic events as a major risk for the area.

Review of Station Access, Access Control Points and Emergency Control Centres During and Following External Hazard Events.

A review of site access following external hazards has been carried out. No major issues have been identified.

Conclusion SZB 2.5: Access of personnel and equipment to the site has been considered as part of the Emergency Arrangements, and following a recent review these arrangements are considered to be appropriate in the light of events at Fukushima.

2.1.2.3.4 Other indirect effects (e.g. fire or explosion)

Seismically Induced Fire

Fire is among the effects which could be produced by the failure of equipment and structures as a result of an earthquake. Where a failure of this kind appears possible, the equipment that has the potential to lead to a seismically induced fire has been designed to be robust against the event of an earthquake and hence a seismically induced fire.

Conclusion SZB 2.6: The potential indirect effects have been considered as part of the safety case and where considered necessary to protect essential plant, interactions have been qualified against the appropriate design basis earthquake.

2.1.3 Compliance of the plant with its current licensing

2.1.3.1 Licensee's processes to ensure that plant systems, structures, and components that are needed for achieving safe shutdown after earthquake, or that might cause indirect effects discussed under 2.1.2.3 remain in faultless condition

The Engineering Change process that each modification goes through requires that all modification proposals check whether plant is seismically qualified or whether the modification could affect seismically qualified equipment. The procedure therefore reduces the risk that the seismic safety case is compromised by changes to the plant and structures.

Inspection and maintenance is important to ensure that the adequacy of the seismic safety case is maintained. Nuclear safety related inspections for equipment qualification are also undertaken with the reviews are carried out at frequencies of between three and five years, depending on the system.

Following either an operational shutdown earthquake or a safe shutdown earthquake, surveys of safety classified areas are carried to ensure that the plant is in a safe state. Any anomalies would be rectified in a timely manner as part of the appropriate station processes.

2.1.3.2 Licensee's processes to ensure that mobile equipment and supplies that are planned to be available after an earthquake are in continuous preparedness to be used

No mobile equipment is required as part of the seismic safety case for the design basis safety case.

2.1.3.3 Potential deviations from licensing basis and actions to address those deviations

A review of the processes used to address potential deviations from the licensing basis has been carried out following the event in Japan, and none of the deviations relate to seismic events.

2.1.3.4 Specific compliance check already initiated by licensee

In light of the events at the Fukushima Daiichi plant, as responsible operators EDF Energy have carried out reviews at each of the sites as a requirement of the Board.

Scope

The review was specified to ensure that systems essential to fuel cooling in an emergency situation in a within design basis event including seismic and flooding scenarios were correctly configured, lined up and in a suitable condition to be declared available/operable. Further to this configuration check, a full seismic housekeeping walkdown was carried out.

This involved appropriate engineers physically inspecting areas of the plant containing seismically qualified equipment and checking that the plant areas did not contain any items which could cause damage to claimed systems, for example by falling over in an earthquake and striking a system or component.

There were seven main objectives, listed as follows:

1) Identify essential systems required to provide fuel cooling in reactor and fuel storage facilities.

2) Verify that Stations seismic housekeeping standards are suitable to be adequately prepared for a 'within design basis' seismic event.

3) Perform a review of systems identified in Objective 1 to identify the current status of the systems.

4) Perform a physical review of systems identified in Objective 1 to confirm the current status of the systems.

5) Perform a review of Station documentation associated with the design basis emergency operation of the systems identified in Objective 1.

6) Review the training programmes for the Operators to confirm the extent of Design Basis Accident training (DBA) and assess the ability of the staff to deal with DBA.

7) Identify any station operating experience and subsequent learning through responding to a significant within design basis event.

Stations were asked to capture any issues for further action through normal processes.

Summary of site specific findings

The primary finding was that no major shortfall was identified; however there were a number of minor issues. These are being closed out using the appropriate company processes. There were also a number of conditions highlighted by the walkdowns that whilst being compliant with our existing safety case requirements, did not meet industry best practices.

Conclusion SZB 2.7: The reviews undertaken and the actions identified therein, have confirmed that Sizewell B is compliant with the current licensing basis, although opportunity for process improvements has been identified.

2.2 Evaluation of safety margins

The experiences at Fukushima Dai-ichi outline the significance of the plant experiencing events more severe than were considered within the design basis. As previously mentioned two levels of seismic event were considered for design purposes namely the safe shutdown earthquake and the operational shutdown earthquake, however as part of the overall safety case the seismic fault analysis justified the safety of the station for seismic events with corresponding exceedance frequencies down to the 10^{-8} p.a. level.

This was done by calculating the appropriate PDS frequency contributions and building these into the overall fault analysis results as with any other contributions. Hence the necessary inputs into the analysis are derived for the 10^{-4} p.a., 10^{-5} p.a., 10^{-6} p.a., 10^{-7} p.a. and 10^{-8} p.a. return frequency seismic events. These inputs are the seismic fragility probabilities for safety critical items. They represent the probabilities that items of equipment or structures will fail when demanded following a particular level of seismic event. All such fragility probabilities are based on seismic loads derived from floor response spectra.

Section 2.1.1.3 outlined that conservatisms and margins exist in the calculation of the design basis earthquake. Section 2.1.2.1 noted that the methods use to seismically qualify systems, structures and components are also inherently conservative. It is this conservatism which is explored in this section to help illuminate the safety margins.

The approach that has been adopted is to recommend methods of assessment and acceptance criteria that ensure that, for the specified earthquake excitation, there will generally be a high confidence of low probability of failure. This assertion lies in the theory of seismic fragility functions. The seismic fragility concept is the means by which the capability of plant, components and structures to withstand seismic events can be represented in a probabilistic sense. The results are expressed in terms of failure probabilities at a given hazard level. The probability that a seismically qualified structure would fail at the safe shutdown earthquake or less will therefore be very small but nevertheless non-zero. Conversely, the probability that the same item or structure would fail at very much higher levels of earthquake would be large but not necessarily 1. Based on a large amount of support work for Sizewell it has been possible to derive discrete probabilities of failure (for specific failure modes) for all of the components modelled in the fault trees, all important buildings and all important tanks on site at the 10^{-4} p.a., 10^{-5} p.a., 10^{-6} p.a., 10^{-7} p.a. and 10^{-8} p.a. return frequency levels.

A deterministic seismic margin study was carried out in addition to the probabilistic studies to demonstrate that the station has adequate seismic margins. The intent of the study was to provide additional assurance of the robustness of the seismic safety case for Sizewell B. The results of the study showed that sufficient margins existed within the procedures used to qualify the equipment to enable seismic qualification to be claimed in all cases for a 0.2g seismic event.

2.2.1 Range of earthquake leading to severe fuel damage

From the previous section it can be seen that as the earthquake hazard was analysed probabilistically in the LPSA, there is a potential for all such hazard return frequency levels of 10^{-4} p.a., 10^{-5} p.a., 10^{-6} p.a., 10^{-7} p.a. and 10^{-8} p.a. to lead to severe fuel damage and the frequency of core damage is calculated in the LPSA. Due to the high probabilities of failure for the lower frequencies and issues associated with modelling success paths with high failure probabilities within the PSA software, the 10^{-7} p.a. earthquake is conservatively assumed to lead directly to core damage in the LPSA. Even with this assumed conservative 'cliff-edge' at 10^{-7}p.a. the results from the latest LPSA Version 3.40 model indicate that the earthquake hazard contributes less than 19% to the overall core damage frequency.

The LPSA analysis covers both at power and shutdown conditions and demonstrates that although earthquake is a significant contributor to core damage it does not dominate the result when compared with other faults and hazards.

Fuel route faults, from the fuel storage pond and radwaste plant due to earthquakes are also considered within the LPSA. These plant damage states contribute to a large uncontrolled release and although the hazard frequency is not reported directly in the Safety Case it can be deduced from the LPSA results that the total contribution from ex-reactor sources of fuel damage is around 2% of the total contribution to the uncontrolled release frequency and demonstrates again that earthquake hazards do not dominate the results.

2.2.2 Range of earthquake leading to loss of containment integrity

Once again the loss of containment integrity is assessed probabilistically in the LPSA. Building failure possibility has been analysed for several failure modes e.g. building-to-building impact and structural failure for all of the safety classified buildings. Plant damage states were then identified directly using judgement. It is noted that even for a 10^{-7} p.a. earthquake, there is a low probability of reactor building damage leading directly to a large release. The loss of containment integrity is also assessed as a result of sequences leading to the loss of systems supporting containment integrity. The reactor building damage plant damage state contributes to a large early release of radioactivity and although the hazard frequency is not reported directly in the Safety Case it can be deduced from the LPSA analysis that the total contribution from reactor building damage alone to an uncontrolled release of radioactivity is less than 1%. Once again this demonstrates that the earthquake hazard does not dominate the results when assessed with all other initiating faults and hazards.

2.2.3 Earthquake exceeding the design basis earthquake for the plant and consequent flooding exceeding design basis

There are no reservoirs within the vicinity of Sizewell Power station so the only type of external flooding consequential from a large earthquake would be tsunami.

Historically, the UK has felt the effects of tsunamis. The main events of note are a small wave observed in some areas of the south of England following the Lisbon earthquake of 1755 and historical/geological data supporting large tsunamis affecting the far north of Scotland and Shetland following large-scale submarine landslides off Norway. Both of these events were remote from the site.

The station safety case documentation does not explicitly cover coincident local earthquakes and tsunami, as it is not judged credible that a local earthquake would be powerful enough to produce a tsunami. It should be noted that The North Sea earthquake of 7 June 1931, with a magnitude of 6.1ML and with an epicentre offshore in the Dogger Bank area (120 km NE of Great Yarmouth), did not cause any noticeable changes in water levels on the east coast. This judgement is supported by a detailed study undertaken by DEFRA in 2005 to evaluate the tsunami risks to the UK. The study concluded that the probability of a tsunamigenic seismic event in UK coastal waters was very low and that if it did occur the likely coasts affected would be eastern England and Eastern Scotland. It stresses that these are events of very low probability; first, such earthquakes are rare, and secondly, they are much more likely to be non-tsunamigenic than tsunamigenic if they do occur. The potential risk is therefore one of flooding without coincident local seismic effects, which is discussed in Chapter 3.

The other sources of flooding considered at Sizewell such as extreme rainfall and storm surges are meteorological in origin and are therefore independent of the seismic event. The frequency of a coincident beyond design basis earthquake and beyond design basis flood from these sources is extremely small. Again the flooding risk at Sizewell is discussed in Chapter 3.

Conclusion SZB 2.8: There is not a credible risk posed to UK plant from a beyond design basis earthquake and consequential beyond design basis flood.

2.2.4 Potential need to increase robustness of the plant against earthquakes

In light of the events at the Fukushima Daiichi plant, as responsible operators EDF Energy have carried out reviews at each of the sites as a requirement of the Board.

Section 2.1.3.4 discusses the scope and findings of the specific seismic aspects for Within the Design Basis assessments. The findings of the seismic aspects for beyond design basis assessments are discussed below on a fleet wide basis; this is because the learning from each of the sites is judged to be applicable across the stations.

Scope

The beyond design basis review ensured that documentation, training and plant associated with response to beyond design basis events were examined, along with the adequacy of the emergency response organisation. Due to the nature of the questions asked, this was primarily a paper-based exercise with workshops between station and central support engineers where appropriate. Equipment provided specifically for response to beyond design basis events was also physically inspected to ensure that the condition of the plant was as expected.

Summary of Findings

In general the fire-fighting systems are not claimed for the seismic safety case as there is not considered to be a risk of significant fire in a design basis earthquake. However feasibility to enhance the seismic capability of unqualified fire systems could be considered.

With regard to the events in Japan it was noted that site access, although possible in the current time frame, remained a significant logistical issue beyond this point. This issue is generic to all situations and is covered in Chapter 6.

Given the extreme nature of the events witnessed in Japan there was a general concern about the pressure and burden that would be placed on the operators during the recovery from an incident of such magnitude. This issue is generic to all situations and is covered in Chapter 6.

Conclusion SZB 2.9: The robustness of the plant against design basis earthquakes and beyond design basis earthquakes is considered to be appropriate.

Consideration SZB 2.1: Consideration should be given to the feasibility of enhancing the seismic capability of appropriate unqualified fire systems.

Consideration SZB 2.2: The demands upon personnel to respond to beyond design basis events should be included within the review of the emergency response capabilities (considered further in chapter 6).

2.3 Summary

The information presented in the preceding sections shows that the processes for ensuring robustness of the plant for seismic events are well developed and implemented and give appropriate consideration to the requirement for margins. They make appropriate use of international experience and standards both nuclear specific and discipline specific.

Furthermore they have been reviewed periodically in line with company process and regulatory expectations. The methodologies are internationally recognised and have been constructed with appropriate conservatisms, margins and sensitivity studies employed. Thus:

- The severity of the earthquake chosen for the design basis event is considered conservative;
- There is high confidence that the essential systems structures and components will remain functional in a design basis earthquake, and
- The essential systems structures and components are tolerant to more severe earthquakes.

The robustness of the plant against design basis earthquakes and beyond design basis earthquakes is considered to be appropriate.

Chapter 3 – External Flooding

Sizewell B

3 External Flooding

In the Office for Nuclear Regulation's (ONR) report on the Japanese Earthquake and Tsunami Implications for the UK Nuclear Industry, the following is stated.

"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."

In a number of places, this document refers to the need for ongoing development work. Some of this work had been previously identified and captured by normal company processes, whilst some is new work highlighted by the post-Fukushima review. In the latter group, there are some potential work packages referred to as 'Considerations'. These considerations will be carefully reviewed following the completion of the Stress Test reports and an appropriate programme of work formulated.

Overview

In line with the statement quoted above from the ONR report, the Stress Test focuses on the external flooding hazard. Within EDF Energy Nuclear Generation, the external flooding hazard is defined as 'extreme rainfall, snowmelt, overtopping of sea defences or gross failure of reservoirs external to the licensed site which directly or indirectly could result in the risk of a radiological release'. The internal flooding hazard, which considers flooding from sources within the licensed site, such as failed pipework, tanks, etc. is considered by the station safety case but is outwith the scope of this report. Any further references to floods in this report concerns the external flooding hazard.

This chapter assesses the margins of the existing design basis, as well as the extant sea protection in place at the Sizewell B Nuclear Power Plant. It demonstrates that:

- Sufficient margin exists between the maximum design basis flood (7.6 m AOD) and the coast defences comprising a 5m AOD secondary defence and a primary 10m AOD raised embankment. The physical elevation of the main nuclear island is 6.4 m AOD);
- During extreme rainfall events, essential function availability is maintained by the site drainage and the natural fall of the land away from the station;
- The information presented shows that the methodology used to calculate the design basis flood for Sizewell B has been constructed using independent expertise based on well regarded sources of information. The methodology has also been constructed with appropriate conservatisms, margins and sensitivity studies employed;
- The methodology for determining external flooding risk has been reviewed periodically in line with company process and regulatory expectations;
- Appropriate consideration has been given to the predicted impact of global warming on the risk of external flooding due to sea level rise and increasing wave heights. It has been demonstrated that appropriate margins will be maintained beyond the operating life of the station;
- Operating procedures and emergency activities identified for the management of actions in response to external flooding have been reviewed and their adequacy confirmed;
- For the purposes of beyond design basis risks management a number of physical plant modifications have been considered, primarily affording protection of external plant areas, and will be prioritised based on the benefit to robustness of essential plant and the potential risk to plant during implementation/operation.

3.1 Design Basis

The following section identifies the external flooding events that are determined to pose a credible threat to the Sizewell B site, the protection provided against these threats and the compliance route by way of which Sizewell B Power Station complies with the nuclear site licence for the design basis flood.

3.1.1 Flooding against which the plant is designed

Applicable Standards

During the original design process, it was decided that the plant shall be designed to be unaffected by external floods, taking into account tidal surges, wave heights, fresh water flows and any other local phenomena which could affect tide levels.

Section 3.15 of the ONR Principles addresses external hazards. Principles 275 and 277 address flood. Principles 275 Definition of Flood Levels, 276 Design features to prevent adverse effects on plant due to flooding and 277 Provision of Drainage Systems are relevant to Sizewell B.

An IAEA document on the "Flood Hazard for Nuclear Power Plants on Coastal and River Sites" has been issued. This supersedes safety guides that were issued in the 1980s. The current safety case has been reviewed against the guidance in this IAEA document and no outstanding issues have been identified. The following key points merit comment:

Section 2.5(2) of the guide requires the maximum probable tsunami hazard to be taken into account.

Section 15 of the guide recommends monitoring and warning equipment 'when flooding proves to be a significant hazard for a plant site.'

The IAEA recommends that the "plant layout should be based on maintaining a 'dry site concept', where practicable, as a defence-in-depth measure against site flooding." (The concept of defence-in-depth is explained in Chapter 1.) It is important to note that EDF Energy sites can accept a limited degree of flooding and provide means for draining off the flood water with the intention of providing suitable margins (see section 3.2.1).

3.1.1.1 Characteristics of the design basis flood

Design Basis

The external flooding hazard at Sizewell B is screened as separate events. For Sizewell B the characteristic flooding events considered as part of the Assessment of Internal and External Hazards are:

- Waves/wind, tide/storm;
- River diversion;
- Precipitation;
- Snowmelt;
- Tsunami, Seiche;
- High water table.

There are no reservoirs in the vicinity of the station that could introduce floodwater into the site.

The design basis flood is the most severe external flood attributable to the above events and considered credible and that is applicable to the nuclear reactor plant with a return frequency equal to once in 10,000 years (i.e. 10^{-4} p.a.).

The design basis flood for Sizewell B with a probability of exceedance of 10^{-4} p.a. comprises:

- A significant sea level based on a combination of extreme wave and surge conditions, which are calculated to cause a run-up to 7.6 m AOD, assuming a linear combination of their respective effects. All of these conditions occur independently at a 10^{-4} p.a. frequency;
- Rainfall of 100 mm over a 1-hour period and 200 mm over a 24-hour period.

The other characteristic flooding events are screened out on the basis of the screening criteria identified in the safety case.

3.1.1.2 Methodology used to evaluate the design basis flood

Original methodology employed at Sizewell B

The original derivation of extreme seawater level for Sizewell B was made from two separate analyses. The first considered a maximum still seawater level based on highest astronomical tide and a one-in-fifty-year return storm surge, extrapolated to beyond (less than) a 10^{-3} p.a. return frequency to give a maximum still seawater level of 5 m AOD.

The second analysis calculated a value for the maximum wave height based on the maximum still seawater, the height of the offshore Dunwich Bank and a ratio that determined the height of non-breaking waves for a given seawater depth. Having determined a maximum wave height of 7.2 m AOD by this approach (for a return frequency of 10^{-4} p.a.) run-up calculations were preformed for a given embankment profile that predicted wave run-up on the embankment to a height of 7.6 m AOD.

Whilst the analysis noted historical evidence dating from 1930-1975 that indicated mean sea level rises for Southend of between 1 and 3mm per year, it concluded that there was no basis for projecting this historical trend into the future.

Sea Level

The original analysis inferred a highest astronomical tide for Sizewell with a 19-year return frequency of 1.9 m AOD. The inference was made from the Admiralty Tidal Tables, Volume 1, 1983. Accounting for a predicted mean sea level rise over the anticipated 50-year lifetime of the power station, an increase of 0.1 m was added to the value for highest astronomical tide, giving 2.0 m AOD.

Storm Surge

Based on the 2.5 m AOD surge level estimated for the extreme storm surge experienced in 1953 along the coastline between Great Yarmouth and Harwich, The original analysis postulated a worst-case maximum storm surge of 3.0 m AOD. This value, combined with the worst-case 2.0 m AOD highest astronomical tide gave a maximum still seawater level of 5.0 m AOD.

Waves

The original study of wave attack of coastal defences at Sizewell discussed the findings of another study of wave height data collected over a period of time at coastal sites close to Sizewell. This study determined that beyond offshore wave heights of around 2.5 m to 3 m, the height of inshore waves beyond the Dunwich bank did not increase accordingly. It was noted that significant attenuation of storm surge waves occurred over the Dunwich bank. Adopting calculation guidelines from a U.S. Shore Protection Manual, which described the ratio between water depth and wave height at which waves will break, the original study calculated a maximum non-breaking wave height over the Dunwich bank of 7.2 m AOD for return periods greater than 100 years. Due to the limiting effect of the Sizewell Dunwich banks on inshore wave height, it was predicted that the 10^{-4} p.a. frequency for inshore waves would not exceed 7.2 m AOD.

Run-up calculations were performed using a method described in the aforementioned US Shore Protection Manual for the re-profiled Sizewell coastal section. For a 7.2 m AOD wave with a period of 10 s, a run-up to 7.6 m AOD was calculated.

Review of Original Methodology

Since the publication of the original analysis, on which the 10^{-4} p.a. design basis extreme sea level and wave is based, an independent review of the original methodology sought to re-assess the levels of extreme sea level and waves for Sizewell as well as accounting for the directional influence and point of origin of offshore waves on inshore wave height. The study determined a worst-case combined extreme sea level and inshore wave height of 5.6 m AOD. This value included an error margin to accommodate uncertainties inherent in the limits of, and extrapolation of data and methods employed to derive the results. Although the independent review tentatively compares its results with those of the original study, the comparison would suggest the design basis magnitude for extreme sea level and wave is conservative and adequate margin exists between it and the Sizewell B 10 m AOD embankment. The independent review study, whilst briefly discussing sea level rise, does not quantify any rise in its overall numerical predictions.

River Diversion

As reported in the safety case, there are no major rivers close to the site, which is also some 5 to 6 m above any rivers in the region. Therefore any river diversion will not affect the plant, and the hazard is screened out as not applicable.

Precipitation (Rainfall)

The Meteorological Office has supplied predictions of extreme rainfall events for the Sizewell area.

To provide confirmation that the predictions are representative of rainfall in the Sizewell area, records of local data have also been obtained from the Meteorological Office, from which rainfall, having a return period of up to five years, can be reliably estimated.

The predictions have been compared against local meteorological observations to investigate the ability to predict extreme rainfall events with return periods up to 10 years. The results of the investigation have been used to estimate the 24-hour rainfall for return periods of between six months and 10 years and one-hour rainfall for return periods of between six months and five years.

This can be expected to provide reasonable estimates provided that the return period is small compared to the period of observation.

There is good agreement between the observations and analyses, giving conservative predictions for all cases. This result gives confidence in the data set being used within the extreme value program to predict rainfall for Sizewell B, and suggests that the rainstorm with a 10^{-4} p.a. probability of exceedance is unlikely to be underestimated.

The design basis rainfall depths with a 10^{-4} p.a. probability of exceedance are as follows:

- a depth of 100 mm in 1 hour;
- a depth of 200 mm in 24 hours.

Plant design provisions and the station siting characteristics ensure that extreme precipitation up to the highest theoretical values will not endanger safety. Flooding due to precipitation was therefore bounded by effect and was screened out during an internal and external hazard assessment.

Snowmelt

The design of the site surface draining system is such that water resulting from melting snow after a heavy snowfall will be drained away without causing any flooding hazard on the site.

Tsunami

Tsunamis are long period waves that are produced from geological rather than meteorological events, principally submarine earthquakes, but also volcanic activity and submarine or shoreline landslides. A study commissioned by DEFRA in 2005 reports that within the UK, tsunami waves could possibly hit the south west of England and Wales and the Yorkshire and Humberside area. The assessment was made by collecting past evidence of tsunamis, considering possible source regions, and modelling the propagation of the waves. From the calculated models, heights of tsunami waves were found to be up to 2m. This is comparable to heights of waves from storm surges, however the report does state that the impact of a tsunami should not be assumed to be the same as that from a storm surge.

Since the DEFRA study calculates a maximum tsunami generated wave height of up to 2m, tsunamis are not considered to present a significant hazard at Sizewell B. The DEFRA report states that the most credible source for a strong, potentially damaging tsunami reaching the coasts of the UK, aside from exotic events such as meteorite impacts, would be a large passive margin earthquake in the Sole Bank area (western Celtic Sea) or in the North Sea Fan area (with a possible underwater landslide similar to the Storegga event). It stresses that these are events of very low probability; first, such earthquakes are rare, and secondly, they are much more likely to be non-tsunamigenic than tsunamigenic if they do occur. The last Storegga Slide (an underwater event on the edge of Norway’s continental shelf) occurred around 6100BC and traces of this tsunami have been found in Scotland. It should be noted that the North Sea earthquake of 7 June 1931, with a magnitude of 6.1ML and with an epicentre offshore in the Dogger Bank area (120 km north east of Great Yarmouth), did not cause any noticeable changes in water levels on the east coast.

High Water Table

A high water table would result from either storm conditions or from extreme precipitation, which is discussed under `Precipitation' above. Any increase in the height of the site's water table would be expected to impact on the soil properties with potential consequences for building foundations. Through the application of hazards screening criteria, this hazard was screened out on the basis that it is bounded by extreme precipitation.

Climate Change Adaptation

Work has been commissioned by EDF Energy to investigate the effects of climate change. The main flood risks for the EDF Energy Nuclear Generation stations identified within the work were storm surges. It was noted that the current case was secure, although the data needed to be kept under review.

In preparation for the decommissioning of Sizewell A from 2007 an assessment was carried out investigating the risks from coastal flooding, erosion and climate change for the Sizewell area over a prolonged timescale. The information is reproduced below to provide an indication of the potential effects, given that Sizewell B will itself generate to the middle of the century and then require decommissioning.

Sea Level At UK Coasts

Changes are expected in sea levels, storm surges and wave heights over the next 100 years. Mean seawater level at UK coasts is affected by both the movement of the land and the rise in sea level as a result of global warming. The UK landmass is still adjusting to the de-glaciation from the last ice-age such that the north-west of the UK is rising and the south-east is sinking. The highest rate of sinking is experienced in Kent and East Anglia at around 1.3 mm per year. Predictions for sea level rise up to 2100 have been modelled by the Met Office for a number of CO_2 emission scenarios. Under all scenarios, a rise in sea level is observed, ranging from 0.30 m to 0.49 m by 2100. These predictions of UK mean sea level rise have been coupled with relative land changes across the UK to give an overall indication of change in sea level at Sizewell by the year 2100 of between 0.43 m and 0.62 m. In contrast to these Met Office predictions the advice issued by DEFRA indicate that the cumulative rise in sea level in 50 years (i.e. by 2057) will be 411 mm and in 100 years (i.e. by 2107) will be 1080 mm. DEFRA do not provide any indication of error bars or sensitivity range for these predictions which are issued as a guide to planners and decision makers rather than a precise indication of sea level changes.

Storm Surges

A storm surge is a rise in sea level that propagates outwards from an area of very low atmospheric pressure. The effect can be amplified as the sea area becomes restricted both in depth and width. Such events on the Suffolk coast are likely to have their origin in storms in the northern part of the North Sea. Storm surges are likely to become more frequent and more extreme with the changing climate over the next 100 years. Higher sea levels will mean that less powerful storm surges are required for flooding, so flooding is likely to occur more often. The UK Climate Impacts Programme has predicted that by the 2080s, the sea off the east coast of England could experience an increase in 50-year storm surge height of between 0.8 m and 1.4 m on top of the original 3.0m AOD.

Wave Height

Flood defences may be breached more often by overtopping from waves, rather than direct overflow due to a high mean sea level. Maximum wave heights are determined by the seawater level, the atmospheric conditions including wind speed, and the coastal topography. UK Climates Impact Programme predictions suggest that mean wind speeds for the east coast will increase by 8% by 2080 and that maximum waves will also increase. However, due to the complex variables involved, it is difficult to make any reliable estimates of how wave height will increase as a result of climate change, and for this reason, specific figures are not quoted.

Combined Effects

Climate change, as described above, will lead to an increased frequency of storms and will alter the return intervals for given sea levels. Sea level rise, independent of any changes in storm surge frequency and intensity, can be accounted for simply by adding the rise in mean sea level to the sea level associated with any particular return frequency. As stated above, mean sea level is predicted by the Met Office to rise by between 0.43 m and 0.62 m at Sizewell by 2100 and by DEFRA to 1.08m. These increases would take the 1 in 100 year sea level (which includes a 1 in 50-year storm surge) from 3.1 m AOD to between 3.53 m AOD and 3.7 m AOD using Met Office predictions and to 4.18 m AOD using DEFRA guidelines. If the predicted increase in 50-year storm surge height is also included, then the maximum 1 in 100 year water level lies between 5.12 m AOD (Met Office) and 5.6 m AOD (DEFRA). These levels compare with the secondary dune height of 5 m AOD, a primary dune height of 10 m AOD, and a general site level of 6.55 m AOD. Wave heights are also expected to increase throughout the coming century with further potential to increase the maximum extreme water level and wave run-up distances. However, as noted earlier, wave height predictions involve a complex number of variables and for this reason have not been included in the predictions.

It should be noted that the uncertainties associated with such future predictions are significant and the mitigation of threats will be managed by monitoring and appropriate interventions by the Sizewell Shoreline Management Steering Group. The current case is secure and valid.

Physical Margin

There is a 2.4m margin between the conservatively judged 1 in 10,000 year bounding flooding event (including wave and wave run-up) and the lowest elevation of the sea defence. There is a 1.4m margin between the conservatively judged 1 in 10,000 year still seawater level and the site ground level.

3.1.1.3 Conclusion on the adequacy of protection against external flooding

The information presented in the preceding sections shows that the methodology used to calculate the design basis flood for Sizewell B has been constructed using independent expertise based on well regarded sources of information. Furthermore, it has been reviewed periodically in line with the company process and regulatory expectations. The methodology has been constructed with appropriate conservatisms, margins and sensitivity studies employed.

However, as a result of the advancement of scientific understanding of climate change and as a prudent operator, EDF Energy has initiated further flooding studies. This is particularly important because the external flooding hazard presents the possibility of 'cliff-edge' effects; for example the overtopping of bunds could lead to significant damage at the point of overtopping with no effect until that point.

It should also be noted that as the current methodologies for calculating the design basis flood vary across the fleet, the new flooding studies will allow inter comparison and provide enhanced consistency across the fleet.

This work is currently in progress with two of EDF Energy's contract partners who are specialists in this area.

Conclusion SZB 3.1: The methodology for calculating the design basis flood is robust, has appropriate conservatisms, margins and has been periodically reviewed.

Conclusion SZB 3.2: In line with Recommendation 10 of the ONR Interim Report on the Japanese Earthquake and Tsunami Implications for the UK Nuclear Industry, the design basis flood at Sizewell B has been confirmed, however further studies accounting for climate change have been initiated to reconfirm the design basis flood.

Consideration SZB 3.1: In line with Recommendation 10 of the ONR Interim Report on the Japanese Earthquake and Tsunami Implications for the UK Nuclear Industry, flooding studies have been initiated for all eight stations. These studies re-evaluate the design basis flooding scenarios using the most recent data and taking account of climate change, they cover the period until 2035.

3.1.2 Provisions to protect the plant against the design basis flood

3.1.2.1 Identification of systems, structures and components that are required for achieving and maintaining safe shutdown state and are most endangered when flood is increasing

As in keeping with the IAEA guidelines, in terms of flooding, Sizewell is designed as dry site in that defences, described below, are put in place to prevent potential flood sources from reaching the site. In the event of a design basis flood there should be no specific actions required to be performed on site as the site should not be affected. The main exception to this is from rainfall, which requires systems on-site to deal with its effect. Both prevention and mitigation of flooding are described below.

Section 3.1.2.2 outlines the flood defences on the site designed to protect systems required for achieving and maintaining safe shutdown equipment. It should also be noted that design basis flood events will not affect safeguard systems and will not cause an automatic reactor trip.

Requirements for Safe Shutdown

Following a plant fault or hazard it is necessary that:

- The short-term consequences of the event are adequately limited;
- The plant is taken to an appropriate safe stable shutdown state;
- The plant is maintained safely at the chosen shutdown state for as long as is required; for example, to rectify the fault.

The safety case documentation identifies those systems required for achieving and maintaining safe shutdown.

3.1.2.2 Main design and construction provisions to prevent flood impact to the plant

Recent reviews of nuclear safety classified buildings concluded that with one exception (the reserve ultimate heat-sink) no buildings important to nuclear safety appear to be vulnerable to seawater spray or waves over-topping the sea defences. Regarding 'standing-water' ingress to the station buildings, all key buildings have their floor levels ~150 mm above the site road/ground/drainage levels.

It is noted that a key defence against ingress of surface water into building basements is provided by principal fire barriers which are designed to act as flood barriers up to a minimum of 1 m water depth.

Site Protection Requirements

Site ground levels

The site ground level is 6.40 m AOD which is in excess of the extreme still seawater level (5.0 m AOD) and the station ground floor level is required to be at 6.55 m AOD. Unacceptable site flooding as a result of inclusion of wave effects is to be precluded.

Structural Description Of Sea Defences

The sea defences are constructed and landscaped to reproduce as far as possible, the former existing features of the site. They consist of a secondary bank, with a crest of 5.0 m AOD at the rear of the present beach, behind which there is a depression before the ground rises up again to the primary sea defence bank with a crest of 10.0 m AOD. During extreme events it is probable that erosion of the secondary, 5 m bank (see Figure 3.A.2) will occur, perhaps leading to breaching of the crest. This probability is part of the design of the defence complex, since erosion of the secondary bank will result in sand accumulation on the fronting beach thus reducing wave impact. Flooding of the depression between the primary and secondary defence may occur, but will not impair the structural integrity of the primary defence (see Figure 3.3). Contingency plans to repair any breaches in the secondary defence after an extreme event are in place.

Protection against External Hazards

The sea defences are also themselves subject to external hazards. The sea defences have been designed to be robust against the effects of external hazards. The stability and integrity of the sea defences is monitored closely by the Sizewell Shoreline Management Steering Group.

Sea Defence Management

There is a consensus of scientific opinion that in the past few years a change in climate has occurred in North West Europe evidenced by increase in westerly winds and resulting in flood defences on the east and south coasts having to be raised from levels which have been adequate for several decades.

If calculations based on new data show that the potential flood level is increasing with time, then additional flood defences could be provided if required.

In order to manage the shoreline and sea defence provisions a specific formal monitoring and management steering group is in place.

The Sizewell shoreline management steering group exists with the agreement of the companies at Sizewell B and A sites to facilitate the understandings set out in the legal agreement established within the context of the sale and purchase agreement of EDF Energy (known as British Energy at the time).

The Sizewell shoreline management steering group is responsible for the production and implementation of a beach management plan for the common Sizewell frontage.

The Sizewell shoreline management steering group, through its Chairman or their nominee, provides the interface between the companies and external authorities on matters relating to the region's coastal management.

The group operates a tiered monitoring, measurement and assessment function with response thresholds; ultimately requiring intervention or contingency plans to be drawn up.

The provision of early warning of deterioration in the standard of defence for the Sizewell power stations is an essential element of the beach management plan. To this end a programme of continuous measurement and surveillance is central to flood protection planning. The data from this monitoring programme is reviewed by the Sizewell shoreline management steering group at their regular meetings, and more frequently, as and when the need arises, by an independent assessor.

Coastal Stability

The arrangements that provide for an early warning of any deterioration in the standard of defence for the Sizewell site is an essential element of the Sizewell beach management plan. The data from this monitoring programme is reviewed by the Sizewell shoreline management steering group at regular intervals to ensure that the shore defences continue to provide an adequate level of safety for the Sizewell B Power Station workforce and plant as well as the long term sustainability of the natural coastal assets of the area. The Suffolk coastline on which the Sizewell power stations are located is in a dynamic state of sediment erosion and transport. In the coming century, additional environmental influences as a result of global climate change are likely to have significant, although uncertain influence on the morphology of this coastline. This will have implications for many coastal users including the power stations at Sizewell. To ensure that the hazards posed by seawater flooding and coastal erosion do not threaten the integrity and security of the nuclear power stations at Sizewell, the coastline will be regularly monitored throughout the operational and decommissioning periods for Sizewell A and B for any significant physical deviations in response to environmental change. Any such identified change will result in mitigating action being taken in order to satisfy the requirements of the nuclear licensed site safety cases. Given the timescales, the complexity of the issues surrounding flood defence and the status of the Sizewell coastline, an ongoing integrated approach to the management of erosion and flooding issues will be taken, and with many organisations and individuals having an interest, any intervention will conform to the wider requirements of all stakeholders as far as practicable.

Rainwater

For the purpose of design of the site primary drainage system, a storm with a return period of 10 years is predicted to deliver 21mm of rain in one hour. For comparison, the storm with a return period of 100 years is expected to deliver

36mm of rain in one hour. This system collects water resulting from precipitation on all building roofs and other impervious areas on site. Storm drains are discharged out to sea.

The design basis for the secondary drainage system is a storm with a return period of 10,000 years. The storm is predicted to deliver 100mm of rain in one hour or 200mm in 24 hours.

Additional protection is given by the level of the station ground floor which is 150mm above the site level. Furthermore any significant build-up of water on the site is prevented by the site characteristics which are such that the ground level falls towards marshland over 5.5m lower than the site on the north and west sides. The maximum flood level that could theoretically build up on the marshes is 4.0m AOD as this is the general height of the Bent Hills north of the site. These site characteristics ensure that rainfalls with very low probabilities, both short term and long term and with correspondingly high intensities can not jeopardise the safety of the station. Such a hazard is therefore considered to be beyond the design basis.

A prediction based on a low probability of exceedance storm falling in the catchment area of the River Yox/Minsmere River and the associated streams draining into Minsmere, indicates a maximum flood level of 3.0m AOD.

The height of the site access road (3.5m AOD) is based on having adequate clearance above this extreme flood level when considering that the site access road is not required within a short period of any external hazard.

Any flat roofs surrounded by parapets or similar features which could cause substantial water build-up in the absence of adequate drainage provisions are equipped with roof drainage systems designed to drain water from a 1-hour rain storm with an intensity of 50 mm/h. Both storm sewer and roof drainage systems are adequate for short-term surges as the storage capacity of pipes is not taken into account. Additionally, a secondary emergency drainage system is provided to prevent excessive accumulation of water on roofs in the event of blockage of the primary drainage system.

Groundwater

Unacceptable flooding of plant important to safety, due to groundwater ingress into the buildings, is avoided by:

- Appropriate design of the buildings to ensure adequate leak tightness;
- The provision of sump drain pumps to extract seepage water from the basements of buildings.

Conclusion SZB 3.3: The flood defence provisions for Sizewell B are suitable and are appropriately inspected and maintained.

3.1.2.3 Main operating provisions to prevent flood impact to the plant

Operating instructions

The operators at Fukushima Daiichi were hampered in their recovery actions by the situation on and around the site. This was initially as a result of the inundation but also once the waters had receded as a result of debris, radiation levels and conventional hazards as a result of the event.

Sea Borne Flood Warnings and Flooding due to Heavy Rainfall

Warnings of exceptionally high tidal surges likely to result in flooding of areas around the Sizewell Site will be issued by the Environmental Agency, (Meteorological Office or HM Coastguard).

The shift manager will pass on any warnings of unusual weather or tidal activity received from the Meteorological Office or HM Coastguard to station staff who will be requested to be on the alert for flooding. In addition, special patrols of potentially sensitive plant areas will be established by the shift manager and managed and maintained by the main control room supervisor.

Extreme rainfall poses a slightly different threat, and appropriate measures are in place to ensure that windows, louvers, temporary equipment and bunded areas are adequately protected/maintained.

Station Operating Instructions

The Sizewell B site has a variety of alarms to inform operators of water levels. These are supported with documentation that allows the operator to appropriately monitor the situation and act as required.

Summary

It can be seen from the information presented that the claims made on the operator actions are not onerous in the event of a severe flood before the reactor is shutdown. Local to plant actions prior to trip are primarily related to the inspection of lower lying areas of the site.

Conclusion SZB 3.4: The claims made on the operator for flooding events are not onerous given the level of design basis flood. Further review of them has been undertaken as part of the response to the Fukushima Daiichi event and it is judged that the reliance on these claims continues to be appropriate.

3.1.2.4 Situation outside the plant, including preventing or delaying access of personnel and equipment to the site

The operators at Fukushima Daiichi were hampered in their recovery actions by the situation on and around the site. This was initially as a result of the inundation but also once the waters had receded as a result of debris, radiation levels and conventional hazards as a result of the event.

The safety case states that the safety systems are able to operate for a period of 24 hours solely from station resources and therefore does not require access from external personnel to the site. Consideration for the extension of the 24-hour mission time is presented within Chapter 5.

External to the site, the Local Resilience Forums are the local authority body in the UK with responsibility for providing emergency response in the community. The review of emergency arrangements is in Chapter 6. This assessment aligns with that within EDF Energy in that there could be expected difficulty with access to and from site for a period, although it should be noted that the magnitude of this impact would be very much less than that seen in Japan. Outside the site, there are plans regarding emergencies for the local area. A community risk register has been compiled of potentially disruptive events (including external flooding) that responder agencies (including emergency agencies such as the police, fire services etc.) have considered in order to prepare for the emergencies and return the area to a state of normality.

A review of site access following external hazards is currently being carried out. The results of the review will be handled as part of the company's normal operating procedures.

Work is also being undertaken by flood modelling specialists to assess the effect of external flooding on the access to plant in very extreme flooding scenarios and this work will be used to inform the development of any emergency backup equipment model for mitigation in accident scenarios.

Conclusion SZB 3.5: Access to the site and deployment of personnel has been considered as part of the emergency response. Further review has been undertaken as part of the response to the Fukushima Daiichi event and it is judged this continues to be appropriate.

3.1.3 Plant compliance with its current licensing basis

3.1.3.1 Licencee's processes to ensure that plant systems, structures and components that are needed for achieving and maintaining the safe shutdown state, as well as systems and structures designed for flood protection remain in faultless condition

All modifications are implemented using the engineering change process which requires that all modification proposals check whether plant affected by the proposal is qualified against external flooding or whether the modification could have a deleterious effect on equipment qualified against the flooding hazard. The procedure therefore reduces the risk that the flooding safety case is compromised by changes to the plant and structures. Inspection and maintenance is important to ensure that the adequacy of the flooding safety case is maintained. The nuclear safety related inspections are listed in the surveillance programmes for Sizewell B, which form part of its operating rules.

3.1.3.2 Licencee's processes to ensure that mobile equipment and supplies that are planned for use in connection with flooding are in continuous preparedness to be used

There is no mobile equipment claimed in the safety case for design basis flooding events as a design basis flood would not cause any flooding on-site.

3.1.3.3 Potential deviations from licensing basis and actions to address those deviations

A review of the processes used to address potential deviations from the licensing basis has been carried and none of the deviations relate to flooding events.

Conclusion SZB 3.6: There are no issues identified with the flooding safety case.

3.1.3.4 Specific compliance checks already initiated by the licensee following the Fukushima-Daiichi Nuclear Power Plant Accident

In light of the events at the Fukushima Daiichi plant, as responsible operators EDF Energy have carried out reviews at each of the sites as a requirement of the Board.

Scope

The review was specified to ensure that systems essential to fuel cooling in an emergency situation in a within design basis event including seismic and flooding scenarios were correctly configured, lined up and in a suitable condition to be declared available/operable.

There were seven main objectives, listed as follows:

1) Identify essential systems required to provide fuel cooling in reactor and fuel storage facilities.

2) Verify that Stations seismic housekeeping standards are suitable to be adequately prepared for a 'within design basis' seismic event.

3) Perform a review of systems identified in Objective 1 to identify the current status of the systems.

4) Perform a physical review of systems identified in Objective 1 to confirm the current status of the systems.

5) Perform a review of Station documentation associated with the design basis emergency operation of the systems identified in Objective 1.

6) Review the training programmes for the operators to confirm the extent of design basis accident training and assess the ability of the staff to deal with design basis accident.

7) Identify any station operating experience and subsequent learning through responding to a significant within design basis event.

Stations were asked to capture any issues for further action through normal processes.

Summary of findings

The primary finding was that no major shortfall was identified; however there were a number of minor issues or defects. These are being closed out using the appropriate company processes. There were also a number of conditions highlighted by the walkdowns that whilst being compliant with our existing safety case requirements, did not meet industry best practices.

Conclusion SZB 3.7: The reviews undertaken and the actions identified therein, have confirmed that Sizewell B is compliant with the current licensing basis.

3.2 Evaluation of safety margins

3.2.1 Estimation of safety margin against flooding

An estimation of the safety margins against flooding is presented below outlining that Sizewell B Power Station has sufficient margin against a design basis (and beyond) flood.

Design Basis

As described in section 3.1.1.1 the 10^{-4} p.a. design basis maximum seawater level plus storm surge plus wind-induced wave level event is expected to cause a run-up of 7.6 m AOD on the primary sea defence at Sizewell B. As this defence is 10m OD it is not expected that any overtopping would occur. In addition the ground level of the site (6.40 m AOD) is an additional 1.4 m higher than the extreme 10^{-4} p.a. still seawater level (5.0 m AOD) and thus no inundation is expected to occur from sea level alone for a 10^{-4} p.a. flooding event. (See Table 3.1).

The original estimate of extreme sea level (at a 10^{-4}p.a. return frequency) exceeds the highest value recorded at any of the ports (4.07 m at Holland-on-Sea in 1953) by 0.93 m.

Flooding from the sea due to wave inundation has been examined, and it is concluded that this will not occur at the design basis return frequency of once in 10,000 years. This is because (conservatively) taking together extreme wave, tide and surge conditions would cause run up to 2.4 m below the proposed crest level. All of these three conditions could occur independently at 10^{-4} p.a. frequency.

The original analysis estimated that 'under extreme conditions' wave run-up on the 10m dune defence fronting the B Station could reach 7.6 m AOD. Although the independent review did not give run-up elevations they conclude that the 1:10,000 year event is not likely to be of a magnitude to cause damage to the structural integrity of the defences.

Table 3.1: Evaluation of Margins

	Seawater Level	Site Level	Station Ground Floor Level
	5.0 m AOD	6.40 m AOD	6.55 m AOD
Margin		+1.40 m	+1.55 m
	Run-up (on primary defence)	Primary Sea Defence	
	7.6 m AOD	10.0 m AOD	
Margin		+2.4 m	

These margins are illustrated in Figure 3.A.1 (contained within Appendix 3.A).

Flooding due to precipitation on-site

Section 3.1.2.1 covers the flooding protection on site for extreme rainfall. As mentioned previously there is good agreement between the observations and the analyses, giving conservative predictions for all cases. This result gives confidence in the data set being used within the extreme value program to predict rainfall for Sizewell B, and suggests that the rainstorm with a 10^{-4} p.a. probability of exceedance is unlikely to be underestimated. In addition, due to the 150mm ground floor level on site there is a 50mm margin between the design basis 1 hour rainfall and the ground floor level of the buildings, note that this does not take into account the availability of any on-site drainage or the fire protection doors that offer 1m of flooding protection.

Combination of severe external flooding from landward and seaward side

The maximum flood level that could theoretically build up on the marshes is 4.0 m AOD as this is the general height of the Bent Hills north of the site. These site characteristics ensure that rainfalls with very low probabilities, both short duration and long duration and with correspondingly high intensities can not jeopardise the safety of the station. Such a hazard is therefore considered to be beyond the design basis.

A prediction based on a low probability of exceedance storm falling in the catchment area of the River Yox/Minsmere River and the associated streams draining into Minsmere, indicates a maximum flood level of 3.0 m AOD.

The height of the site access road (3.5 m AOD) is based on having adequate clearance above this extreme flood level when considering that the site access road is not required within a short period of any external hazard.

Tsunami

According to the DEFRA report and the safety case, the probability of a tsunami hitting Sizewell is extremely low and therefore can be considered as an incredible event. DEFRA considers tsunamis over a 100 year return period, while in comparison those considered within design basis for nuclear plants are within a 10,000 year return period. This is also concluded within the ONR report on the response to the Japanese Earthquake and Tsunami.

Conclusion SZB 3.8: The review has shown that there are suitable and sufficient margins present within the methodology and plant for compliance with the current Sizewell B safety case.

3.2.2 Potential need to increase robustness of the plant against flooding

In light of the events at the Fukushima Daiichi plant, as responsible operators EDF Energy have carried out reviews at each of the sites as a requirement of the Board.

The findings of the flooding aspects for beyond design basis assessments are discussed below on a fleet wide basis; this is because the learning from each of the sites is judged to be applicable across the stations.

Scope

The beyond design basis review ensured that documentation, training and plant associated with response to beyond design basis events were examined, along with the adequacy of the emergency response organisation. Due to the nature of the questions asked, this was primarily a paper-based exercise with workshops between station and central support engineers where appropriate. Equipment provided specifically for response to beyond design basis events was also physically inspected to ensure that the condition of the plant was as expected.

The fleet wide findings and suggestions for improvements beyond the design basis that may be considered are presented below as part of the 'robustness beyond the design basis'.

Summary of Findings

In general all stations have some safety related plant which is either at ground level or in a basement. This plant has adequate flood protection and physical margins for a design basis event.

The sea barriers provide adequate protection from floods expected at site and even in the event of beyond design basis overtopping of the barriers the impact at some sites would be manageable.

There is local to plant protection or margin that would defend against beyond design basis flooding but clearly this could be subject to a cliff-edge effect if for example a local bund overtopped.

Dewatering capability is generally available but is in some cases reliant on electrical supplies, which makes it more vulnerable in an extreme beyond design basis scenario.

With regard to the events in Japan it was noted that site access, although possible in the current time frame, remained a significant logistical issue beyond this point. This issue is generic to all situations and is covered in Chapter 5.

Given the extreme nature of the events witnessed in Japan there was a general concern about the pressure and burden that would be placed on the operators during the recovery from an incident of such magnitude. This issue is generic to all situations and is covered in Chapter 6.

Summary of findings

- The primary finding was that no major shortfall was identified; some possible design changes were suggested that could be made to increase the robustness of the plant even further. These are being dealt with through the response process setup within the JER team.

Conclusion SZB 3.9: The robustness of the plant against design basis floods is considered to be appropriate; in considering the robustness to beyond design basis floods, several areas have been identified where enhancement could be considered. These have been captured as part of the review process.

Consideration SZB 3.2: Consider enhancing mitigation against beyond design basis floods. For example, improvements to flood protection around the seaward facing reserve ultimate heat-sink and electrical back-up supplies.

Consideration SZB 3.3: Consider enhancing the robustness of dewatering capability, in particular focussing on independence from other systems.

3.3 Summary

The information presented in the preceding sections shows that the processes for ensuring robustness of the plant for flooding events are well developed and implemented and give appropriate consideration to the requirement for margins. They make appropriate use of international experience and standards both nuclear specific and discipline specific.

Furthermore they have been reviewed periodically in line with company process and regulatory expectations. The methodologies are internationally recognised and have been constructed with appropriate conservatisms, margins and sensitivity studies employed.

The robustness of the plant against design basis floods is considered to be appropriate; in considering the robustness to beyond design basis floods, several areas have been identified where enhancement could be considered.

At Sizewell B the bounding case for a 10^{-4} pa flooding event is seawater induced flooding. The methodology calculates that the extreme event will be below that of the sea defences. The site level is higher than that of the 10^{-4} p.a. still seawater level, hence no flooding due to seawater on-site is expected to occur.

Appendix 3.A – Figures

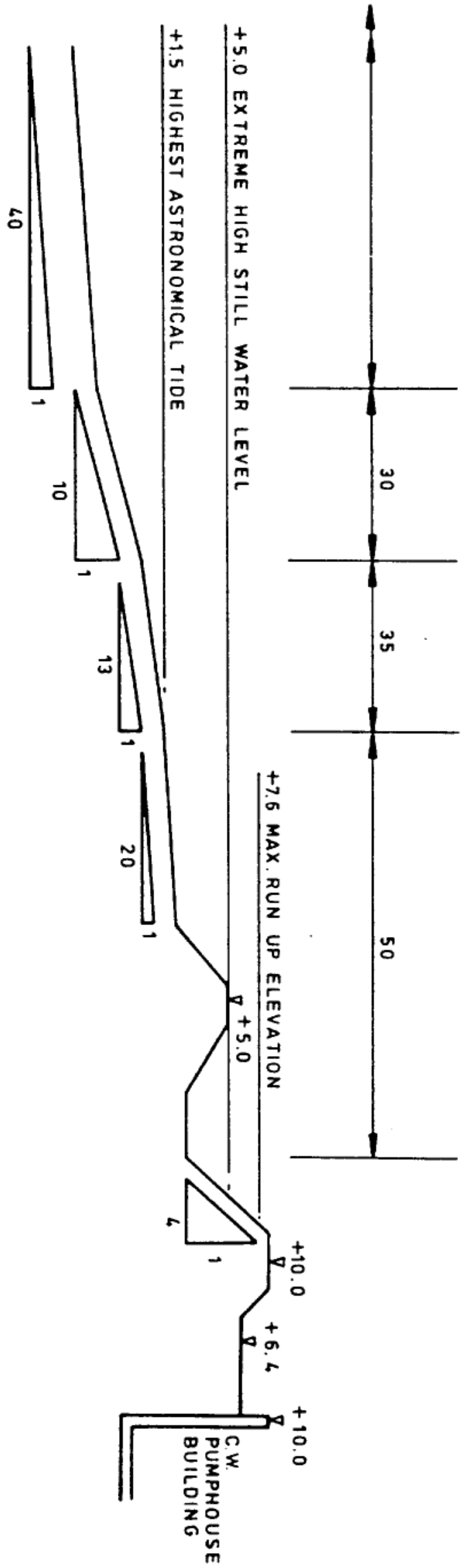

Figure 3.A.1: Schematic Beach Profile in Front of CW Pumphouse

Figure 3.A.2: Secondary +5mOD Flood Defence at Sizewell B

Figure 3.A.3: Sizewell B Flood Defences

Chapter 4 – Extreme Weather Conditions

Sizewell B

4 Extreme Weather Conditions

In the Office for Nuclear Regulations (ONR) Interim Report into the Japanese Earthquake and Tsunami, Recommendation 13 states that "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." and Recommendation 16 states that "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."

EDF considers a range of hazards, some of which are initiated or come about as a result of events on the site (internal hazards) and others that arise off-site or which relate to conditions which envelop the site (external hazards). This chapter considers those external hazards that are related to meteorological events other than external flooding, which is addressed in Chapter 3.

For each of the hazards addressed by the chapter, consideration has been given to:

- the existing design basis against which the hazard safety cases have been assessed;
- the safety margins inherent in the cases; and
- the potential for improvements in the robustness of defences against these hazards.

These topics are dealt with in sections 4.1, 4.2.1 and 4.2.2 respectively.

The extreme external environmental hazards considered in the design of Sizewell B are as follows:

- Extreme air temperature;
- Extreme seawater temperature;
- Extreme wind and wind generated missiles;
- Extreme precipitation (snow, ice) and external flooding (sea and rainwater);
- Lightning;
- Drought.

Each of the above environmental hazards has the potential to damage or challenge the performance of safety related equipment either directly or via building structures which house the equipment. The objectives of protection are to provide an effective barrier between the equipment and the hazard or to design the equipment to operate under the conditions imposed by the hazard. In providing protection, structures and equipment are designed to withstand the extreme hazard loadings individually; extreme hazard loadings are not combined, unless they are likely to be related.

Not all of the above hazards were subject to detailed assessment as some were screened out. The aim was to screen hazards which cannot occur at, or near, the site or whose impact can be demonstrated to be within the capacity of the plant, or have a risk which is small enough to be neglected. The criteria which has been applied to some of the above hazards is screening by effect. A hazard was excluded by effect if the maximum impact of the hazard does not exceed the design capability of the plant or sufficient warning time is available to allow the operators to take appropriate actions such that the hazard does not lead to a large uncontrolled release of activity.

In the EU Stress Test Reports external flooding hazards, as a result of extreme weather conditions, are covered in Chapter 3. This Chapter focuses on the remainder of the identified extreme weather conditions.

As well as looking at individual hazards, it is necessary also to consider hazard combinations. These can arise in different ways, e.g. as independent and coincidental events, events where one hazard arises as a consequence of another, or two or more hazards arising as a result of some underlying cause such as a severe storm. Of these, independently occurring coincidental hazards are normally discounted on low frequency grounds. External Flooding is considered in this Chapter when combinations of hazards are considered.

The definitions of these external hazards relating to extreme weather conditions are given below:

Extreme Wind

Any building, structure or system exposed to the outside air is affected by wind. The action of the wind produces air pressures on the exposed surfaces. This is influenced by many factors depending on the wind regime, the site topography, the shape of the building, structure or system, its dimensions etc. The resulting pressures produce wind loading on the building, structure or system. The performance of heating, ventilation and air conditioning systems may be affected and it is possible that grid connections to station could be lost resulting in a loss of offsite power.

In high wind conditions there is a danger of objects being dislodged and carried by the action of the wind and gravity, subsequently impacting onto structures or equipment on the site. These are termed wind generated missiles. Naturally occurring missiles could include, for example, branches of trees, shrubs or straw; however, the effect of these is not considered to be as significant as the effect of man-made missiles. The types of man-made material most easily blown around a site such as paper, cardboard containers, polythene or tarpaulin sheets are least likely to do impact damage. Denser material such as timber or metal sheets or bars may do more damage particularly if they originate at high level.

Extreme Air Temperature

Extreme low or extreme high atmospheric air temperatures can affect both the operational and safety related characteristics of the station in the following ways:

- reducing the effectiveness of atmospheric heat-sinks (coolers) at extremely high ambient temperatures;
- uncomfortably high temperature working conditions for operators, maintenance personnel etc;
- exceedance of design limits of both safety and non-safety related heating, ventilation and air conditioning equipment leading to high/low room temperatures and possible degradation and common mode failure of electrical equipment;
- freezing, or partial freezing, of the contents of external water tanks and associated pipework and cooler coils with subsequent loss of operability;
- condensation within electrical control cabinets (e.g. remote switches, marshalling cubicles) leading to failure due to high humidity conditions where there is no inherent heat source within the cabinets.

Both extreme high and low air and sea temperatures have been considered; taken to occur together, where applicable, and with related effects such as icing-up of intakes.

Extreme Seawater Temperature

Extreme low or extreme high sea temperatures can affect both the operational and safety related characteristics of the station in the following ways:

- reducing the effectiveness of heat-sinks (heat exchangers) at extremely high sea temperatures;
- uncomfortably high temperature working conditions for operators, maintenance personnel etc;
- exceedance of design limits of both safety and non-safety related heating, ventilation and air conditioning equipment where such equipment rejects heat to coolers served by water which in turn rejects heat to the sea. This could lead to high room temperatures and possible degradation and common mode failure of safety classified equipment;
- overcooling or potential freezing of water in safety classified cooling water systems.

Snow

Roof loading from extreme snowfalls could prejudice the structural integrity of buildings housing safety related plant. Drifting snow also has the potential to impose greater loads on roofs and also on walls against which it is drifting. An additional concern is that snow blockage of roof-mounted air intakes, exhausts or the coolers of safety classified equipment could seriously impair their capability.

Lightning

A lightning strike has the potential to cause structural damage and electrical and electromagnetic interference which could cause common mode failure or spurious operation of electrical or electronic equipment. In addition to direct lightning strikes on the buildings housing safety classified equipment, lightning strikes on other buildings or on the grid lines off-site may feed damaging surge currents into safety classified buildings and equipment and potentially result in a loss of off-site power.

NB: Electro-magnetic interference and lightning electromagnetic pulse were screened out as part of the internal and external hazard assessment process for Sizewell B.

Drought

Severe drought conditions could introduce a threat to the station's water supply (from the water company) and could also reduce the groundwater table level resulting in ground settlement.

4.1 Design Basis

The Nuclear Safety Assessment Principle for hazard protection states that, for natural hazards, and where adequate data exist, the magnitude of the hazard, which should be treated as a design basis event, should correspond to a severity consistent with a return frequency of 10^{-4} p.a. at the site

Extreme Wind

The bounding design basis hazard for extreme wind is defined as a wind speed of 60.2 m/s at a frequency of10^{-4} p.a.

For wind generated missiles, the bounding design basis hazard is defined as cladding panels and scaffolding planks moving with a 55 m/s horizontal velocity and a 30 m/s downward velocity and scaffold poles with a downward velocity of 40 m/s. It is assumed that such missiles may strike a building in any orientation.

The derivation of the above extreme wind speed is outlined below.

The original design levels for wind loadings on buildings and other structures were based on the British Standards Institution Code of Practice CP3, Chapter V, Part 2. The following discussion describes the basis of the safety case based on CP3 derived figures and methods. The basic wind speed for the Sizewell site is given in CP3 as 43 m/s. This is the maximum three-second gust speed with a mean return period of 50 years at 10 m above the ground in open country. To convert this to a wind speed with a 10^{-4}p.a. probability of exceedance and to take account of conditions specific to Sizewell B power station, a number of factors were considered.

i) S_1 – a site exposure / roughness factor with a value of 1.0;

ii) S_2 – is a factor dependent on ground roughness and gust duration appropriate to the shape, size and height or elevation of the building or element thereof under consideration. It varies for the principal structures, buildings and component features for this station, typical values being 1.0 for 10 m height, 1.15 for 60 m height;

iii) S_3 – is a statistical factor used to convert the once in 50 years wind speed of 43 m/s to a design basis wind speed for Sizewell. For the design basis wind speed with a 10^{-4} p.a. probability of exceedance, the factor is 1.40;

iv) S_4 – is a factor related to wind direction, the basic wind speed being greatest from the direction of the prevailing wind. However, use of this factor unduly complicates the design process, and a factor of 1.0 has been conservatively adopted.

The extreme design basis wind speed is obtained by multiplying the basic wind speed by S3 giving the bounding value of 60.2 m/s. The speed is then further modified for detailed design purposes by applying the multiplying factors S1, S2 and S4.

For wind generated missiles, the bounding design basis hazard is defined as cladding panels and scaffolding planks moving with a 55 m/s horizontal velocity and a 30 m/s downward velocity and scaffold poles with a downward velocity of 40 m/s. It is assumed that such missiles may strike a building in any orientation.

An assessment of tornados in the United Kingdom has shown that they are not as severe as those in the US to which the standardised nuclear unit power plant system plant was designed to. This is discussed further in section 4.2.1.1.

Structures which house plant and equipment, which is required to function for safe shutdown or for protection of stored fuel and radioactive waste, are designed to withstand loadings based on the extreme wind speed identified above. The same extreme wind speed applies to safety equipment which is directly exposed to the wind.

For structures and equipment which are not themselves required to remain functional following an extreme wind, but are required not to impair the functioning of any structure or equipment that is required to operate following the extreme wind, the extreme wind speed of 60.2 m/s also applies this 40% margin on basic wind speed results in wind forces which are approximately twice those corresponding to the 43 m/s basic wind speed, as the wind loading is proportional to the square of the wind speed.

The remaining buildings and plant, which do not have a specific safety function, are designed to withstand the basic wind speed of 43 m/s.

<u>Extreme Air Temperature</u>

The bounding design basis hazard for instantaneous high and low air temperature is defined as 36°C and -17°C respectively at a frequency of10^{-4} p.a.

The equivalent 12 hour average high and low air temperatures are defined as 29.5°C and -13°C respectively.

The derivation of the above extreme air temperature values is outlined below.

Meteorological records were available for eight sites in the vicinity of Sizewell. Extreme temperature conditions are generally associated with radiation heating or cooling of the ground surface, when winds are generally light. Under such conditions the moderating influence of the sea is appreciable in reducing the extremes experienced by a coastal site as opposed to an inland site. For this reason, and after consultation with the Meteorological Office, it was considered not to be appropriate to include data gathered from inland sites and treat only the coastal data from Gorleston (Yarmouth), Felixstowe and Lowestoft records in the assessment for Sizewell B.

The Gorleston, Felixstowe and Lowestoft air temperature data for both August and January were compared graphically and no significant differences were detected. This is judged to indicate that very little variation in temperature exists between different locations along the coast near Sizewell and consequently that the data from any of the three sites are representative for Sizewell. Gorleston data exist for the longest period (1871 to 1981), and were consequently selected to represent conditions at Sizewell due to the greater availability of data.

The minimum and maximum air temperatures recorded at Gorleston during the above 111 year period were -12.2°C and 31.6°C respectively.

There is no universally recognised method for determining 10^{-4}p.a. extreme maximum and minimum air temperatures from historical records at a specific site. For Sizewell, extreme high and low dry bulb air temperatures with a 10^{-4}p.a. probability of exceedance, have been derived by adding approximately 4EC to the maximum recorded temperature at Gorleston and by subtracting approximately 4EC from the minimum recorded temperature. This approach has been adopted elsewhere (e.g. at Heysham) and is judged to produce adequately conservative design parameters. The resultant extreme temperatures with a 10^{-4}p.a. probability of exceedance, are 36EC and -16EC. However, a previous estimate of -17EC for the extreme low temperature has been used in various design documents. Consequently this conservative value has been retained and the design basis extreme air temperatures are 36EC and -17EC.

Analysis to support this judgement, and to determine intermediate temperature and frequency combinations, has been performed. The Meteorological Office advised that as the return period increases and the amount of data reduces, so the accuracy which can be claimed for a straight line fit reduces. Application of a least squares fit would result in temperatures which are too conservative for design purposes. Under these circumstances where a physical constraint exists, the fitting of an alternative curve, which recognises the constraint, by eye or by other methods, is a valid procedure.

Further analysis and investigation into the methods available to extrapolate extreme temperatures has concluded that the original judgement of applying an additional margin of 4EC was appropriate and remains robust.

The extreme temperatures quoted are the peak temperatures which may occur on the day in question. For these extreme conditions, daily temperature variations will occur. These have been estimated to be 13EC for the maximum temperature and 8EC for the minimum temperature. These give mean daily temperatures, with a 10^{-4}p.a. probability of exceedance, of 29.5EC and -13EC corresponding to the extremes of 36EC and -17EC respectively.

The design approach to protecting against the above design basis hazard is outlined below.

Heating, ventilation and air conditioning systems for safety category 1 buildings have in general been designed on the mean temperature range of -13°C to 29.5°C rather than the peak values. This is on the basis that the thermal inertia of the buildings will enable associated equipment to be maintained within its temperature limits during short periods when peak temperatures may exceed the design maxima and minima.

The maximum temperature for which the reserve ultimate heat-sink is required to function depends on the fault which places the demand on the system. The derived temperatures are based on a coincidence time of four days (i.e. the minima and maxima are defined on a probability of exceedance over a 4 day period at a return frequency of 10^{-8} p.a. when combined with the initiating fault frequency).

Safety category 1 equipment and piping systems for control and instrumentation comply with company standards intended to prevent freezing.

All safety category 1 structures are designed to survive the extreme external ambient air temperatures (daily means -13°C and 29.5°C respectively and peaks -17°C and 36°C respectively). Buried pipework and other buried equipment is also designed to survive these temperatures.

Equipment which could cause a loss of off-site power for more than 12 hours is designed to avoid this failure mode by designing the equipment to withstand the relevant external hazards.

Battery charging diesels are required following total loss of AC. power lasting for longer than two hours. As the external building systems are exposed to external ambient conditions, it was considered prudent during the design process to provide protection down to the 10^{-4}p.a. air temperature extremes.

Externally located isolation valves from water tanks and equipment to prevent flooding of buildings following a pipe break are required to function to prevent a pipe break in a building from causing a significant flood. The derived minimum air temperature of -14°C is based on a coincidence time of one day.

Extreme Seawater Temperature

The bounding design basis hazard for high and low seawater temperature is defined as 26°C and 0°C respectively. The probabilities of exceeding these maxima and minima are calculated as $9x10^{-3}$p.a. and $3x10^{-2}$p.a. respectively.

The derivation of the above extreme seawater temperatures is outlined below.

The Meteorological Office has supplied deep sea (i.e. away from the coast) surface temperature data for the period 1879 to 1980 recorded approximately 10 km off the Sizewell coast. The measurements, recorded aboard the lightship 'Shipwash', are given in terms of annual maxima and minima.

A hydrographic survey was carried out in 1975 which provides information on seawater temperatures and currents in the vicinity of Sizewell B.

The absolute minimum and maximum seawater temperatures measured by 'Shipwash' were -0.5°C and 21.6°C respectively. Extreme value analysis using the Lieblein method has been carried out by the Meteorological Office for the maximum and minimum deep sea surface temperature data. The plot of the data points suggest a curved line fit with a steeper gradient at the 'higher return period' end of the graphs. This implies a limit of maximum and minimum temperature less severe than that predicted by extending the plotted straight line, a trend that is similar to that observed for plots of ambient air temperatures at coastal sites. The Meteorological Office attributed this effect to the moderating influence of large drift currents, which will act so as to cool the local sea during extremely hot conditions and warm the locality during severe cold spells. To allow for these effects, hyperbolic curves were calculated from a regression analysis of the data which represent the trend of the data away from the original linear correlations.

To estimate the extreme intake temperatures it is necessary to combine the deep sea surface temperatures with the solar and artificial temperature fields that may be expected to prevail under such conditions. The hydrographic survey identified four independent contributors to local seawater temperature:

i) Deep sea ambient temperature;

ii) Solar heating of inshore water;

iii) Primary plume of warm water discharging from power station outfall;

iv) Secondary temperature field developed from repeated tidal oscillations of the primary plume.

The extent of the contributions from these sources depends on environmental conditions; particularly the combined effects of prolonged sunshine, low wind speeds and deep sea drift currents.

The survey identified a maximum inshore solar field of +3.1EC for at least the first two kilometres out to sea. Analysis of the primary plume due to the Sizewell B outfall predicts a maximum artificial contribution of +1.65EC; the average over the twelve-hour tidal cycle is predicted to be +0.95EC.

Combining the maximum predicted deep sea surface temperature, with a probability of exceedance of 10^{-4}p.a., with the maximum inshore solar field and the maximum predicted contribution due to the Sizewell B outfall gives a predicted maximum temperature of 28EC (using the same calculational method, the design basis temperature of 26EC has a probability of exceedance of $9x10^{-3}$p.a.). Over a tidal cycle this reduces to 27.3EC and if the station is shut down it reduces further to 26.4EC.

Seawater freezes at approximately -2EC, which defines the absolute minimum seawater temperature which could be achieved. A deep sea surface temperature of -2EC is predicted to occur with a probability of exceedance of 10^{-3}p.a. (using the same calculational method, the design basis temperature of 0EC has a probability of exceedance of $3x10^{-2}$p.a.). The mean deep sea surface temperature over a tidal cycle is predicted to be -1EC. However no benefit is claimed for the effect of solar heating of inshore water or for the heating effect of the Sizewell B station outfall.

Snow

The bounding design basis hazard for snowfall is defined as being a depth of 0.543 m at a frequency of10^{-4}p.a. This corresponds to a loading of 0.8 kN/m^2.

The derivation of the extreme snow depth is outlined below.

Data from 50 UK weather stations with records of 15 years or more were available from which a general assessment of snow depth in the Suffolk area could be made. The Meteorological Office also provided the results of an extreme value analysis for level snow depth, carried out using extreme winter data from the coastal site of Gorleston over the 15 year period from 1958/59 to 1972/73. The snowfall corresponding to the 10-4p.a. probability of exceedance was determined by extrapolation.

The design basis level snowfall depth with a 10^{-4}p.a. probability of exceedance is calculated as 0.543 m. This depth of snow imposes a level surface snow load of 0.8 kN/m^2, assuming the snow load intensity of 1.47 kN/m^2 per metre of depth as recommended by Building Research Establishment Digest 290. In accordance with British Standard 6399 Part 3, the design basis imposed loading is increased to 1.5 kN/m^2 for roof structures to which personnel access is anticipated for maintenance purposes. Loadings due to drifted snow are determined using the shape coefficients given in Building Research Establishment Digest 290. If heavy snow falls are accompanied by strong winds, then high local snow roof loads may arise from snow drifting against vertical obstructions. Safety classified buildings are designed to withstand a snow loading of up to 1.5 kN/m^2 and localised snow drift intensities of up to 7.35 kN/m^2.

The reserve ultimate heat-sink tube coolers are frost protected whilst the main control room, auxiliary shutdown room, the reactor and fuel buildings heating, ventilation and air conditioning systems can be isolated against external smoke for up to 24 hours. The blockage of the air intakes is therefore acceptable. It is considered that manual clearance of snow would be achieved within 24 hours.

It is concluded that buildings conservatively designed to withstand an imposed roof loading of 1.5 kN/m^2, would withstand a uniform snow loading of 1.6 kN/m^2 associated with a 10^{-8}p.a. snow fall. Design provisions have been provided, which would prevent safety classified plant being disabled by extreme snow conditions and the hazard is screened out on the basis of its effect.

Lightning

The bounding design basis hazard for lightning is defined as being a current of 290 kA and a rate of current rise of 340 kA/ µs at a frequency of 10^{-4}p.a.

The assessment is judged to be conservative. At 10^{-6}p.a. level the peak current and rate of current rise are also conservatively assessed as 500 kA and 550 kA/µs respectively.

The lightning protection (conductor) system for building structures is sized to meet structural strength requirements and its actual lightning protection capability is well in excess of the design basis level of 10^{-4}p.a. peak currents. It is therefore judged that the peak current will not be a concern.

The Sizewell B lightning protection system is provided in accordance with British Standard 6651:1985. This system will provide the following protection functions:

- Protect the buildings in which components or devices are housed, by providing features (i.e. air terminals and down conductors) to attract lightning strikes and hence prevent a strike on a structure or protuberance;
- Discharge the lightning surge current into the mass of earth, by providing multiple, low impedance downcomer, individually earthed and bonded to station earth system;
- Provide an adequate earthing and bonding system to discharge surge currents without giving rise to unacceptable potential differences on sensitive equipment;
- Protect electrical equipment from possible electromagnetic or other electrical effects by screening and isolation of cables and equipment from the lightning protection system;
- Provision of surge protection on systems, where necessary, to limit surge voltages to values which will not disrupt operation of the system or equipments electrically connected to the system.

Sizewell B buildings and main electrical systems are protected against the effects of a lightning strike. The effects of very low occurrence lightning strikes will be within the capability of the protection system and the hazard has been screened out on the basis of effect.

Lightning strikes also have the potential to cause loss of grid supplies at station. Such events are considered in the assessment of the frequency of loss of grid events and are included in the relevant initiating fault frequencies. Loss of off-site power events are considered in Chapter 5 of this report.

Drought

No numerical design basis hazard level has been defined for drought.

Drought was screened out by the hazard assessment on the following basis.

Severe drought conditions could introduce a threat to the station's external water supply and could also reduce the groundwater table level resulting in ground settlement.

Industrial and domestic water will be provided by the townswater services system which receives water from the local water company.

The townswater services system incorporates a reserve water supply from two reservoirs which have the combined capacity to meet a minimum of five days of coincident demand from the auxiliary feedwater system and the fire-fighting systems. The design provisions for discontinuation of off-site water supplies ensure that there is sufficient warning available to the operators to allow the appropriate actions to be taken. This aspect of the hazard can therefore be screened out by effect.

A significant reduction in the groundwater table at site could bring about a change in soil properties with potential consequences for building foundations. The design and construction rules for the project are based upon the ASME Code for concrete reactor vessels and containments. These rules specify that design analysis for settlement will take account of the effects of significant changes in the groundwater table and the properties of the soils under load. With regard to drought-induced changes to the site's water table, the impact upon building foundations would be within the design capacity and can therefore be similarly screened out by virtue of effect.

4.1.1 Reassessment of weather conditions used as design basis

4.1.1.1 Verification of weather conditions that were used as design basis for various plant systems, structures and components: maximum temperature, minimum temperature, various type of storms, heavy rainfall, high winds, etc.

Consideration is given in this section to the continuing validity of the design basis definitions.

4.1.1.1.1 Extreme Wind

The derivation of the original bounding design basis hazard level for extreme wind was based on the British Standards Institution Code of Practice CP3, Chapter V, Part 2:1972 as outlined in section 4.1 above. This was subsequently withdrawn and so the design was reviewed against the latest edition of the replacement code, British Standard 6399-2:1997 Loading for buildings, Code of Practice for Wind Loads, as part of PSR1. There are a number of differences between the approaches in the two codes, however, it was concluded that the change will not affect the design integrity.

The review has recently been further supplemented by the work commissioned by EDF to investigate the effects of climate change. This report reviewed the recently produced UKCIP technical notes on storm projections (UKCIP 2009a) and probabilistic projections of wind speed (UKCIP 2011b) based on UKCP09 climate data and climate models. The latter study projects changes in monthly mean wind speed but excludes extreme wind speeds. For this reason the UKCP09 probabilistic projections of wind speed are not suitable for assessing hazards caused by high wind speed. However, the earlier UKCIP storm projection study found that on balance the complex concurrent atmospheric and oceanic effects lead to little or uncertain changes in the frequency and intensity of storms over the UK thus providing no evidence that the severity of the risk will change significantly in the 21st century.

British Standard 6399-2:1997 (2002) has recently been withdrawn and replaced by the new Eurocode and UK National Annexe. Preliminary indications are that the impact of these changes should not affect current claims, however, a comparison with the new codes will be undertaken as part of the current safety review process.

Conclusion SZB 4.1: Based on the above reviews, it is concluded that the extreme design basis hazard level for extreme wind remains appropriate based on the provisions of the relevant British Standards. These have recently been withdrawn and replaced by the Eurocodes and UK National Annexes, the impact of which is being assessed under the safety review process.

4.1.1.1.2 Extreme Air Temperature

The derivation of the bounding design hazard level for extreme air temperature is presented in section 4.1 above.

The last periodic safety review for Sizewell B reviewed more recent air temperature data recorded by the meteorological instrumentation system at Sizewell B and the nearest Meteorological Office measuring station at Westleton. (The Gorleston measuring station had closed but the original assessment concluded that there were no significant differences between the temperatures recorded at local coastal measuring stations.)

Despite 1998 being the hottest year on record, the 4°C margin between the extreme temperature measurements and the bounding design basis hazard levels were maintained. The review concluded that any increases in maximum air temperature due to global warming up to the 10 yearly safety review would be small.

Work commissioned by EDF to investigate the effects of climate change has recently reviewed the methodology for extreme air temperature.

The work has examined and has taken the results from a Meteorological Office report based on UKCIP02 data and found this to be of greater value than the probabilistic method offered by the UKCIP09 weather generator. With this data it was then able to establish the risk of absolute temperatures on the plant.

Using historic data, a mean of maximum summer temperatures were extrapolated to include the predicted future increase in summer temperature per site. This work showed that there was an increase in the predicted temperatures.

For Sizewell B the extreme high temperature was predicted to increase to 41EC by 2030, which is an increase of 5°C above the 36°C design value.

In summary, it is judged that extreme maximum air temperature could rise by 5°C above the existing extreme design basis hazard level over the next 20 years. Although this is beyond the current design basis, it is a longer term safety issue and there is significant uncertainty in the forward projection. Changes in extreme air temperature will be reviewed at 10-yearly intervals within the safety review process, and no immediate action is required.

Conclusion SZB 4.2: Based on the above reviews, it is concluded that the extreme design basis hazard level for air temperature remains appropriate at the present time. The design basis for air temperatures has recently been further reviewed for all sites as part of Climate Change Adaptation and it was identified that the expected increase in extreme air temperature may impact the station within its expected lifetime. Changes in extreme air temperature will be monitored through the safety review process.

4.1.1.1.3 Extreme Seawater Temperature

The derivation of the bounding design hazard level for extreme seawater temperature is presented in section 4.1 above.

The Shipwash lightship ceased reporting in June 1981. The only seawater temperature reports since that date have been from vessels in transit. To capture significant data, observations have been considered from a large area centred on the old position of Shipwash. In the period 1981 to 1991 inclusive, the recorded extreme values were +20.5EC in August 1982 and +0.9EC in February 1991.

These values are within the previously reported extremes obtained from Shipwash. It is judged that the 1981 to 1991 data is broadly consistent with the earlier Shipwash data and that taking account of the large area over which the latest data have been collected (over a large area, localised extremes will tend to exaggerate the quoted values above those appropriate to Shipwash), the previously predicted extreme deep sea surface temperatures are still valid.

In 2003, the first periodic safety review for Sizewell B reviewed more recent data on seawater temperature. The recorded temperatures again all lay within the range of the original data. The review concluded that any increases in maximum seawater temperature due to global warming up to the second 10 yearly PSR would be small.

The work commissioned by EDF to investigate the effects of climate change has recently reviewed the methodology for extreme seawater temperature.

It is judged that there could be a small rise (of the order of 1°C) in the extreme maximum seawater temperature above the existing extreme design basis hazard level over the next 30 years. Although this is beyond the current design basis, it is a longer term safety issue and the projected increase is very small. Changes in extreme seawater temperature will be reviewed at 10-yearly intervals within the periodic safety review process, and no immediate action is required.

Conclusion SZB 4.3: Based on the above reviews, it is concluded that the extreme design basis hazard level for seawater temperature remains appropriate at the present time. The design basis for seawater temperatures has recently been further reviewed for all sites as part of Climate Change Adaptation and it was identified that the expected increase in extreme seawater temperature may marginally increase within the expected station lifetime. Changes in extreme seawater temperature will be monitored through the safety review process.

4.1.1.1.4 Snow

The derivation of the bounding design hazard level for snow is presented in section 4.1 above. The hazard was screened out by effect. For an event with a probability of exceedance of 10^{-4} p.a. the snow loading has been taken as 0.8kN/m^2. Safety classified buildings are designed to withstand a uniform snow loading of up to 1.5 kN/m^2 and localised snow drift intensities of up to 7.35 kN/m^2.

British Standard 6399-3: 1988, gives more information on imposed roof loads and in particular gives snow loading data separately, allowing account to be taken of the variation of snow in the UK and the effect of redistribution of snow on roofs due to wind. The design implications of the revisions to this code have been reviewed as part of PSR 1, and it is concluded that the amendments will not affect the design integrity.

Work on snow loading commissioned by EDF Energy identified the depth of snow expected at Nuclear Generation sites from events with return frequencies of 1 in 50, 1,000 and 10,000 years. The best estimate uniform snow loading on the ground for Sizewell B is predicted to be 1.05kN/m^2 for an infrequent (10^{-4}p.a.) event. Though this is greater than the design basis snow load, it is still within the imposed roof load and the design capability of the nuclear safety related buildings.

British Standard 6399-2:1988 has recently been withdrawn and replaced by the new Eurocode and UK National Annexe. Preliminary indications are that the impact of these changes should not affect current claims, however, a comparison with the new codes and the recent Met Office findings will be undertaken as part of the current PSR2 process.

Work commissioned by EDF to investigate the effects of climate change and consultation with in-house specialist civil engineers and reported that the level of risk from snow loading was low.

EDF Energy has reviewed the information contained within the UKCP09's 'Interpretation and use of future snow projections from the 11-member Met Office Regional Climate Model ensemble' and also commissioned the Met Office to undertake a study of snow loading for UK nuclear power stations.

The UKCP09 snow note discusses the number of snow days associated with different snow scenarios. The report concludes that "significant future reductions in numbers of snow days, mean snowfall rates and the intensity of heavy events are projected for the end of the 21st century, consistent with the projection of warming temperatures".

At present snowfall has not affected the safe and reliable operation of EDF Energy's nuclear power stations. As the UKCIP09 snow note states there will be significant future reductions in numbers of snow days therefore EDF Energy are not concerned that snowfall will pose a more significant threat to the safe and reliable operation of our nuclear power stations than does it does today.

In summary, it is judged that the bounding design hazard level for snow remains conservative for the foreseeable future. It will be kept under review under the periodic safety review process.

Conclusion SZB 4.4: Based on the above reviews, it is concluded that the extreme design basis hazard level for snow remains appropriate for the foreseeable future. It will be kept under review through the PSR process.

4.1.1.1.5 Lightning

The derivation of the bounding design hazard level for lightning is presented in section 4.1 above.

The hazard was screened out by effect and no subsequent reviews have been undertaken. It will kept under review through the periodic safety review process.

Conclusion SZB 4.5: It is concluded that the extreme design basis hazard level for lightning remains appropriate for the foreseeable future. It will be kept under review through the PSR process.

4.1.1.1.6 Drought

No numerical bounding design basis hazard level has been defined for drought in section 4.1 above.

The hazard is not amenable to quantification and was screened out by effect.

Work commissioned by EDF to investigate the effects of climate change notes that hotter, dryer summers will give rise to greater risks of drought. This is not considered to be of immediate concern to the timescales involved in drought affecting the station.

The original hazards assessment is judged to remain appropriate. It will be kept under review through the periodic safety review process.

Conclusion SZB 4.6: It is concluded that, although drought is not amenable to quantification, the original hazards assessment remains valid. It will be kept under review through the PSR process.

Fleet wide Review

During this review, it has been found that the methodology used to calculate the extreme ambient temperature and extreme wind conditions expected during the infrequent event is inconsistent across the fleet. Though this does not invalidate the design bases currently employed, it is considered that the methodologies currently adopted be analysed alongside any modern standards and approach and consideration be given to whether a common fleet wide methodology should be used.

Consideration SZB 4.1: Consider re-evaluating the methodologies used to calculate the infrequent extreme ambient temperature and extreme wind event conditions and whether a fleet wide methodology should be adopted.

4.1.1.2 Postulation of proper specifications for extreme weather conditions if not included in the original design basis

All of the extreme weather condition hazards were assessed as part of the original design basis, and so therefore no postulation is required.

4.1.1.3 Assessment of the expected frequency of the originally postulated or the redefined design basis conditions

This is covered for all the extreme weather condition hazards in the above sections as there is a properly defined magnitude and return frequency for the extreme wind hazard.

4.1.1.4 Consideration of potential combination of weather conditions

Many of the above environmental hazards can occur in a variety of combinations. In the majority of cases, it has been conservatively assumed that each of the extreme design basis hazard levels can occur concurrently. The exception is the combination of high wind and low air temperature as outlined below.

4.1.1.4.1 Extreme Wind and Low Air Temperature

The design requirements for equipment exposed to the outside air include a requirement for frost protection down to external ambient air temperatures well below 0EC. It is also necessary to consider high winds which may be coincident with low ambient air temperatures, as high winds will increase the frost protection requirements. Since it is believed that the lowest air temperature may be associated with light winds, an investigation has been undertaken to examine the available coincidence data for Gorleston, which is representative of the Sizewell area as far as air temperatures are concerned and which is judged to be representative as far as winds are concerned, to establish this dependency and to make recommendations for design purposes.

For design purposes an equation has been derived to derive the minimum air temperature as a function of maximum wind speed, such that the probability of exceedance of the combined parameters is 10^{-4}p.a. This and other combinations of parameters are used in the design of externally located safety classified equipment.

4.1.1.4.2 Possible credible combinations

Though some stations have addressed the possibility of combinational hazards, it seems that only two hazards combining together have been considered. Other combinations such as External Flooding combining with Extreme Wind and Lightning may not have been assessed.

Conclusion SZB 4.7: Combination hazards have been considered, however there is the potential that some credible combination hazards have not been assessed.

Consideration SZB 4.2: Consideration should be made to confirm that all credible combinations of hazards have been assessed.

4.2 Evaluation of safety margins

4.2.1 Estimation of safety margin against extreme weather conditions

Analysis of potential impact of different extreme weather conditions to the reliable operation of the safety systems, which are essential for heat transfer from the reactor and the spent fuel to ultimate heat-sink.

Estimation of difference between the design basis conditions and the cliff edge type limits, i.e. limits that would seriously challenge the reliability of heat transfer.

A local instruction is available for Sizewell B that describes the process to be used to prepare Sizewell B for reliable operation during the summer and winter periods.

4.2.1.1 Extreme Wind

The design approach to extreme wind and wind generated missiles is to:

Ensure that all safe shutdown equipment required is either enclosed in structures which are designed to withstand the design basis extreme wind or missile loading or is designed to remain functional without structural protection.

Assume that grid connections to the station are lost in the case of extreme wind and essential power supplies are required to be maintained through operation of the essential diesel generators.

Design the reserve ultimate heat-sink to withstand extreme wind event though it is considered extremely unlikely that the cooling water flow will be reduced due to screen blockage occurring before, during or following this event.

For Sizewell B. structures and externally located equipment are allocated to an extreme wind category dependent on the importance of the structure or equipment to nuclear safety. The three categories are:

- Extreme wind category 1;

Structures and equipment required to withstand the effects of extreme wind and wind generated missiles, that is to remain structurally intact, leaktight (in the case of fluid systems) and functionally operable to the extent required by their safety role.

- Extreme wind category S;

Structures and equipment which are required not to fail as a result of extreme wind or wind generated missiles if such a failure would impair the functioning of any structure or equipment in extreme wind category 1.

- Extreme wind category N.

All other structures and equipment not in one of the above categories, i.e. these are not required to be designed against extreme wind or wind generated missiles.

Most equipment and systems claimed in the fault analysis are contained in structures assigned to wind category 1. The exceptions are discussed below.

The turbine hall and transformers are qualified for the basic wind speed expected to occur every 50 years; failure of certain items could cause loss of grid. However the frequency of loss of grid caused by extreme wind is included in the frequency of the *initiating faults* representing loss of grid.

The circulating water pumphouse is qualified for the basic wind speed. However, the bracing members have been upgraded to enable the structure to withstand a wind speed of 53 m/s corresponding to the 10^{-3}p.a. frequency of occurrence.

The extreme wind category S structures are designed not to fail such that they affect extreme wind category 1 structures. It is therefore assumed that these structures will remain essentially intact at the 10^{-4}p.a. wind speed; however they may not remain functional at this wind speed. The only plant item in this category that is claimed in the fault analysis is the emergency charging storage tank. This tank is designed to remain functional during a 50 years return period wind, i.e. $2x10^{-2}$p.a. wind speed of 43 m/s.

Justification of survival of structures and equipment

The following subsection provides justification that wind category 1 structures and equipment will survive a 10^{-8}p.a. wind speed.

The 10^{-8}p.a. extreme wind speed is estimated to be 90.5 m/s based on extrapolation of the CP3 methodology. The effect of the increased wind speed from the 10^{-4}p.a. to the 10^{-8}p.a. extreme would be to increase the wind loading by a factor of the square of their speeds, since wind load is proportional to the square of the wind speed. This increased load factor would therefore be 2.26.

For the reactor building primary containment, the wind loading represents only 2% of the safe shutdown earthquake loading.

A doubling of the wind loading (in the absence of seismic loading) is therefore acceptable without invoking margins to failure on allowable stresses given in the civil design manuals and associated documents. The reinforced concrete structures are also judged to be unaffected by the increased wind generated missile velocities.

It is therefore judged that when taking the actual design and design margins into account, the structures can be expected to survive wind and wind generated missile speeds considerably in excess of design values.

Operating Procedures

Instrumentation measures both high level (40 m altitude) and low level (10 m altitude) wind speed at Sizewell B. Both the high and low level wind speed measurements will generate alarms if the alarm setpoints are exceeded.

Appropriate station documentation is available to allow the operator to maintain the plant in a safe and stable state in response to the wind speed alarms being triggered.

4.2.1.2 Extreme Air and Seawater Temperature

Extreme hazard temperature curves down to the 10^{-8}p.a. return frequency utilised in the fault analysis have been developed by using mathematical techniques to extrapolate the historic measured data for the annual maxima and minima for air and seawater temperature. The only physical limit which was identified was -2°C for low seawater temperature, which is the temperature at which seawater freezes.

As outlined above, the hazard levels for extreme air and seawater temperatures were compiled separately from different data sources. It is therefore difficult to assess if there is any correlation between the two, although a survey suggest that high sea temperatures tend to lag slightly behind high air temperatures. For the purposes of the hazards analysis, it was pessimistically assumed that the extreme air and seawater temperatures would occur at the same time. The two hazards are therefore considered jointly within this section of the report.

Effect of Extreme Air Temperature on Environmental Control

For equipment which is qualified to withstand the 10^{-4}p.a. extreme external air temperatures of –17°C and 36°C, the following generic arguments are used to justify that they will function adequately during the 10^{-8}p.a. extreme external air temperatures of –20°C and 41°C:

- It is judged that all mechanical components are essentially insensitive to extreme temperatures.
- A 5°C increase in temperature (the maximum that could occur due to an external increase of 5°C) is judged not to lead to an unacceptable degradation of the performance of electrical, control and instrumentation systems. So long as the administrative procedures designed to reduce heat loadings are followed such that the tolerances within the systems and design margins will ensure that the equipment performs its function adequately.
- Claiming more than minimum safeguards such as redundant heating, ventilation and air conditioning units will reduce the temperatures in some critical rooms. For low frequency events such as extreme temperatures, an extreme temperature event of say 10^{-8}p.a. in combination with independent failure of the heating, ventilation and air conditioning system will be significantly less than 10^{-8}p.a. and therefore was not considered.

The safety classified buildings and externally located plant have been individually reviewed for the extreme 10^{-8}p.a. return frequency hazard.

Effect of Extreme Temperatures on Heat-Sinks

Decay heat and other essential heat loads are ultimately removed via one of the two diverse heat-sinks – the essential service water system or the reserve ultimate heat-sink. The essential service water system uses seawater as the coolant whereas the reserve ultimate heat-sink uses atmospheric air coolers. The maximum design basis air temperature for the operation of the reserve ultimate heat-sink is 30°C. The reserve ultimate heat-sink is also capable of meeting the heat loads of a safe shutdown earthquake and a large loss of coolant accident at an air temperature of 26.1°C.

Temperature extremes outside of these design bases were considered in the hazards analysis. The approach used was to determine whether heat loads could be removed for all relevant combinations of fault and extreme temperature combinations with a combined frequency of 10^{-8}p.a.. Combinations with lower frequencies were not considered.

The impact of extreme temperatures on the capability of the seawater and air heat-sinks are reviewed in turn as follows.

Seawater Cooling Route – Extreme High Temperatures

For intact circuit faults, extreme hazard return frequencies of 10^{-8}p.a. have been reviewed.

The circulating water pumphouse heating, ventilation and air conditioning system designed for air temperatures up to 36°C. However, it is judged that the essential service water supply pumps could continue operating up to the 10^{-8}p.a. extreme high temperature of 41°C.

The maximum design seawater temperature is 26°C which has a return frequency of $3x10^{-2}$p.a. as a peak temperature and 10^{-3}p.a. as a 12-hour average. The peak temperature of 26°C is not considered to represent a limit for essential service water supply operation but it is a design limit for condenser vacuum. If this temperature was exceeded, it would be necessary to trip the reactor or reduce power in order to retain the condenser vacuum within its design limits. If the reactor is tripped, decay heat can be removed via the steam generator relief valves for at least 24 hours (or longer if make-up water is available) before the residual heat removal cooling route is used.

The peak and 12-hour average seawater temperatures corresponding to the 10^{-8}p.a. return frequency are 31.2°C and 30.2°C. These figures are conservative (by the order of 0.6°C) as they were based on the assumption that Sizewell A was operating. Sizewell A has now ceased generation.

A calculation has been undertaken of the loss of heat removal capacity for a more extreme seawater temperature of 32.3°C. With both trains of component cooling water system in operation with one pump operating per train, the heat removal capacity is reduced from 55.05MW to 35.26MW. Only a single train of component cooling water system and essential service water supply with a single pump operating are required to fulfil the safety function. Heat removal capacity could be increased by placing additional pumps in operation.

On the basis of the above, it is concluded that the essential service water supply/ component cooling water system can remove all heat loads following intact circuit faults as there will be at least 17MW spare capacity to remove essential heat loads after two days shutdown and there is significant redundancy within the systems.

For a loss of coolant accident and steam line break inside containment, there is an immediate heat removal requirement which is primarily to maintain the containment pressure and temperature within design limits. The relevant hazard return frequency is that, which when associated with the initiating fault frequency, gives an overall return frequency of 10^{-8}p.a. On the assumption that high temperatures could persist for a week, the extreme seawater temperature has been calculated as 27.8°C. This could potentially require initiation of the reserve ultimate heat-sink to cool the low temperature loads. However, the design basis temperature of 26°C is on the assumption of minimum safeguards. For low frequency sequences it is reasonable to claim the operation of redundant plant as failure of such equipment would further reduce the fault frequency. In addition, it is judged that the design limit of 26°C is not an absolute cut-off (noting that the maximum temperature is only 1.8°C higher and that a further reduction of 0.6°C can be claimed due to Sizewell A no longer operating).

On the basis of the above, it is concluded that extreme seawater temperatures in combination with a loss of coolant accident of steam line break do not represent a significant challenge to the capability of component cooling water system/essential service water supply cooling.

<u>Seawater Cooling Route – Extreme Low Temperatures</u>

The minimum design basis temperature for seawater is 0°C, with an absolute minimum of -2°C at which seawater will freeze. At such temperatures, seawater below the surface is likely to be at a higher temperature due to the density effect. Solar heating and outfall from the operating Sizewell B station will also increase temperature.

The circulating water pumphouse is designed to operate at air temperatures down to -13°C, which has a frequency of $5x10^{-3}$p.a. The air temperature which corresponds to a 10^{-3}p.a. frequency is -14.5°C. It is judged that design margins in the essential service water supply will allow it to operate at air temperatures down to -14.5°C, which is only 1.5°C below the design temperature.

Freezing of the drum screens could occur at low air temperatures even if the seawater temperature was above -2°C. However, although this would require the station to be shut down, the essential service water supply would still remain operable with the drum screens stationary.

On the basis of the above, it is concluded that the essential service water supply will remain operable for low air and seawater temperatures with a frequency of 10^{-3}p.a. For more extreme low temperatures, the safety case assumes that only the RUHS will be operable.

Air Cooling Route – Extreme High Temperatures

Following intact circuit faults, the reserve ultimate heat-sink is designed to remove all heat loads with an air temperature of up to 30°C. Additionally, the auxiliary reserve ultimate heat-sink is designed to remove essential heat loads at an ambient air temperature of 31.5°C. The above temperatures have a frequency of the order of 10^{-2}p.a.

The reserve ultimate heat-sink was only designed to operate following loss of seawater cooling via the essential service water supply/component cooling water system. The limiting faults for loss of essential service water supply cooling are due to other external hazards (e.g. safe shutdown earthquake for which the essential service water supply is not qualified) or to common mode failure of the component cooling water system or essential service water supply, which have an assumed frequency of 10^{-4}p.a. It is assumed that reserve ultimate heat-sink cooling will be required for the above events for a period of up to four days. On this basis, the above maximum design temperatures are bounding for events with a combined frequency of 10^{-8}p.a.

For a loss of coolant accident, the design temperature is 26.1°C. When combined with an safe shutdown earthquake and a large loss of coolant accident, the design temperature is bounding for events with a combined frequency of less than 10^{-8}p.a.

It is concluded on the basis of the above design margins, and the fact that only minimum safeguards are claimed, the frequencies of combined faults for which the maximum air temperature is outside of the design basis is insignificant.

Air Cooling Route – Extreme Low Temperatures

The reserve ultimate heat-sink, including its frost protection system, is designed to be operated down to air temperatures of -17°C. The minimum air temperature at the 10^{-8}p.a. frequency is -20°C. It is judged that the RUHS will remain operable down to -20°C as sufficient heat will be available to prevent freezing.

Operating Procedures

Instrumentation measures both high level (40 m altitude) and low level (10 m altitude) air temperature at Sizewell B. Both the high and low level air temperature measurements will generate alarms if the alarm setpoints are exceeded.

Appropriate station documentation is available to allow the operator to maintain the plant in a safe and stable state in response to the temperature alarms being triggered.

Instrumentation will similarly generate alarms on high or low seawater temperature.

Appropriate station documentation is available to allow the operator to maintain the plant in a safe and stable state in response to the temperature alarms being triggered.

Conclusion SZB 4.8: Arrangements are in place to protect against extreme wind and extreme ambient air and seawater temperatures. The safety margins have been reviewed and found to be adequate.

4.2.1.3 Snow

Snow has been screened out by effect as described in section 4.1 above. It is judged that there is adequate safety margin to protect against this hazard.

Operating Procedures

Appropriate station documentation is available to allow the operator to maintain the plant in a safe and stable state in response to heavy snowfall.

4.2.1.4 Lightning

Lightning has been screened out by effect as described in section 4.1 above. It is judged that there is adequate safety margin to protect against this hazard.

4.2.1.5 Drought

Drought has been screened out by effect as described in section 4.1 above. It is judged that there is adequate safety margin to protect against this hazard.

Conclusion SZB 4.9: Arrangements are in place to protect against extremes of lightning, snow and drought. These hazards have been screened out by effect on the basis that either the maximum impact of the hazard does not exceed the design capability of the plant or sufficient warning time is available to allow the operators to take appropriate actions such that the hazard does not lead to a large uncontrolled release of activity.

4.2.1.6 Mitigating Action

As discussed above, there are operator actions which can help mitigate against the extreme weather hazards due to the predictable nature of the hazards discussed. These include seasonal preparations undertaken prior to winter and summer and actions undertaking when warnings of extreme weather are received.

This is considered to add margin to the existing hazard margin.

Conclusion SZB 4.10: The predictable nature of the extreme weather hazards discussed in the chapter allow operator actions to be taken to help mitigate the effect of the hazard.

Consideration SZB 4.3: Consider reviewing the seasonal preparedness measures currently undertaken to identify areas to increase robustness.

4.2.2 Potential need to increase robustness of the plant against extreme weather conditions

Periodic Safety Review

Each of the hazards that have been addressed in this Chapter have been subject to review as part of the periodic safety review. It was concluded that the extreme weather safety cases for Sizewell B were adequate.

Climate Change

Climate change has the potential to modify the severity of meteorological hazards and for this reason EDF Energy regularly monitors revisions to predictions. In 2011 EDF Energy undertook a climate change adaptation review. This considered the effects of predicted climate change on meteorological related hazards including those that have been considered in this Chapter. Considering the effect on climate change across EDF Energy's fleet of nuclear stations, a number of gaps were identified by the adaptation risk exercise. For each gap identified, a suggested adaptation option was also specified. Based on these findings, EDF Energy has a number of initiatives that it will be progressing aimed at building on its existing adaptive capability. Over the next year, EDF Energy will be considering in detail its forward strategy with respect to these options. The areas relevant to this chapter are listed below.

Table 4.1: Gaps identified during work commissioned by EDF Energy to investigate the effects of Climate Change

Gap identified by adaptation risk exercise	Suggested adaptation option
Some chemicals and oils are volatile and/or degrade at extreme air temperatures	Investigate options for cool chemical/oil storage to protect against extreme ambient temperatures
Some stations are more likely to exceed their thermal discharge consents	Liaise with EA to discuss viability of temperature consent increases on vulnerable sites
Subsidence and landslide: A need for a watching brief	Continue to monitor landslide and subsidence.
Storage of process water from water companies is limited. Thus in the event of a severe drought stations	Engage with water companies to firm up arrangements for ensuring continued supply of townswater (e.g. Ensure

could be left without adequate provision.	minimum flow rate) during drought conditions Engage with EA on inclusion of sites within drought management plan Gauge better understanding as to the likelihood of drought in each catchment and produce a summary report

Review

As responsible operators, EDF Energy undertook two reviews in light of the events at the Fukushima Daiichi plant. The Licensee Board required a number of checks to be carried out in the days immediately following the events and these were reported through the first of these reviews.

The information gathered by these self-assessments was also used to provide a formal company response to address the recommendations of INPO IER 11-1 and WANO Significant Operating Experience Review 2011-2 (which are the same).

The findings of the extreme weather aspects are discussed below on a fleet wide basis; this is because the learning from each of the sites is judged to be applicable across the stations.

This assessment was carried out very soon after the event and was primarily focussed on seismic and flooding hazards. Some consideration was given to other extreme events, commensurate with the level of impact of the hazard.

Scope

The review was specified to ensure that systems essential to fuel cooling in an emergency situation in a within design basis event are correctly configured, lined up and in a suitable condition to be declared available/operable.

The review was also specified to ensure that documentation, training and plant associated with response to beyond design basis events were reviewed, along with the adequacy of the emergency response organisation. Due to the nature of the questions asked as part of the review, this was primarily a paper-based exercise with workshops between station and central support engineers where appropriate. Equipment provided specifically for response to beyond design basis events was also physically inspected to ensure that the condition of the plant was as expected.

Summary of Findings

The review found that the systems essential to fuel cooling in an emergency situation in a within design basis event are correctly configured, lined up and in a suitable condition to be declared available/operable. No additional concerns were identified at station with regard to all hazards considered in this chapter.

All stations have procedures for preparation for seasonal readiness and extreme weather events. In general they dictate allowable operations for weather conditions.

Some, but not all, of the stations receive site specific weather forecasts to enable preparation of plant for weather events.

All stations had some experience of within design basis adverse weather conditions such as heavy snow, localised flooding or prolonged heat and in reviewing that experience it was generally noted that some simple actions could provide benefit particularly with regard to station access.

There are mechanisms for identifying any areas of concern or anomalies within the safety case.

Conclusion SZB 4.11: A fleet wide review has been carried out to identify any fleet wide measures which can be implemented to improve robustness against extreme weather conditions.

Consideration SZB 4.4: Consideration should be given to all stations receiving site specific weather forecasts.

Consideration SZB 4.5: Consideration should be given to the provision of additional station based robust means of personnel transport for extreme weather conditions.

Chapter 5 – Loss of Electrical Power and Loss of Ultimate Heat-Sink

Sizewell B

5 Loss of Electrical Power and Loss of Ultimate Heat-Sink

Severe damage of the reactor is prevented by the essential safety functions of reactor trip, shutdown and hold-down, adequate post-trip cooling and maintaining the containment for the fuel and fission products. One of the main aspects of the Fukushima incident relates to the provision of adequate post-trip cooling and this is the main essential safety function that is affected by the scenarios in this section.

Chapter 5 focuses on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat-sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances. The effects on both the reactor and fuel storage ponds are considered within this chapter.

The Stress-Test requires a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.

The Stress Test also requires a consideration of 'Loss of Ultimate Heat-Sink'. Within this a number of scenarios are considered, the impact of the loss of the primary ultimate heat-sink (seawater) as well as, loss of primary ultimate heat-sink combined with loss of alternate heat-sinks (i.e. other cooling water supplies and heat-transfer routes to atmosphere). The Stress Test also required the combined consequences of station black out and loss of primary ultimate heat-sink.

It should be noted that many of the scenarios discussed in this chapter are beyond the design basis. This formally means that they occur with a frequency much less than 1 in 10,000 years. In fact, EDF Energy confidently expect that the scenarios in this chapter, especially those concerning the combination of station black out and loss of heat-sink, are not credible.

The sections of this Chapter consider the impact upon the reactor essential safety functions due to the above scenarios and consider the plant requirements for fulfilling the essential safety function of post-trip cooling for both the pressurised reactor and de-pressurised reactor state.

5.1 Nuclear power reactors

As described in Chapter 1, Sizewell B was designed using the principles of segregation, diversity and redundancy. As such, systems that are defined as being safety related, have appropriate levels of segregation, diversity and redundancy. For events that result in loss of electrical power, the following systems are in place:

- On-site AC electricity generation;
- On-site DC battery charging system;
- Permanently installed DC electricity supplies;
- Permanently installed uninterruptible power supplies.

For events that result in a loss of heat-sinks, Sizewell B has a diverse and segregated ultimate heat-sink.

5.1.1 Loss of electrical power

A summary is given below of the key electrical systems and their associated plant that support the essential safety functions outlined. Further detail of plant systems that provide the essential safety functions is given in Chapter 1 of this report.

The stress-test review of the various scenarios for 'loss of electrical power' at Sizewell B and their impact on the plant that is required to carry out the essential safety functions is contained within this section (5.1.1) and its sub-sections. Conclusions and judgements are made throughout the sections below and suggested 'Considerations' for improvement are identified. Further potential improvements to the robustness of plant during a loss of electrical power scenario are considered in section 5.1.2.

5.1.1.1 Loss of off-site power

Loss of off-site power is assumed to mean the loss of the national grid supply to the station. This is considered within design basis for the station.

If off-site power is lost to Sizewell B station, the reactor will be automatically tripped and shutdown. The on-site electrical generation systems will then be used to provide a diverse supply to the systems required to achieve safe cold shutdown. Uninterruptible power is maintained to low voltage systems that require a no-break supply.

The plant is designed so that it can be brought to a safe shutdown condition following a loss of off-site power.

5.1.1.1.1 Design provisions taking into account this situation: back-up power sources provided, capacity and preparedness to take them into operation

The on-site electrical AC generation system is appropriately segregated. It has been designed to withstand all external design basis hazards. Starting the on-site electrical AC generation system requires low voltage power supplies. The system is self sufficient for the time required to bring the plant to a safe and stable state and will start on receipt of the appropriate alarm signal. Essential stocks to this system exceed the 24 hour mission time described in Sect 0.7 of Chapter 0.

The benefit of having increased stocks of essential supplies has been highlighted by the events at Fukushima Dai-ichi, and means in which to extend the availability of essential stocks should be considered.

5.1.1.1.2 Autonomy of the on-site power sources and provisions taken to prolong the time of on-site AC power supply

The on-site power generation system does not require operator action to start-up and provisions to prolong supply are in place. The appropriate station documentation is available to assist the operator in prolonging provisions.

Conclusion SZB 5.1: The loss of off-site power is considered within the Sizewell B station safety case. In the event of loss of off-site power, there are sufficient supplies of fuel oil for the diesel generators to continue operating under full load for at least a 72 hour mission time.

5.1.1.2 Loss of off-site power and loss of the ordinary back-up AC power source

The loss of off-site and on-site electrical AC power was considered during the design process at Sizewell B. A further back-up electrical DC generation system is available to allow the plant to be brought to a safe shutdown following the loss of both the off-site and on-site electrical AC generation systems.

A passive system is also available to provide a forced water supply to the secondary side of the steam generators. This system is powered by the steam produced from the decay heat from the fuel. The system requires DC electrical power to remain controllable, however it will continue to operate (albeit at a reduced capacity) following a complete loss of AC and DC power.

5.1.1.2.1 Design provisions taking into account this situation: diverse permanently installed AC power sources and/or means to timely provide other diverse AC power sources, capacity and preparedness to take them into operation

Sizewell B has a segregated AC electricity generation system with high levels of redundancy. The provision of a segregated and diverse DC battery charging system also provides another level of protection following the loss of the installed AC power sources.

5.1.1.2.2 Battery capacity, duration and possibilities to recharge batteries

The DC electrical system used to provide power to safety related systems is supported by a dedicated on-site DC battery charging system. This extends the battery capacity from a minimum of 2 hours (for an individual system) to well beyond 24 hours.

Battery charging diesel generators

The on-site DC battery charging system provides supplies to all essential and certain non-essential battery chargers when supplies are not available from the main electrical system.

Conclusion SZB 5.2: The loss of both off-site power and on-site power generation system is considered within the Sizewell B station safety case. There are diverse supplies to recharge batteries via the DC battery charging system and keep them charged for at least 24 hours.

Consideration SZB 5.1: Consideration should be given to the practicability of extending the availability of essential stocks by either providing additional on-site storage facilities or additional means to replenish stocks to allow an extended operating period.

5.1.1.3 Loss of off-site power and loss of the ordinary back-up AC power sources and loss of permanently installed diverse back-up AC power sources

Loss of both on-site and off-site AC power was a fault considered as part of the design process at Sizewell B. As such, the plant is capable of achieving safe shutdown using DC power alone.

5.1.1.3.1 Battery capacity, duration and possibilities to recharge batteries in this situation

As discussed in section 5.1.1.2.2, DC power supplies are maintained by a dedicated on-site DC battery charging system, and as such, battery capacity and duration extends beyond the 24 hour mission time.

Conclusion SZB 5.3: In the event of station black out, electrical supplies to essential safety equipment will be maintained by using the DC battery charging system.

Consideration SZB 5.2: Consider whether additional means could usefully be installed to extend current battery capacity and supply.

5.1.1.3.2 Actions foreseen to arrange exceptional AC power supply from transportable or dedicated off-site source

There is a set of emergency equipment that would support some safety functions but this is at present very limited in this scope. This equipment is located remotely off site and centrally within the UK on trailers to be transported to the affected site within hours following the declaration of an Off-Site Nuclear Emergency activation (see section 6.1.2.1). Additional time would then be required to deploy this equipment.

Conclusion SZB 5.4: There are provisions off-site that can be deployed to station within hours that would provide power generation capability and aid continued post-trip cooling of the reactor.

5.1.1.3.3 Competence of shift staff to make necessary electrical connections and time needed for these actions. Time needed by experts to make the necessary connections

No external AC power connections are required in the event of a station black out (loss of off-site and on-site AC power). This is due to the DC circuits mentioned previously. Operator action is focused on returning the on-site AC electrical generators to service as soon as possible.

As it is beyond design basis, there is no formal requirement for the training of shift staff to connect the off-site generators to the station. However, all shift staff go through a structured training programme for their normal duties and specific additional training for the roles they perform as part of the emergency arrangements.

In a severe accident situation technical experts at the central emergency support centre would support the technical staff on site by considering the strategies required and formulating a plan to implement those strategies. Clearly the time then taken on-site to achieve the actions would be dependent on the extent of the work required, which would be a function of the damage to plant by the initiating events.

It is the central emergency support centre organisation which is able to mobilise the beyond design basis trailers, and procure other equipment or consumables. To aid the procurement process there is a standby team of procurement specialists who are part of the central emergency support centre arrangements.

Conclusion SZB 5.5: Following a severe accident, actions required by shift staff could be hindered by conditions on-site. Mitigation of this is provided in the form of the central emergency support and station operating procedures for beyond design basis events.

Consideration SZB 5.3: Consideration should be given to provision of training, planning or pre-engineering in order to improve mitigation measures.

5.1.1.3.4 Time available to provide AC power and to restore core cooling before fuel damage: consideration of various examples of time delay from reactor shutdown and loss of normal reactor core cooling condition

The loss of all AC power (both off-site and on-site) was considered during the design process, and as such there are systems in place to protect the plant against fuel damage in the event of a loss of all AC power. The time that the plant can be maintained in a safe state without off-site power extends well beyond the station mission time of 24 hours.

5.1.2 Measures which can be envisaged to increase robustness of the plant in case of loss of electrical power

The preceding sections have shown that there are diverse and redundant provisions for design basis loss of power scenarios. Furthermore, where specific issues have been noted appropriate considerations are raised. These include consideration of:

- Extended availability of essential stocks
- Improved training, planning and pre-engineered provisions in order to improve mitigation measures

Chapter 6 contains further considerations for additional emergency backup equipment which would mitigate against the effects of a beyond design basis loss of electrical power.

Conclusion SZB 5.6: The current robustness and maintenance of the plant is compliant with its design basis against loss of electrical power. However, steps can be made to improve the resilience of the plant for a beyond design basis event.

Consideration SZB 5.4: For beyond design basis faults related to station black out, several specific potential enhancements have been identified and their practicability should be assessed.

5.1.3 Loss of the ultimate heat-sink

The ultimate heat-sink at Sizewell B is the sea. A summary of the main systems is included below.

The essential services water system consists of four pumps, four backflushable strainers and associated piping, valves and instrumentation arranged in two separate independent trains. Each train provides cooling water to corresponding trains of component cooling water system heat exchangers.

Seawater is drawn into the essential services water system from the clean side of the main circulating water screens through common headers with the auxiliary circulating water system. Water is discharged from the essential services water system to the circulating water outlet surge chamber. The circulating water inlet and outlet are located such that essential services water system flow recirculation is minimised thus ensuring that the sea is an effective heat-sink for the essential services water system.

Sizewell also has a reserve ultimate heat-sink. This system uses forced air through heat exchangers to reject heat to the air. Even when the ultimate heat-sink and the reserve ultimate heat-sink fail, heat still can be removed from an intact primary circuit by the turbine driven systems, namely the auxiliary feedwater system and the emergency charging system. Again with this method heat is rejected to the atmosphere by boiling and venting of the secondary circuit. It should therefore be noted that the scenarios regarding the loss of all electrical power discussed in section 5.1.1 are the bounding ones as they effectively can lead to the loss of control of the turbine driven systems, whereas loss of both the ultimate heat-sink and reserve ultimate heat-sinks still leaves the turbine driven systems available.

5.1.3.1 Design provisions to prevent the loss of the primary ultimate heat-sink, such as alternative inlets for seawater or systems to protect main water inlet from blocking

Seawater is drawn through twin offshore structures which include stationary coarse screens. It then passes along a single intake tunnel and thence through 4 revolving fine mesh screens to the pumping plant. Biological fouling within the system is minimised by continuous injection of dilute sodium hypochlorite solution into the seawater at the offshore intake works and the drum screen intake channels. Also essential cooling water is sufficient if reactor is shutdown and drum screens fail to rotate.

Conclusion SZB 5.7: Several means of preventing the loss of the circulating water system by blockage of the water intakes are employed at Sizewell B including drum screens and chemical control.

5.1.3.2 Loss of the primary ultimate heat-sink (e.g. loss of access to cooling water from river, lake, sea or main cooling tower)

Upon loss of the primary ultimate heat-sink, the diverse reserve ultimate heat-sink can be used to provide forced air to cool the safeguards equipment. The reserve ultimate heat-sink heat exchangers reject heat to the atmosphere and so are therefore considered to be appropriately diverse to the primary ultimate heat-sink (the sea).

5.1.3.2.1 Availability of alternative heat-sink

The reserve ultimate heat-sink is not normally required during normal power operation but is maintained in the standby mode at all times. It is also used during maintenance of the primary ultimate heat-sink.

Major electrical supplies for the reserve ultimate heat-sink are drawn from separate trains of the electrical system to maintain a high reliability factor for all the equipment. Make-up water is supplied from the water storage and transfer system.

Conclusion SZB 5.8: There exist diverse alternative heat-sinks for essential cooling in case of loss of the ultimate heat-sink.

5.1.3.2.2 Possible time constraints for availability of alternate heat-sink and possibilities to increase the available time

The reserve ultimate heat-sink is maintained in the standby mode at all times and is started automatically on loss of primary ultimate heat-sink, long before safeguards plant will see any major rise in temperatures. As long as AC power is available on-site, this system will continue to function as intended.

5.1.3.3 Loss of the primary ultimate heat-sink and the alternate heat-sink

Upon loss of the primary ultimate heat-sink and the alternate heat-sink (reserve ultimate heat-sink), it is assumed that the reactor will trip. It will then become necessary to manage cooling, criticality and containment until safe shutdown is achieved. Cooling (decay heat removal) is achieved through continual cold water feed to the steam generators. This can be achieved using either the motor driven or turbine driven auxiliary feedwater system, which use the auxiliary feedwater storage tanks and townswater system which together have the capacity to supply feedwater for several days (see section 5.1.3.4.2). If both these systems were unavailable, bleed and feed using the safety injection system would be used to maintain cooling. Criticality and containment are not threatened by the loss of the primary and alternate heat-sinks.

5.1.3.3.1 External actions foreseen to prevent fuel degradation

There are no external actions required to prevent fuel degradation as equipment is available, following the loss of both the primary and alternate heat-sink, to achieve safe shutdown.

5.1.3.3.2 Time available to recover one of the lost heat-sinks or to initiate external actions and to restore core cooling before fuel damage: consideration of situations with various time delays from reactor shutdown to loss of normal reactor cooling state

Fuel damage is not expected to occur following the loss of both the primary and alternate heat-sink.

5.1.3.4 Loss of the primary ultimate heat-sink, combined with station black out (i.e. loss of off-site power and ordinary on-site back-up power source)

The loss of ultimate heat-sink and reserve ultimate heat-sink is considered to be comparable to the loss of all AC power as both systems require AC power. As mentioned previously the loss of off-site and on-site AC power is considered within design basis, and as such no core damage will occur.

EDF Energy recognises the nature of the stress test and as such has considered events beyond the scope of the stress test. In order for core damage to occur at Sizewell B, the loss of off-site and on-site AC power would have to be combined with the loss of the diverse and segregated on-site DC battery charging system. This would lead to a loss of control of the auxiliary feedwater system as the valves used to regulate flow to the steam generators require DC power. The system has been designed so that when the control valves are no longer supplied with DC power a bypass route is utilised to maintain a set flow.

5.1.3.4.1 Time of autonomy of the site before start of water loss from the primary circuit starts

Water inventory loss from the primary circuit will occur once the secondary circuit has stopped removing sufficient heat from the primary circuit. The loss of water inventory will be through the release of pressurised steam through the pressure relief valves in the pressuriser. These discharge to the pressuriser relief tank which will pressurise and relieve into the primary containment.

This should not occur providing the battery charging diesel generators remain in operation and provide support for the auxiliary feedwater system.

5.1.3.4.2 External actions foreseen to prevent fuel degradation

Fuel degradation will not result from the loss of both the primary and reserve ultimate heat-sink, combined with the loss of off-site and on-site AC power. As discussed above, because control of the auxiliary feedwater system would be lost, fuel degradation could occur if the battery charging diesel generators are unable to maintain adequate supply to the systems controlling the auxiliary feedwater system. In scenarios where the auxiliary feedwater system is not used (i.e. not intact primary circuit), gravity fed water supplies can be used to provide a water supply to the primary circuit, thus maintaining cooling.

It should be noted that the loss of off-site and on-site power and battery charging capacity is considered to be extremely improbable.

At Power/Hot Shutdown (incl Cold Shutdown with reactor coolant system Intact)

In the event of a loss of the primary ultimate heat-sink, combined with station black out (loss of all AC power on-site and off-site), the DC battery charging system can be used to maintain low voltage essential electrical supplies. These, together with nitrogen backed-valves, are sufficient to enable operation of turbine driven auxiliary feedwater system, emergency charging system and relief valves on the secondary system – thereby maintaining both core cooling and reactor coolant system integrity.

The turbine driven auxiliary feedwater system can be used to pump water to the steam generators. The system can operate without AC power and as it is a once through cooling system (with the ability to use the condensers if appropriate) no heat-sink is required. The system will vent steam to atmosphere to dissipate heat. The turbine driven auxiliary feedwater system does require DC power, and without the DC battery charging system, it is expected that the batteries will last a minimum of 2 hours. Following exhaustion of the batteries, the valves required for continued operation of the auxiliary feedwater system will fail in a safe position (i.e. they will fail so that the auxiliary feedwater system will continue to take heat away from the steam generators). It is therefore considered that even with failure of the all dc power, heat will still be removed from the primary circuit although as mentioned above it will not be controlled. External actions could be to supply back-up DC battery charging system supplies from mobile diesel generators.

A proportion of the water in each of the two condensate storage tanks is dedicated to the auxiliary feedwater system. The amount of dedicated water in each tank is sufficient to maintain the plant at hot standby conditions for several hours followed by a cooldown at an average rate of 28°C per hour, to a temperature of 177°C. The combined capacity of both tanks is sufficient to maintain the plant at hot shutdown for 24 hours followed by a cooldown, as above. There is a normally closed interconnection between the two condensate storage tanks, which enables any auxiliary feedwater system pump to be aligned to either condensate tank in the longer term.

Additional feedwater supplies are provided by the townswater system, which normally has sufficient capacity to extend the period at hot shutdown to seven days. In the unlikely event that a major fire occurs and results in a significant demand for water for fire-fighting purposes, this period would be reduced but would not be less than five days. Either subsystem can be manually realigned to take water from the townswater system, via separate lines. Realignment to this source is carried out only when all sources of condensate quality water have been exhausted.

Cold shutdown with reactor coolant system **not** Intact/Refuelling

All engineered make-up routes to the reactor coolant system, whilst not intact require on-site AC generation systems or grid supplies, with the exception of the gravity fed water supply from the refuelling water storage tank and the safety injection accumulators. Gravity feed is only expected to be available if the reactor coolant system is incapable of pressurisation. Gravity feed is not expected to be effective when in a cold shutdown state with the RPV head in position on the vessel – even if not tensioned, however this is a transient state during the refuelling process which occurs approximately once every 18 months. Potential mitigations for this state are included for assessment under Consideration 5.6. With the head removed, then at decay heat levels below 10.5MW, and the refuelling pool not filled, gravity feed would last 24 hours. If the refuelling pool is filled then in excess of 36 hours will be available before the core is uncovered due to the boil off of water.

Depending on the plant state, nitrogen pressurised boronated water may be available through the Safety Injection Accumulators. Injection can be achieved by manual valve operation from within Containment, outside of the Bio-Shield. But this is only expected to be possible if these valves are operated within the first few hours of a fault. Once core uncovery/damage has occurred it is judged that Containment entry would not be possible.

For the above scenario, external actions could be to provide external pumps and water supplies for make-up purposes. At the end of a refuelling cycle (e.g. the start of a refuelling outage) the intrinsic reactivity of the core is low and sub-criticality would be unlikely to be jeopardised by some make-up with unborated water e.g. from the Fire System, especially if the water-loss is by boiling, as this will tend to leave boron in solution. However, earlier in the cycle (e.g.

following core load), the intrinsic reactivity of the core is significantly higher, and make-up with unborated water could significantly increase the risk of criticality.

5.1.4 Measures which can be envisaged to increase robustness of the plant in case of loss of ultimate heat-sink

The preceding sections have shown that there are robust provisions for design basis loss of heat-sink scenarios. The Sizewell B design is generally tolerant to the loss of the primary ultimate heat-sink as a result of the inherent capacity to transfer heat to atmosphere via the reserve ultimate heat-sink. Hence, fewer specific issues have been identified when compared with the loss of electric supplies scenarios.

Chapter 6 contains further considerations for additional emergency backup equipment which would mitigate against the effects of a beyond design basis loss of all ultimate heat-sinks.

Conclusion SZB 5.9: The current robustness and maintenance of the plant is compliant with its design basis for loss of the ultimate heat-sink. However, steps to improve the resilience of the plant following a beyond design basis event should be considered.

5.1.5 Licensee Review of Robustness

As responsible operators, EDF Energy undertook two reviews in light of the events at the Fukushima Daiichi plant. The Licensee Board required a number of checks to be carried out in the days immediately following the events and these were reported through the first of these reviews.

The information gathered by these self-assessments was also used to provide a formal company response to address the recommendations of INPO IER 11-1 and WANO Significant Operating Experience Review 2011-2 (which are the same).

The findings of the loss of power and heat-sink aspects are discussed below on a fleet wide basis; this is because the learning from each of the sites is judged to be applicable across the stations.

This assessment was carried out very soon after the event and was primarily focussed on seismic and flooding hazards. Some consideration was given to other extreme events, commensurate with the level of impact of the hazard.

Scope

The review was specified to ensure that systems essential to fuel cooling in an emergency situation in a within design basis event are correctly configured, lined up and in a suitable condition to be declared available/operable.

The review was also specified to ensure that documentation, training and plant associated with response to beyond design basis events were reviewed, along with the adequacy of the emergency response organisation. Due to the nature of the questions asked as part of the review, this was primarily a paper-based exercise with workshops between station and central support engineers where appropriate. Equipment provided specifically for response to beyond design basis events was also physically inspected to ensure that the condition of the plant was as expected.

Summary of Findings

All stations noted that there was the potential for improvement to resilience to loss of power and heat-sink scenarios.

In view of Fukushima experience, 24 hours seems a short mission time for essential stocks.

Loss of non essential equipment will provide additional challenges for longer term events and various locations have local fire fighting air compressors that will not be re-supplied and eventually will lead to deluge valve trips and wetting of equipment and additional demands of water/fuel stocks plus operator action to terminate

Access issues will be created by loss of supplies at most sites, requiring manual breaching of fences/turnstiles around certain plant areas.

Summary of site specific findings

Some suggestions from the review process are highlighted below to illustrate some of the initial measures considered to increase robustness of the plant in case of loss of ultimate heat-sink. The Japan earthquake response team is tasked with developing these and other measures further.

Feed systems injection point(s)

It may be possible to engineer an installed connection to inject water directly to the steam generators e.g. via an installed 'Tee' to either the main or auxiliary feed systems. The safety benefit of such a connection would be that it could be used with a portable pump/hydrant, (as per the existing fuel storage pond hydrant make-up connection) to provide secondary circuit cooling to the core, in the event of failure of all other feedwater routes. It would require analysis to demonstrate that it would not increase the risk to nuclear safety from more frequent faults (failures/leaks), and consideration would have to be given to the need/capability for steam generator depressurisation prior to injection.

Reactor coolant system injection point(s)

Consideration could be given to providing an installed connection to inject water directly to the reactor coolant system e.g. via an installed 'Tee' to, for example, the chemical and volume control system charging Line. The safety benefit of such a connection would be that it could be used with a portable pump/hydrant, (as per the existing fuel storage pond hydrant make-up connection) to provide water to ensure that the core remains covered in the absence of other cooling. In particular, this could reduce the risk from the reactor coolant system 'Not Intact' states. It would require analysis to demonstrate that it would not increase the risk to nuclear safety from more frequent faults (failures/leaks) – especially in the context of a containment bypass route for activity in the event of a major design basis fault. It may be possible to engineer a route taking water from the boric acid tanks, thereby also addressing any criticality concerns.

Reactor building injection Point(s)

These already exist in the form of the fire protection system to containment allowing water to be pumped (via diesel driven pumps) into the reactor building if no other pumps are operable. These could be extended/increased though the tenability of rooms adjacent to containment may be an issue.

Conclusion SZB 5.10: The current robustness and maintenance of the plant is compliant with its design basis against loss of ultimate heat-sink. However, steps can be made to improve the resilience of the plant for a beyond design basis event.

Consideration SZB 5.5: Consideration should be given to increasing the provision of off-site back-up equipment including: equipment to enable cooling for fuel, containment or pool and essential water supplies.

Consideration SZB 5.6: For beyond design basis faults relating to the provision of water, several specific potential enhancements have been identified and their practicability should be assessed.

5.2 Spent fuel storage pools

The fuel storage facility provides protection, cooling and shielding for new and irradiate fuel assemblies, and ensures that the fuel assemblies are maintained in a sub-critical array both during normal operation and under fault conditions. It also provides an efficient basis for safe and reliable fuel handling operations.

5.2.1 Loss of electrical power

Loss of electrical power to the fuel storage pond is considered within the design basis for Sizewell B. Provisions are in place to maintain adequate cooling to the fuel for at least the station mission time of 24 hours.

Fuel pond cooling during prolonged loss of normal pond cooling

The removal of decay heat from the spent fuel would be maintained by the boil off of pond water. Losses due to boiling are made up from the water storage tank, or from the emergency make-up supply.

Fuel pond cooling system operation during total loss of AC power

Following a total loss of AC power, normal fuel storage pond cooling is lost. The pond water is allowed to heat up and will boil off. The water level in the pond is maintained at all times at a level where even after complete loss of pond cooling, at least 24 hours would be available before the fuel became exposed.

The emergency hydrant connection can be used to deliver water directly to the fuel storage ponds, from either the hydrant system (diesel driven pumps) or from a fire tender/portable pump. There is no requirement to introduce boron into the fuel storage pond as studies have shown that sub-criticality is ensured by the racks and the fixed absorbers, with no soluble boron.

Conclusion SZB 5.11: In either the event of both loss of grid or Station Black Out (SBO), sufficient cooling can be maintained to the station fuel route areas for a 24 hour mission time, beyond 24 hours there are provisions available for emergency water make-up.

5.2.2 Measures which can be envisaged to increase robustness of the plant in case of loss of electrical power

The preceding sections have shown that there are robust provisions for design basis loss of power scenarios. Furthermore, there are also arrangements for mitigation of the effect of loss of power faults beyond design basis.

Generic measures set out in section 5.1.2 to increase robustness of the plant in case of loss of electrical power would also increase robustness of the fuel route plant areas

The specific issues for the fuel route plant areas are raised below.

Fuel storage pond level instruments improvements

These could be replaced with instruments that would be unaffected by the loss of instrument air and/or were ranged to include the full height of the fuel storage racks. If no changes are made to these instruments it would be prudent to ensure that procedures exist to bypass/over-ride the associated fuel pond cooling system pump trips upon failure of the instruments.

Conclusion SZB 5.12: Whilst there are no vulnerabilities identified in the current design basis for the fuel ponds against loss of electrical power, further resilience enhancements can be envisaged.

Consideration SZB 5.7: Consider improving resilience of pond cooling and make-up against loss of electrical power. For example, guidance to operators, replenishment of lost pond water, instrumentation and standalone pond cooling facilities having no dependence on any other station supplies or systems.

5.2.3 Loss of the ultimate heat-sink

Loss of the ultimate heat-sink is considered within design basis at Sizewell B. This event proposes the loss of all seawater and all alternate cooling systems through failure or unavailability. This is a total loss of all otherwise available cooling via any systems available.

In the event of a failure of the ultimate heat-sink, the reserve ultimate heat-sink can be used to provide cooling water to the fuel storage pond. As the reserve ultimate heat-sink is an air-cooled system, it is considered to be sufficiently diverse to the primary ultimate heat-sink (Seawater).

The loss of the reserve ultimate heat-sink and the primary ultimate heat-sink is considered to be bounded by the loss of electrical power, since the use of reserve ultimate heat-sink and the primary ultimate heat-sink requires the use of AC power for pumped flow (as discussed in section 5.2.1).

5.2.4 Measures which can be envisaged to increase robustness of the plant in case of loss of ultimate heat-sink

As mentioned above, the loss of the ultimate heat-sink would not affect fuel integrity in the spent fuel ponds. The loss of the reserve ultimate heat-sink at the same time would be comparable to loss of both off-site and on-site AC power as both heat-sinks require AC power. As mentioned above, loss of both off-site and on-site AC power would also not affect fuel integrity beyond the Sizewell B station mission time. The engineered route to increase water inventory is considered an adequate measure to maintain fuel integrity.

Conclusion SZB 5.13: There are no vulnerabilities identified as a result of the loss of the ultimate heat-sink due to the provision of the reserve ultimate heat-sink.

Chapter 6 – Severe Accident Management

Sizewell B

6 Severe Accident Management

In the ONR Interim Report into the Japanese Earthquake and Tsunami, Mike Weightman states:

"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."

"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."

"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."

This chapter will explore the organisation and management measures which are in place within EDF Energy to deal with severe accidents.

In a number of places, this document refers to the need for ongoing development work. Some of this work had been previously identified and captured by normal company processes, whilst some is new work highlighted by the post-Fukushima review. In the latter group, there is some potential work packages referred to as 'Considerations'. These Considerations will be carefully reviewed following the completion of the Stress test reports and an appropriate programme of work formulated.

6.1 Organisation and arrangements of the licensee to manage accidents

EDF Energy Nuclear Generation has a robust organisation and has emergency arrangements in place that have been developed and maintained to respond effectively in the unlikely event of an emergency.

There are three main obligations that underpin EDF Energy Nuclear Generation's approach to an emergency:

1. Moral – we have a moral duty to protect both personnel and the public. We must have robust emergency plans and their use demonstrated to outside agencies and the public.
2. Legal - under the Nuclear Installations Act 1965, the Ionising Radiation Regulations 1999 and Radiation Emergency Preparedness & Public Information Regulations 2001 we must ensure safe operations and make arrangements to respond to an off-site nuclear emergency. Our Nuclear Site Licence Condition 11 states: "…the licensee shall make and implement adequate arrangements for dealing with any accident or emergency arising on the site and their effects…"
3. Commercial – a safe company is also a successful company, so it is in our interests to have robust emergency arrangements.

In addition, EDF Energy Emergency Arrangements are approved by the Office for Nuclear Regulation under a license instrument.

Processes and practices are in place to ensure ongoing development and maintenance of the emergency arrangements.

EDF Energy Nuclear Generation's emergency arrangements form part of a line of defence for the improbable event that robust measures have not been sufficient in preventing. The emergency arrangements are designed to deal with events which, though very unlikely, are reasonably foreseeable. All EDF Energy Nuclear Generation's sites have operator plans as defined by Regulation 7 of Radiation (Emergency Preparedness & Public Information) Regulations. These provide the principles of the site emergency arrangements and the site emergency response guidelines for emergency role holders. These detailed plans are designed to be sufficiently scalable to provide the base from which an extended response to more serious events can be developed.

Regulation 9 of Radiation (Emergency Preparedness & Public Information) Regulations explains the requirement on the Local Authority to prepare an off-site plan for any premises with an operator's emergency plan. The off-site emergency plan is an integrated emergency management document to bring together the emergency arrangements of all the off-site agencies with a role to play in the intervention of an off-site nuclear emergency. EDF Energy supports external stakeholders ensuring an integrated approach to emergency management.

6.1.1 Organisation of the licensee to manage the accident

All of EDF Energy Nuclear Generation power stations' emergency arrangements are developed in line with an EDF Energy Integrated Company Practice; where clear responsibilities and accountabilities are published, highlighting the specific roles assigned within the business to manage the emergency arrangements.

The objectives of the emergency arrangements are:

- To enable the situation and the extent of hazards to people and the environment, on-site and off-site to be determined, in order to provide protection measures and reassurance.
- To enable the event to be managed on-site so as to ensure that a safe and stable plant condition is established.
- To notify those off-site who need to be informed.
- To provide advice to those off-site organisations who have the responsibility for the protection of the public and the need for protective measures to be taken, if any.
- To provide information about the event to the public through the media.
- To enable the business of the company to be secured.

It is an EDF Energy Nuclear Generation policy that the emergency arrangements will be generic and similarly implemented across all nuclear sites and other locations. Locally agreed exceptions to the generic emergency arrangements can occur which take into account geographical or specific local issues. Standards used for managing the emergency arrangements will be traceable back to national and internationally recognised practices or quality standards. The aforementioned process ensures continuously improving arrangements and so optimum intervention at any given time.

Emergency Preparedness Engineers oversee the establishment and maintenance of emergency arrangements at each of EDF Energy's nuclear power stations utilising central guidance in the form of company processes and procedures. The emergency arrangements are regularly reviewed, experience is captured, lessons identified and proposed changes are adequately considered and communicated before implementation.

6.1.1.1 Staffing and shift management in normal operation

Maintaining adequate staffing levels is critical to the organisation's ability to maintain its essential functions. Posts and roles essential to the continued safe operation of the nuclear fleet have been identified and, should it become necessary, actions will be taken to implement an 'essential staff only' regime to ensure the continued manning of essential posts and roles by suitably qualified and experienced personnel.

It should be noted that based on learning from other external events, emergency scheme staff with a decision making role will be EDF Energy employees who are suitably qualified and experienced personnel. It is permissible following the completion of the required training for contract staff to fulfil supporting roles within the emergency scheme.

The number of persons on site during a normal day is approximately 500-600 people, this includes contract staff. During an outage this figure will increase.

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6.1.1.2 Plans for strengthening the site organisation for accident management

In line with the company's generic approach to emergency planning, each EDF Energy Nuclear Generation power station adopts the emergency organisation depicted below Figure 6.1:

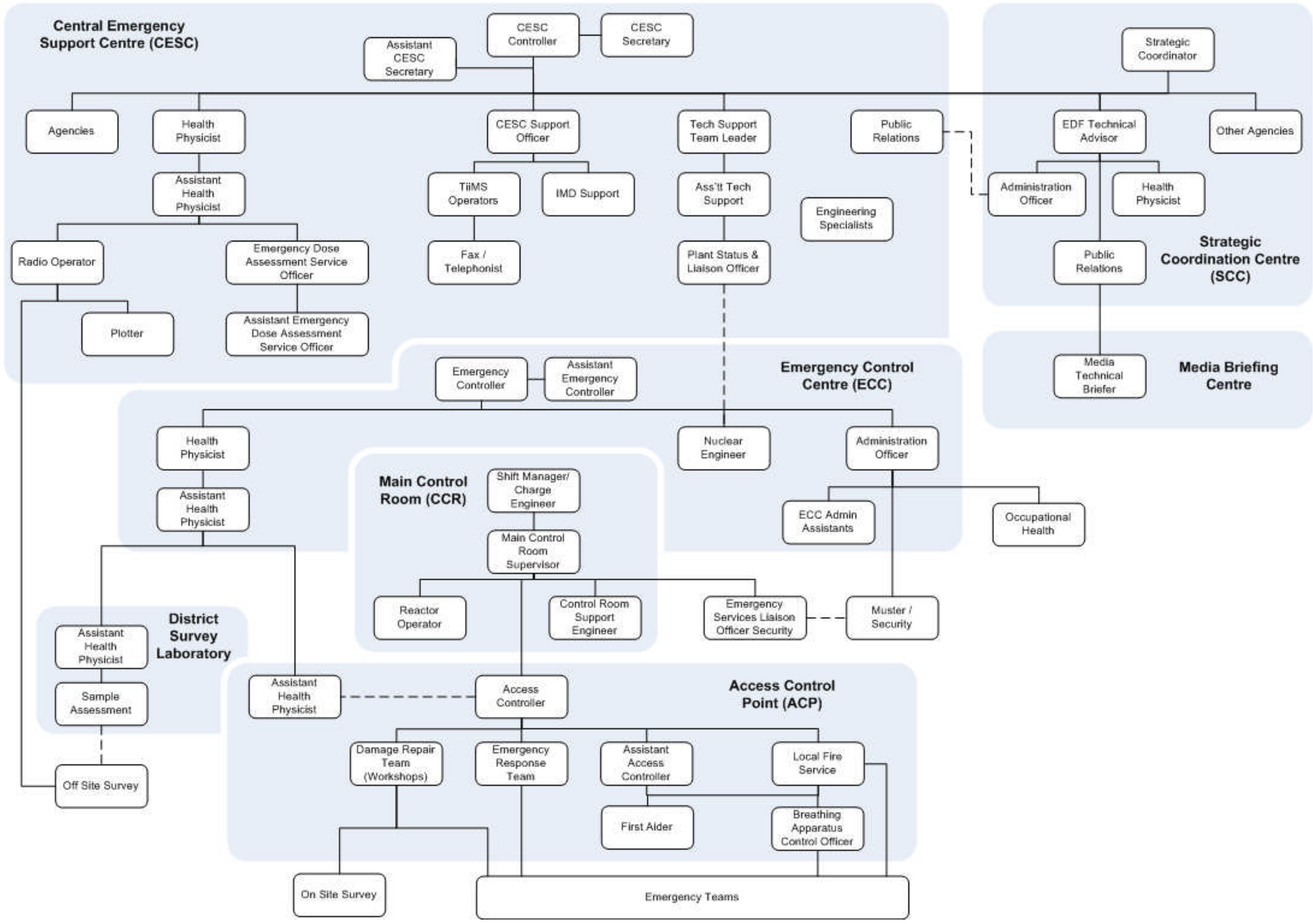

Figure 6.1: EDF Energy Generic Emergency Response Organisation

EDF Energy Nuclear Generation has adopted two declaration states which are as follows:

1. Site Incident is a hazardous condition which is confined within the boundary of a Nuclear Licensed Site. A site incident could be an accident that is not necessarily nuclear in nature, but possibly a fire or a chemical incident. It may involve the plant becoming hazardous in some way but with no release of radioactivity to an area outside the site boundary.
2. Off-Site Nuclear Emergency is a hazardous condition which results in or is likely to result in the need to consider urgent countermeasures to protect the public outside the site security fence from a radiological hazard. A site incident will usually need a more limited response than an off-site nuclear emergency.

During an emergency of either type, the following centres operate on the station site, working together to provide a co-ordinated and focused response. The centres are detailed below:

Main Control Room

Within the main control room there are dedicated facilities to enable the initial management of the site, take command of the response organisation and interface with external support during an emergency. Once the duty Emergency Controller takes responsibility, the main control room will be used to manage and co-ordinate the ongoing activities in the damaged area of the site and to make the plant safe. The facilities include maps, station procedures, drawings, communications equipment, tenability monitoring equipment, wind speed and direction indicators, plotting equipment, log sheets and general stationery. The initial management of the incident will normally be the main control room, however should the need arise an alternative indication centre is available and is similarly equipped.

Emergency Control Centre

The emergency control centre at Sizewell B is a dedicated facility to enable the site to be managed, take command of the internal response and interface with external support during an emergency. Should the need arise an alternative emergency control centre is available.

The basic equipment provided in the emergency control centre includes maps, station procedures, drawings, communications equipment, tenability monitoring equipment, wind speed and direction indicators, plotting equipment, log sheets and general stationery.

The emergency control centre staff will include the following key personnel available on a 24 hour standby rota to become operational as part of emergency arrangements:

- Emergency Controller;
- Emergency Health Physicist;
- Nuclear Engineer;
- Assistant Emergency Controller;
- Emergency Administrative Officer;
- ECC Communication Officer;
- ECC Support Staff;
- Emergency Chemist;
- Damage Repair engineer;
- Cascade officer.

Sizewell B also has a Technical Support Centre located in a room close to the emergency control centre. The role of this cell is to monitor plant and reactor conditions.

Access Control Point

For any event which creates an uncontrolled hazardous area, an entry and egress point will be established to enable command and control activities to be carried out safely in the area. The control point will be located as appropriate for the event, taking into account the prevailing conditions. In its simplest form this may be a single barrier, e.g. in a road for minor fires.

For all events a dedicated access control point facility is available and will be established to provide safe, controlled and rapid access to the affected area. Should the primary access control point be untenable an alternative access control point is available. All access to the affected area will be made through an access control point. Exceptionally other routes may be used but only with the agreement of the access controller.

The access control point and its alternative are equipped with means of communicating directly with emergency teams and the main control room. There is adequate space, equipment and facilities for the contamination, radiation dose and breathing apparatus control necessary for the safe and effective dispatch and reception of emergency teams, including emergency services, and for the initial treatment of casualties.

Site Access and Egress Control

Within the security gatehouse there are dedicated facilities to enable the site to be secured, initiate the roll call and manage access and egress from the site including the emergency services. The facilities include: maps, emergency procedures, communications equipment and tenability monitoring equipment.

Declaration of an event

The main control room is manned at all times and has access to detailed information on the state of the plant. In the event of this information indicating abnormal conditions the shift manager will carry out an immediate investigation and assessment. If the situation demands, the shift manager will initiate actions in accordance with the conditions for declaring a site incident or an off-site nuclear emergency.

Depending upon the nature and duration of an accident the emergency organisation may evolve in three stages:

Stage 1 begins with the declaration of a site incident or off-site nuclear emergency. Trained staff from the nuclear power station forms a site emergency response organisation under the command of the Emergency Controller. The Emergency Controller is responsible for initiating the emergency actions to be taken by EDF Energy staff, and for alerting the off-site organisations which have responsibility for countermeasures to protect the public.

Stage 2 occurs when EDF Energy Nuclear Generation establish a Central Emergency Support Centre at the EDF Energy offices located in Barnwood, Gloucestershire. For an off-site nuclear emergency a Strategic Co-ordination Centre and associated Media Briefing Centre will be activated by the Police.

During a Site Incident, the Central Emergency Support Centre will provide technical support to the nuclear power station as necessary and, at the appropriate time agreed with the Emergency Controller, take over responsibility for off-site monitoring for radioactive release to continuously assess the possibility of the site incident developing into an off-site nuclear emergency.

During an off-site nuclear emergency the Central Emergency Support Centre, staffed by EDF Energy staff, together with other relevant organisations, will at the appropriate time as agreed with the Emergency Controller, take over control of the deployment of the off-site monitoring resources, assessment of the need for countermeasures and provision of expert advice to the Strategic Co-ordination Centre. The Central Emergency Support Centre will also co-ordinate the technical support to the station.

Stage 3 occurs only during an off-site nuclear emergency, when the Department for Energy and Climate Change appoints a Government Technical Adviser who, after briefing, will assume the responsibility for giving authoritative advice to Police, Local and Health Authorities, and other off-site organisations on any actions necessary to protect the public. The EDF Energy Nuclear Generation Company Technical Adviser and team will support the Government Technical Adviser in this role and continue to liaise with the Central Emergency Support Centre Controller. The Government Technical Adviser will be the principal Government spokesperson for briefing the media.

Emergency Response Staffing

EDF Energy Nuclear Generation emergency arrangements have been developed, embedded and tested against minimum staffing levels for emergency response roles for each nuclear power station in the EDF Energy nuclear generation fleet.

The basis for the current emergency scheme staffing levels was established through systematic analysis. This analysis used an assessment of risks and hazards to identify emergency task requirements. These emergency task requirements were, in turn, used to identify emergency scheme staffing levels and enhancements required for equipment and training.

Emergency plan actions and guidelines have been designed against a minimum staffing resource and with the objective for emergency response to be effective using staff from the power station for the initial 60 minutes of an emergency. The staffing resources are derived for a reasonable foreseeable accident involving a reactor event and release of radioactivity. For other events the resources will be managed to provide additional expertise or staffing levels as required. The emergency roles are staffed from both 'Shift Staff' who would be on-site at the time of an emergency and from 'Standby Staff' who may not be on-site at the time of emergency, but who can attend site within a 60 minute timeframe.

Shift Staff: A record of the current shift staffing is available from the main control room indicating cover for emergency roles which will meet or exceed the minimum manning levels defined. The operations team leader maintains the staffing level for the next 24 hour shift cycle. Any changes in staffing levels during this period will be communicated to the Central Control Room. Part of the shift handover procedure is to ensure that the emergency role responsibility has being passed on effectively.

Sizewell B Power Station is a single pressurised water reactor and as such there are some acceptable differences in the sites emergency arrangements compared to the advance gas cooled reactors owned by EDF Energy.

The site emergency team capability has an Emergency Response Team fully staffed on a shift basis and access control point support, staffed by day post holders in an appropriate discipline.

The actions carried out by site emergency team members are predominately those required by their normal post overlaid with skills in fire fighting, search, rescue, first aid and radiation protection monitoring. It is considered within the current emergency plans that the tasks of site emergency team will be supplemented by specialist resources such as the local Fire and Rescue Service, when the event develops. It is expected that the local emergency services and standby support should be active on site within 60 minutes of a declaration.

Maintaining the site emergency team capability relies on utilising the resources from the off-duty damage repair teams and the off-duty emergency response team, both of which would have a high likelihood of availability. Additional resource could be provided from other unaffected stations this would be organised by the Central Emergency Support Centre.

The emergency scheme role holders are subject to an ongoing alignment programme to improve scope and depth of competence. In the current phase the programme is reviewing the training and competence levels associated with site emergency team capability.

In addition to standby damage repair team it is recognised by all EDF Energy nuclear sites that additional personnel can be called in when a site incident or an off-site nuclear emergency is declared. The site emergency controller is responsible for anticipating where resources are to be deployed. The supporting staff services may be required immediately or within a few hours of an emergency, depending on the event to provide additional specialist services and supplement the existing emergency teams.

During a protracted emergency, beyond a few days or maybe weeks, it is assumed other role holders from unaffected EDF Energy Nuclear Generation sites would provide support. The benefit of adopting a generic EDF Energy Nuclear Generation approach to the emergency arrangements is that it is possible to call upon emergency scheme responders from other sites. Though it is recognised some roles benefit from a detailed knowledge of their power station when responding to an event, the generic nature of the arrangements makes it possible for people to respond effectively to other affected sites and meet the objectives of the emergency plan.

Although not part of the generic emergency roles, the role of assistant health physicist in the access control point is being staffed on a call in basis in most cases by a member of the duty health physics rota.

EDF Energy Nuclear Generation have considered the risk of loss of a significant proportion of the duty Incident Response Team staff during an emergency and would additionally utilise the duty standby emergency response team staff to provide the initial response.

EDF Energy Nuclear Generation works on the basis of having sufficient trained emergency response staff members available at any given time.

Sizewell B does not currently have an Emergency Communications Co-ordinator role within their generic emergency control centre staff complements. Sizewell B recognises the benefits gained from implementing this role and are working towards training staff members.

6.1.1.3 Measures taken to enable optimum intervention of personnel

Command and Control

Specific practices and techniques are utilised to ensure efficient decision making during an emergency response. To do this EDF Energy staff employ a predetermined way of working that is considered and structured. This is known as command and control. The command and control approach means:

- Creating an environment focussed on response and direction.
- Adding detail as the focus and action move down the chain of command.
- There is a faster, more urgent response.
- Staff will be instructed on what to do.

- It is essential that information is communicated and kept up to date.
- Any queries are raised in a timely manner and responded to immediately:

To allow an internal emergency response organisation to function correctly and appropriately it is important to have a command chain structure; so that each part of the organisation understands to whom they are reporting to and from whom they will receive information and tasks. The whole emergency response organisation will be guided by the focus points of the emergency controller. Each layer of the command chain will align their focus to that of the emergency controller. The emergency controller will establish the strategy for the response to the event by use of focus points. The tactics, actions and delivery of operations will be determined by the team leaders and team members of the emergency response organisation. The shift manager will be closely involved in developing the overall strategy for the site with the emergency controller.

All emergency scheme role holders are trained and aware of command and control techniques. This aspect of the emergency response is regularly demonstrated and assessed.

Dose Control

During an off-site nuclear emergency one of the major hazards that has to be managed is radiation. In dealing with radiation our overriding principle is keep exposure as low as reasonably practicable. This principle seeks to ensure that during all emergency activities exposure is kept to a minimum, considering all factors involved. Our priority is to protect everyone involved or affected by an emergency in any way, which includes:

- The public.
- Emergency teams, including the emergency services.
- EDF Energy staff.

ALARP principles are employed throughout the emergency activities lifecycle. ALARP principles influence the design of tasks, the associated preparation and briefing and the approach followed during all tasks.

There is legislation covering exposure to radiation in an emergency. The 2001 Radiation Emergency Preparedness and Public Information Regulations impose a duty on nuclear operators to prepare emergency plans and adopt a system of controlled exposures to radiation which would exceed the occupational dose limits. The three fundamental principles of time, distance and shielding are used to minimise exposure:

- Time – the time that people are exposed to radiation should be as short as possible.
- Distance – the distance between people and the radioactive source should be as large as possible.
- Shielding – there should be as much protection between people and the radiation as possible.

Whenever possible the initial control of radiation exposure during an accident or emergency should adhere to the practices adopted during normal operation and the radiation controls within the Ionising Radiation Regulations 1999. In particular whilst dose control is being maintained within these statutory dose limits the following factors must also be taken into account when setting dose control constraints:

- The current year's occupational exposure for each of the intervention personnel.
- The dose limit for women of reproductive capacity where appropriate. (13mSv in any consecutive 3 month period).
- Any unmeasured exposures already incurred (e.g. internal exposure from inhalation).

Therefore the maximum whole body dose the access controller can authorise without reference to the Emergency Controller is 10 mSv which is a company dose limit (lower than specified by the government). The dose constraints selected for each task will be justified, allowing the teams entering the incident area to effectively perform their duties. The teams must perform their duties in a manner that ensures that all doses are kept as low as reasonably practicable.

Doses in excess of 10 mSv and the use of Radiation (Emergency Preparedness & Public Information) Regulations emergency exposures must be authorised by the emergency controller, after seeking advice from the emergency health physicist. All team leaders must report to the access controller whenever they encounter dose rates in excess of 50mSv per hour and also whenever any individual team member is likely to exceed 10mSv whole body dose. As the incident progresses and the radiological conditions are more clearly established, the access controller can adopt more conservative dose limits for the performance of damage repair duties and other less essential operations.

The access controller must be aware, when deploying intervention teams combining EDF Energy staff and emergency services personnel, that there may be different exposure limits allowed by their employers.

The access controller, until advised otherwise by the relevant emergency health physicist, will control exposure on the results of whole body gamma radiation measurements. He will assume that skin and internal doses are less limiting provided that breathing apparatus and protective clothing procedures are properly enforced.

The details of any instances of potential exposure arising from failed procedures or protective clothing will be recorded. When it becomes apparent that the doses to intervention personnel are likely to exceed the access controller's authorisation limit, the access controller must inform the emergency controller, and ask if the team members are to:

- Stand down.
- Have their authorised dose limit increased up to a limit of 100mSv; or
- Should he ask for volunteers willing to exceed their 100mSv limit up to a maximum of 500mSv in order to save life or prevent a major release of radioactivity.

The actions decided and the names of volunteers will be recorded in the access control point, central control room and emergency control centre logs. Volunteers must be made aware of the significance of the risk associated with the doses for which they have volunteered. The access controller will only authorise entry to the incident area to those persons performing essential duties and he will limit the size of entry teams to the number of persons sufficient to perform the assigned duty effectively.

Welfare

As well as managing exposure to the radiation hazard the emergency controller will consider the general welfare of all staff on site and when to replace emergency role and shift personnel on duty. Such a decision will have to be made early to ensure that oncoming staff are informed and provided with access to the site. A comprehensive handover between outgoing and incoming staff is required under the current arrangements. The current arrangements assume ongoing response staff can access site or in extreme cases staff will be available from other sites to support.

Staff involved in serious incidents may require some form of post traumatic stress counselling. EDF Energy has an employee support programme for all staff to use for counselling which would include traumatic events. The Nuclear Generation occupational health team are all trained in basic debriefing skills post events. A response to an event would be co-ordinated by the Chief Medical Officer. This aspect of the response would be co-ordinated by the Central Emergency Support Centre.

6.1.1.4 Use of off-site technical support

The nuclear industry continues to learn the lessons from emergencies and accidents all over the world. The events at Three Mile Island in the United States in 1979 conveyed the importance of supporting an affected nuclear site by adopting off-site technical support.

EDF Energy Nuclear Generation utilise this approach and the overarching objective of the Central Emergency Support Centre is to relieve the affected station of the responsibility for liaison with outside bodies on off-site issues in as short a time as possible after an accident, thus allowing them to focus on fixing the issue at hand.

The Central Emergency Support Centre will also acquire and assess all necessary technical data that has a bearing upon the radiological hazard to the public and pass clear advice based upon that technical assessment to the Strategic Co-ordination Centre in such a form that those at the Strategic Co-ordination Centre can make informed and timely decisions on the need to take action to protect the public. The radiological assessment team primarily discharges this function.

The Central Emergency Support Centre includes key roles for central support to any of the nuclear power stations in the EDF Energy fleet, available on a 24hr standby that will become operational within one hour of notification.

For protracted emergencies these roles will be supported by assistants and specialists available on standby within a similar timescale as the aforementioned roles. The Central Emergency Support Centre is under the overall direction of the Central Emergency Support Centre Controller who is responsible for ensuring that this centre operates in such a way as to fulfil its functions of serving and supporting the affected site and Strategic Co-ordination Centre if standing.

The Central Emergency Support Centre also provides a technical support service to the affected station and acts as the focal point for routing advice and material assistance to the affected station. The technical support team primarily discharges this function. The Central Emergency Support Centre will also take responsibility for the onward transmission of monitoring results and the outcome of radiological assessments to external agencies such as Food Standards Agency and to the Strategic Co-ordination Centre, as well as supplying information to the Company's Chief Officers. This function is primarily discharged by the Information Support Team using EDF Energy's Emergency Management Information System.

The EDF Energy emergency organisation adopted within the Central Emergency Support Centre has been demonstrated to be flexible from the differing events that have been supported historically; which include protestor action, on-site issues, fuel shortage response and most recently the companies support to events in Fukushima. In each of these events the internal generic response organisation has been appropriately arranged to suit the specific support required. EDF Energy Nuclear Generation has embedded a culture of support to such incidents and as such has the expertise and resource of all suitable staff in the Barnwood Office to call upon.

Current arrangements show that the minimum staffing levels of trained personnel for standby roles are met and staffing levels for each role are reviewed quarterly as part of a continual refreshment programme.

The Central Emergency Support Centre facility is also utilised by Magnox Generation Ltd who own a number of nuclear power stations. Some of these stations are located adjacent to EDF Energy Nuclear Generation stations; however these Magnox stations are non-operational. This facilitates effective communications between the companies, but also highlights the potential risk of both organisations requiring the facility to manage their own events at the same time. Contingencies are in place to mitigate this and the following advice is provided: Central Emergency Support Centre and Strategic Co-ordination Centre Handbook

- Primacy should be given to the site which has declared the most severe incident (i.e. an off-site nuclear emergency has primacy over a site incident).
- If all sites have made the same declaration then primacy should go to the company who arrives at the facility first.
- If staff from both companies arrive at the Central Emergency Support Centre then a decision on the manning, based on the types of incident, should be taken by the EDF Energy Central Emergency Support Centre Controller and the Magnox Controller or Assistant Controller

If there is a need for an additional facility due to the situations described above the second party should consider:

- Using the Strategic Co-ordination Centre Gloucestershire Police HQ in Quedgeley, Gloucester.
- Not taking over Command and Control.
- Using the Alternative Central Emergency Support Centre.
- Using an alternative facility.

6.1.1.5 Procedures, training and exercises

Procedures

A suite of different documents are utilised as part of emergency arrangements to control both preparedness and response activities to comply with applicable legislation.

Preparedness is defined as the organisational structure and associated activities that develop and maintain the emergency response capability.

Response is defined as the organisational structure and activities that are used when an emergency situation occurs. These include compliance documents, e.g. specifications, response guidance handbooks and emergency preparedness procedures.

The standard distribution of emergency planning materials is via electronic medium. Hard copy distribution is kept to a controlled minimum and primarily for storing at response locations. EDF Energy processes ensure that when a formal issue of each new version of emergency documentation takes place the existing version of the documentation is removed from circulation; both in its electronic and hard copy format.

In addition to the above documentation there is Sizewell B procedural guidance for beyond design basis events which is part of the station operating instructions.

Training

The training modules within the EDF Energy Nuclear Generation Generic Emergency Scheme Training Framework are based on the training needs analysis of tasks described in the Emergency Plan and Emergency Handbook. The modules cover a discrete area of procedures, skills and/or knowledge. A module may meet the needs of a number of different role holders who need knowledge or skills in that subject area. Within each module the objective may be differentiated by role. Testing of equipment is carried out by undertaking training modules specified for each emergency scheme role. This is managed and recorded via the standard EDF Energy electronic system.

The EDF Energy Nuclear Generation process for training is outlined in the steps below:

Role Orientation: all role holders will receive orientation for their new role irrespective of whether they are new to EDF Energy, emergency scheme or moving between roles. There are three main elements to this:

- Familiarisation with facilities;
- Provision of practical information, e.g. notification arrangements;
- Analysis and delivery of required training for those moving between or taking on an additional role.

Initial Training and Assessment:

Each emergency role will have a separate route through the training programme for their centre although several elements will be common across roles.

The programme is made up of modules drawn from the matrix of generic Emergency Scheme Training. The programme will involve both national and local provision and include some combination of:

- Role specific mentor guide and job aid;
- Attendance on courses, e.g. Breathing Apparatus training;
- Use of flexible learning materials, e.g. overview, centre/task specific modules;
- Local mentoring;
- Role observation;

- Role shadowing;
- Assessment.

Most station role holder initial training will be provided on-site using multiple methods with some provision of courses for station role holders on a national basis, i.e. the Nuclear Power Academy. Training will conform to the standards and expectations set by EDF Energy.

Assessment of initial training will be undertaken module by module, as an integral part of that training. The method of assessment selected will be appropriate to the objectives and the content covered, but may include a combination of the following:

- Paper or computer based tests using appropriate questions;
- Observed practical tasks or procedures in a realistic setting;
- Questioning by a certified instructor, assessor or internal regulator.

As part of qualification for role, all role holders will demonstrate suitability for and competence in role by participating in a shift exercise or equivalent. The prospective role holder will undertake the role in full and be observed by an assessor who will normally be an experienced practitioner in that role.

Continuing Assessment and Training

To maintain competence and compliance, the core competences for each emergency role will be assessed over a three year cycle. All role holders will be assessed on every competence for their role during this period. In addition there may be a small number of fundamental, personnel safety related competences for some roles that need to be assessed annually e.g. use of Breathing Apparatus.

The role specific mentor guide issued for each role acts as a log book for recording competence. Assessment of core competences will use a number of methods:

- Observation of tasks in exercises and performance assessments events.
- Observation of tasks set in a refresher training session, e.g. simulator.
- Use of computer-based knowledge checks.
- Paper-based tests drawn from initial training.
- Questioning by assessors, i.e. to cover scenarios outside of the scope of a specific exercise/event.

The assessment of core competences will be carried out by:

- Current emergency role holders who have met the requirements of the Umpire/Assessor role. Assessors will have normally completed training specific for umpires & assessors.
- Contracted personnel who provide assessment in specialised key skills or tasks that fall outside of EDF Energy Nuclear Generation core business, e.g. fire fighting, command and control.

Accrediting role holders:

Emergency arrangements training, follows the company systematic approach to training. However, as a non accredited programme, a graded approach is adopted with the methodology tailored to the needs of the emergency scheme and role holders.

A continuous improvement plan associated with adopting the above generic training process is currently ongoing at Sizewell B Power Station.

An evaluation of the current exercise and training associated with beyond design basis events was undertaken by the power station and concluded the frequency and content should be altered to reflect the needs of role holders more accurately. This is being addressed as part of normal company processes.

Exercising

The following describes the types of exercises, personnel involved and frequency of exercise type:

Table 6.1: Emergency Exercising Arrangements

Exercise Type	Description	Frequency
Assessment and Training Drill	An exercise limited in content to test/demonstrate one or two defined areas of the emergency arrangements, e.g. access control points, off-site survey and District Survey Lab, muster roll-call and site security for training purposes or test/develop skill base of participants.	As required
Shift Exercise	An exercise focused on the activities of the whole shift staff complement to demonstrate their ability to deal with the consequence of a simulated event. Areas of activity are limited to the Central Control Room, Access Control Point and Emergency Teams. Any support staff from days that could assist in these areas may be included for training purposes.	Annually
Desk Top Exercise	Focused on an emergency facility in operation and driven by simulating realistic inputs to the facility	As required
Full Scope Exercise	An exercise involving the whole of the nuclear power station. It may extend to full station roll-call and may include external agencies such as emergency services for training purposes. These exercises are not witnessed by the Office for Nuclear Regulation. These exercises are also used to ensure any training or new procedures associated with the emergency arrangements can be evaluated as part of internal regulation of standards.	Annually
Level 1	An exercise – usually annually- involving all nuclear power station staff, visitors and contractors, to demonstrate the adequacy of the current approved emergency arrangements to the Office for Nuclear Regulation. These exercises may involve emergency services and other external organisations. The extent to which the interface with the Strategic Coordination Centre and Central Emergency Support Centre in dealing with off-site implications is tested will be decided by EDF Energy Nuclear Generation or as required by Office for Nuclear Regulation	Annually
Level 2 (off-site plan)	These exercises are aimed specifically at demonstrating the functions of the Strategic Coordination Centre and Central Emergency Support Centre in dealing with off-site implications of an emergency on the basis of a defined input from the site. The Office for Nuclear Regulation will provide a Government Technical Adviser. EDF Energy Nuclear Generation, the Local Authority and Emergency Services will normally be involved to test the interactions between various parties and the decision making process. The aim will be to demonstrate the function of the Central Emergency Support Centre and Strategic Coordination Centre once every three years.	Every 3 years
Level 2 (support station)	A team from the dedicated support station consisting of Emergency Controller, Health Physicist, Admin Officer and Communications Co-ordinator will respond to the Strategic Coordination Centre in the event of an off-site nuclear emergency being declared at the affected power station. This is tested on a	Every 3 years

Exercise Type	Description	Frequency
	three yearly basis and involves the aforementioned personnel responding and operating within the designate Strategic Coordination Centre facility.	
Level 3	A Level 2 exercise, nominated by Department for Energy and Climate Change and the Scottish Executive, will be enhanced to become the relevant Level 3 exercise and the aim will be to have one such exercise within the nuclear industry each year. As per a Level 2 exercise, but additionally includes Central Government response and interactions between Government Departments and Ministers.	One such exercise within the nuclear industry each year
Counter Terrorism Exercise	An exercise – usually annually- involving all station staff, visitors and contractors, to test the adequacy of the site and company Counter Terrorism plan arrangements to the Office for Nuclear Regulation. These exercises may involve emergency services and other external organisations.	Annually

The exercising regime aligns with the requirements of The Radiation Emergency Preparedness and Public Information Regulations.

In order to ensure that the full breadth of the arrangements is adequately exercised, EDF Energy Nuclear Generation manages a rolling programme of exercising to include the alternative response centres and back-up contingencies.

In addition to exercise drills, the management team at the nuclear power stations aim to undertake at least 6 full scope emergency exercises per year. One of these exercises is formally witnessed by the Office for Nuclear Regulation as the annual Level 1 exercise. In addition to the Level 1 exercise, the station is required to complete a Level 2 demonstration exercise every three years.

For all the witnessed exercises the team of inspectors from the ONR and assessors from EDF Energy will review the adequacy of the emergency arrangements and highlight any identified areas for improvement. A timetable of improvements is established in consultation with the Office for Nuclear Regulation and EDF Energy. This is subject to review at an annual emergency arrangements review meeting between the Office for Nuclear Regulation and Station. This rigorous annual review process ensures the station emergency arrangements satisfy the site licensing requirements.

The emergency exercise planning and administration documentation contains information regarding the processes defining the activities that take place when planning and reviewing emergency exercises and defining the activities for modular exercises. This includes timescales, activities, tasks, responsible personnel and completion dates. Following an exercise thorough debriefs take place to ensure lessons and improvements are identified, captured and any resulting actions recorded.

Conclusion SZB 6.1: EDF Energy has detailed robust arrangements for Emergency Response which are subject to a programme of continuous improvement and exercised as required by standard procedures and regulatory demand.

Based on the learning from the Japanese Earthquake, the subsequent EDF Energy Nuclear Generation review of Station safety cases and examination of the associated risks on plant, it is not believed the fundamental risk profile on the nuclear power station has changed. Therefore current arrangements remain fit for purpose. However, as part of EDF Energy standards we ensure any lessons identified by real events and exercises (internal/external) are reviewed and built upon within our arrangements.

Consideration SZB 6.1: EDF Energy will consider how lessons identified from Japan and credible beyond design basis events can be reflected in our facilities, procedures, training and exercise programmes. Utilising experience from other emergency response organisations and the military, EDF will consider enhancement of its staff welfare, human factors and emotional aspects associated with emergency response.

Consideration SZB 6.2: Complete Implementation of Emergency Control Centre Communication Co-ordinator role.

6.1.2 Possibility to use existing equipment

6.1.2.1 Provision to use mobile devices (availability of such devices, time to bring them on site and put them into operation)

Once a site declares an off-site nuclear emergency the Emergency Plan is initiated and an emergency response organisation within the company and external agencies is mobilised. This includes the Central Emergency Support Centre which brings together a team of experts to deal with the emergency. In a severe accident situation the technical team at the Central Emergency Support Centre, supported by the central technical organisation would consider the strategies and formulate an implementation plan. It is the Central Emergency Support Centre organisation which is able to mobilise the any required back-up equipments, procure other equipment consumables. To aid the procurement process there is a standby team of procurement specialists who are part of the Central Emergency Support Centre arrangements.

The lessons identified from the Japanese Earthquake so far highlight the associated issues that degradation of external infrastructure can have on access to and egress from site. The original intent of the off-site equipment focused on specific issues with the plant. The events in Japan have shown that all areas of plant vulnerable to an off-site hazard should be taken into account when designing the off-site equipment requirement.

6.1.2.2 Provisions for and management of supplies (fuel for diesel generators, water, etc)

One of the roles of the Central Emergency Support Centre is to coordinate EDF support cells such as the supply chain to procure essential supplies. The technical support team within the Central Emergency Support Centre is required to acquire materials, equipment and other resources requested by the station this will be done at the earliest opportunity should the need arise. If there are infrastructure issues impacting access to the site this will be recognised as a constraint and an alternative means of delivery will be immediately reviewed.

The judgement is that essential stocks can be procured within the 24hr mission period to replenish the relevant essential systems. However there are uncertainties, for example, the effect of a severe external hazard on transport and communications as noted above, and the detailed arrangements for delivering and offloading the quantities of consumables that may be required.

The essential supplies for the site are identified in the station operating instruction. The quantity of essential stocks is discussed in more detail in Chapter 5 (section 5.1.3.4.2) and Chapter 1 (section 1.3.4.4.3).

Conclusion SZB 6.2: EDF Energy has a range of on and off-site equipment which it can use to respond to emergencies which could affect the site. The provision of this equipment and support is a maintained and formal process within the organisation. This includes arrangements to maintain the essential supply of consumables during and emergency. Based on the lessons from Japan there are areas where EDF could consider further enhancements to equipment and its critical supply.

Consideration SZB 6.3: EDF Energy should consider whether further resilience enhancements to its equipment and critical supplies which take onboard lessons of extendibility and issues that prolonged events could present are appropriate.

6.1.2.3 Management of radioactive releases, provisions to limit them

As part of the existing company Emergency Arrangements there are plans in place for the management of radio active releases and provision to limit the effects of them.

The containment systems contribute to mitigating the consequences of severe accidents and thus to achieving an acceptable level of safety.

Systems are provided that directly contribute to reducing the release of radioactivity to the environment following severe accidents. They include the primary containment building, containment isolation systems, the building cooling and sprays, and a fire suppression system. The reactor building and the containment isolation systems together reduce the potential leakage of radioactive materials to the environment, following a release within the reactor building, to a very low level. The sprays assist in the removal and subsequent retention of fission products from the reactor building atmosphere. This is achieved by providing an extensive coverage of the reactor building atmosphere with water droplets.

In addition to the main safeguards systems, activation of a fire suppression system will delay containment failure, and hence, reduce societal dose uptake.

A Detailed Emergency Planning Zone is provided around a nuclear installation, where there is the potential for an off-site release of radioactivity that would require implementation of countermeasures.

The Detailed Emergency Planning Zone is defined on the basis of the most significant release of radioactive material from an accident, which can be reasonably foreseen. In the event of an accident being larger than the reasonably foreseeable event, arrangements are in place for extending the Detailed Emergency Planning Zone consistent with the concept of 'extendability'.

A number of emergency preparedness activities take place within the Detailed Emergency Planning Zone around EDF Energy Nuclear Generation sites. As part of the company's responsibility under Radiation (Emergency Preparedness & Public Information) Regulations, prior information in the form of a calendar is produced and distributed to residents within the zone, these contain information about what to do in the event of an emergency event and other factual information regarding the radiation. Potassium iodate tablets are also distributed to residents within the area. Residents are also given the option to be added to a Public Emergency Telephone Information System, which would notify them of what action to take in the event of an emergency at their local nuclear power station.

6.1.2.4 Communication and information systems (internal and external)

The station has substantial diversity of communications media to ensure requirements are met during a response situation. The on-site links include the use of the station's routine telephone networks - Private Automatic and Branch exchange lines, and a number of BT telephone lines together with dedicated direct wire telephones linking the on-site response centres. Across the nuclear power station the UHF radio system is in constant use by the operations and security staff.

Off-site communication links are established to enable adequate communications from both the main response centres and the back-up facilities.

Nuclear Industry Airwave Service - this is a system which is predominantly used for communications between the Survey Vehicles and the Emergency Control Centre, and then the Central Emergency Support Centre. The Nuclear Industry Airwave Service is part of a national radio system, which has both security and inherent resilience built in to it, and is utilised by emergency response organisations. The system consists of:

- Mobile Terminals in the survey vehicles.
- Airwave radios are currently located in Emergency Control Centre, Standby Emergency Control Centre, Central Emergency Support Centre and handheld radios are available in the security lodge.
- Airwave Base Stations transmit and receive information.
- EDF Energy Wide Area Network provides connections to the data servers at Barnwood.
- Dispatcher Terminals located in the Emergency Control Centre, Standby Emergency Control Centre and Central Emergency Support Centre which are used to communicate with Survey Vehicles.

Site Siren and Public Announcement – after an emergency is declared the site emergency warning signal will sound for a minimum of 40 seconds and announce a standard message over the PA system. The announcement will be made by the Shift Manager or the Emergency Controller.

Emergency Plume Gamma Monitoring System - provides detection of high and low frequency radiation, by means of monitoring equipment situated around the perimeters of the nuclear power station. The system then alarms in the Central Control Room and Central Emergency Support Centre when high levels are detected.

Rapid Reach Notification System- on the declaration of a site incident or off-site nuclear emergency the affected nuclear power station activates the alert using the Rapid Reach System, which automates the process of calling out duty personnel by paging and phoning staff on various stored numbers simultaneously. Each call requires positive response from the recipient to indicate acceptance or rejection of the call. A display on the computer shows progress of the callout in real time.

Pager System - emergency scheme staff are issued with a pager as the primary form of notifying them to respond to an emergency.

An on-site pager system independent of external service providers also exists though this is not claimed as part of the emergency arrangements equipment.

Public Emergency Telephone Information System - a web based emergency notification service that can dial and transfer messages to landlines, mobiles, faxes, and email recipients and pagers. To activate the system users activate a pre-determined scenario.

Mobile Privileged Access Scheme - mobile telephone networks can become overwhelmed by a high concentration of calls that often occur immediately after an emergency. EDF Energy are currently requesting special mobile telephone SIM cards which allow a higher priority of mobile telephone network access during events where the scheme may be enacted, barring public users. These SIM cards will be made available to staff who could form part of the emergency response.

Advanced Data Acquisition System muster system – electronic access and egress management system for all EDF Energy sites utilised as part of the electronic muster.

The Incident Information Management System - via a direct link on the EDF Energy IT network. This is a computer-based information system designed for emergency situations. Its purpose is to supply the same information to many users at the same time, so ensuring that everyone uses identical, up-to-date data. The system is able to process large amounts of changing information quickly and accurately. It stores all of the information it transmits providing an auditable trail. Data entry on the system is only carried out within the Central Emergency Support Centre. The information management system is available to external responding organisations as well as internally to EDF Energy.

The systems for communication employed by EDF Energy both internally and externally provide a good level of resilient communications. This is based on the opinion of EDF Technical Teams who maintain the technologies and emergency planning role holders who use the systems, based upon historic use and inherent resilience within the systems design. For Nuclear Industry Airwave service, this is also based upon the use of the emergency services that utilise the Airwave Radio System operationally.

Each of the primary communication vehicles, including telephony, mobile telephony, Nuclear Industry Airwave service and UHF radio are separate systems and supporting infrastructure, providing a high level of diversity and robust communications. Where there are potential single points of failure or areas identified for further review then considerations have been included within this report.

6.1.3 Evaluation of factors that may impede accident management and respective contingencies

6.1.3.1 Extensive destruction of infrastructure or flooding around the installation that hinders access to the site

EDF Energy are conducting a review of access control points and emergency control centres during or after external events, and on operators' actions following the events, to provide confirmation that access routes are viable. The review will consider the external hazards:

- Seismic,
- Extreme wind,
- External flooding,
- Industrial hazards,
- Extreme ambient temperatures,
- Electromagnetic Interference / Radio Frequency Interference,

- Lightning,
- Drought, and
- Bio-fouling.

Access to the Sizewell site is via a public, single carriageway. There are multiple access routes to buildings within the site.

In the event of damage to the single approach road or public road access for goods and personnel could be gained by sea or air.

With respect to stock replenishment following a seismic event it is evident that road condition may be a concern compounded by any effects of flooding which may mean that any stocks would need to be flown or shipped in.

Diesel stocks are available on site but the movement of fuel between tanks would require further consideration.

Conclusion SZB 6.3: The review of access to site is currently being carried out through the formal periodic safety review process. Based on the initial analysis carried out for this report the existing emergency arrangements are scalable to allow for the management of response should access be disrupted. This would be achieved through the use of alternative transportation methods, either land, sea or air dependant on the scenario.

Consideration SZB 6.4: Ensure any findings from the periodic safety review are incorporated into the emergency arrangements where appropriate

6.1.3.2 Loss of communication facilities / systems

Communication is a vital component of emergency response. In the unlikely event of an emergency occurring one of the most important communications to initiate the required response is 'initial notification', both to EDF Energy staff and externally to key stakeholders. There are various communication systems utilised by EDF Energy and key stakeholders both during normal operations and response to emergencies. Robust communication protocols, procedures and systems are imperative for successful emergency management.

As detailed in section 6.1.2.4, EDF Energy Nuclear Generation employs several methods of communication. This section of the document highlights the systems used for effective communication, the current levels of resilience in place and highlights where the stress test has identified points of potential failure against improbable emergency scenarios.

<u>Notifications</u>

Personnel on site: the site emergency warning signal will alert staff on site to muster in the event of an emergency. The emergency warning signal is an important element in alerting staff to muster and to enact the emergency response personnel. In the event that site emergency siren was unavailable for example during loss of power or a fault, then loud hailers would be used. The control room can also initiate a group call on the on-site pager system which will be received by all personnel (who each carry a pager) with a predefined message to either internally or externally muster as necessary (in the event of a site incident or fire respectively).

Emergency responders: the shift manager will instruct a member of the central control room team to notify all off-site emergency responders. Notifications will be made through initiation of the Rapid Reach System, dedicated notification contact numbers and also through the Barnwood Alert Centre.

Off-Site Responders: the Alert Centre is staffed continually and will receive the notification from the affected power station. They will then cascade the notification to activate the central emergency support centre and inform key off-site agencies. A back-up Alert Centre also exists.

<u>Rapid Reach (Notification)</u>

When the Rapid Reach system is activated it automatically makes telephone calls to each member of the emergency team, first by use of their pager and, if this fails to gain a response, the system will automatically start a process of trying known phone numbers for that person. Should the system fail to make contact with the first person on the list for that role it will phone, in sequence, other known personnel who are suitably qualified and experienced personnel for that post.

Rapid Reach is a separate system at each site, therefore there is built in resilience, if Rapid Reach fails at one site the support station's Rapid Reach system can fulfil the notification process. If Rapid Reach becomes disabled at further stations then notification will revert back to manual procedures whereby station staff will use the emergency responder contact lists available, contacting staff via telephone / mobile.

Off-Site Pager System

Although the system is historically resilient, it is known that there are some areas of the country with poor mobile telephone network coverage could mean that staff are either delayed in being called or will be identified by the system as unavailable, due to coverage of signal in the locality. The resilience for this issue is for emergency responding staff to be contacted by landline telephone.

Telephony

It is recognise that telephony is a primary communication method for EDF Energy internally and for communication with key stakeholders, including emergency response organisations. All of the EDF Energy Nuclear Power Stations and Barnwood Office, which contains the Central Emergency Support Centre, have several levels of redundancy for its telephone communications which reflect its importance in successful response to incidents. Each of the EDF Energy sites involved in emergency response has the following levels of resilience for telephony:

- Two telephone exchanges, of which all emergency facilities have dual connectivity.
- System resilience through multiple external telephony links.
- Connection to the Cable and Wireless Cloud (Multi-Protocol Label Switching network) via IP.
- Connection to the Public Switched Telephone Network, via BT Integrated Services Digital Network lines with physical separation.
- Back-up power for exchanges and IP routers for several hours supply to ensure system resilience during loss of AC Power.

Nuclear Industry Airwave Service Radio

When other communication systems have failed the nuclear industry airwave service could also be used as a back-up system to communicate between EDF Energy sites. This service is part of a national radio system, which has both security and inherent resilience built in to it, and is utilised by emergency response organisations.

To avoid a single point of failure within the service there are two routers in separate locations. Should one of the routers fail, the second router would be able to assume responsibility for routing network traffic into the Airwave "cloud".

UHF Site Radio

A recent report was produced on all EDF Energy existing nuclear stations radio systems. The primary use of the Power Station site's radio system is for day-to-day operations. There is not a dedicated emergency channel; however emergency calls have priority.

- Potential enhancements have been identified in the UHF radio system at each nuclear power station. These are being addressed as part of normal company process.

Conclusion of SZB 6.4: EDF Energy Nuclear Generation has a wide range of systems which are used for communication, this diversity in itself provides resilience. It is recognised that individual systems could be enhanced to provide further resilience and improve effects from external hazards. The inherent reliance on telephony means that despite there being numerous back-up systems, a great deal of efficiency would be lost without the telephony network.

Consideration SZB 6.5: EDF Energy to consider enhancing current telephony and communications systems to increase levels of resilience of key technological components based on learning from Japan.

6.1.3.3 Impairment of work performance due to high local does rates, radioactive contamination and destruction of some facilities on-site

The existing Emergency Arrangements recognise that there is the potential for radiation levels, in some extreme instances, providing access challenges on-site.

If this is ever the case then remote access would be required or the installation of an appropriate level of shielding. If radiation levels are such that some access is possible then this access will be time restricted. This would impair the recovery operation particularly if operations are time consuming and would therefore require staff rotation after a certain time spent exposed to high levels of radiation. Existing plans acknowledge and make provision for these eventualities.

Destruction of Facilities on Site

The destruction of primary facilities on site would result in moving to the appropriate alternative facilities, assuming that they have remained accessible and can be utilised. This movement could restrict work performance since the alternative facilities may have limited capability compared to the primary facility in terms of available specialist systems and equipment.

The dynamics of the event dictates the hazardous environment that operatives and responders will be required to work in. This environment could present numerous issues which EDF Energy needs to manage effectively to ensure staff safety and welfare; this includes the emotional and psycho-social wellbeing of responders. These are covered by our standard procedures. It should be understood that working within these environments impacts response time as responders have limited exposure times due to breathing apparatus, radiation dose or due to the physical nature of work. This may require increased rotation of staff and therefore subsequent increase demand on staff resource overall.

6.1.3.4 Impact on the accessibility and habitability of the main and secondary control rooms, measures to be taken to avoid or manage the situation

At Sizewell B there is a main control room which is located such that habitability would not be directly impacted by an external flooding event for staff already located in the facility.

In the event that this control room becomes untenable an auxiliary shutdown room serves as an alternative. This facility allows operators to monitor, and to a limited extent control, the reactor to ensure that it will remain safely shutdown and cooled.

6.1.3.5 Impact on the different premises used by the crisis teams or for which access would be necessary for management of the accident

EDF Energy conducted a recent review of access control points and emergency control centres during or after external events, and on operators' actions following the events. This detailed review outlined the impacts on the existing facilities from a range of external hazards.

These facilities are generally qualified for the full range of external hazards and where they are not alternatives have been identified. The Central Emergency Support Centre which is responsible for management of the accident is remotely located from all nuclear power sites.

Conclusion SZB 6.5: In extreme circumstances some on-site facilities may become unavailable. EDF has arrangements in place through use of mobile facilities to respond to this eventuality; however there are opportunities to enhance communications and equipment contained within.

Consideration SZB 6.6: EDF Energy will consider a review of its mobile facilities and the resilience of equipment contained within.

6.1.3.6 Feasibility and effectiveness of accident management measures under the conditions of external hazards (earthquakes, floods)

There will be a number of issues associated with the effectiveness of accident management measures should they occur under the conditions of external hazards. These include:

Emergency Services Support - the availability of emergency services support is unknown with the potential that services will also be responding to a wider emergency. The tasks of the site Emergency Team at the power station will need to be supplemented by specialists; such as the Fire and Rescue Service when the event develops beyond the limits of capability or require specialist equipment. It is a requirement of the Regulator that emergency services and standby support must be active on site within 60 minutes of a declaration.

Under conditions of external hazard there is an increased risk that attendance of responders external to the site within 60 minutes of emergency declaration will not be met. To improve resilience under such conditions EDF Energy will consider off-site resources in appropriate locations to facilitate the emergency response including provision of equipment and staff.

Access to site - (issues responded to as part of section 6.1.3.1) an associated issue related to access to site is the availability of personnel to resource ongoing shifts particularly in the instance of a prolonged emergency. Under the conditions of an external hazard it is possible that trained staff could be unavailable due to their own homes or family members being affected.

Off-site monitoring - there is an established process for providing off-site countermeasures advice to protect the public during a release of radiation from a site involving mobile sampling vehicles. One of the lessons identified from the Japanese Earthquake was the inability of off-site monitoring vehicles to access pre-determined monitoring locations and determine the levels of radiation that were being discharged off-site.

Conclusion SZB 6.6: In light of the events seen at Fukushima it is acknowledged that underpinning assumptions relating to the support of off-site local emergency services and the ability of local staff to attend site is questioned. Following a 'cliff edge' event the duration of response could extend beyond days or maybe weeks. This could result in issues surrounding prolonged use of staff and resources, which may require calling on staff from other stations.

Consideration SZB 6.7: EDF Energy should consider reviewing existing arrangements to ensure the principles of extendability are adhered to.

6.1.3.7 Unavailability of power supply

The loss of power supply to nuclear power stations would impinge on the response to accidents and so EDF Energy Nuclear Generation has redundancy in the essential electrical supplies at both nuclear power stations and key sites supporting emergency response, such as the Central Emergency Support Centre.

Following loss of the external power grid; back-up options such as diesel generators, batteries and battery charging diesel generators ensure electrical supply to essential plant equipment. This includes the facilities required for emergency arrangements.

6.1.3.8 Potential failure of instrumentation

The primary failure mechanism by which instrumentation would be lost is loss of power. Most indicating instruments/sensors require a designated power supply to work. This may be a dedicated supply to the instrument or it may be derived from the instrument signal loop. The method of deriving the power depends upon the design of the instrument.

The availability of instrumentation for information on plant status and control of plant systems is crucial to the success of management of the plant. For this reason station-critical systems have diesel and battery-backed supplies, to provide sufficient indication of the station parameters to monitor shutdown.

A detailed review has been undertaken and this did not identify any issues within the design basis. There is however suggestions that could be employed to enhance resilience beyond design basis.

6.1.3.9 Potential effects from the other neighbouring installations at the site

Sizewell B power Station is situated next to the Magnox owned Sizewell A site. Sizewell A ceased to generate power at the end of 2006 and as such is working through a decommissioning process. This has resulted in the radiological hazard from Sizewell A station being considerably reduced. However, more conventional hazards must still be taken into account such as fire.

On declaration of an event at either site, both sites activate their emergency sirens to muster all staff. Both sites will set up their emergency control centres to ensure ongoing communications. The Central Emergency Support Centre will also be manned by representatives from the unaffected sites company to ensure support is provided where required.

6.1.4 Measures which can be envisaged to enhance accident management capabilities

The Japanese event and findings from recent reviews has provided EDF Energy with an opportunity to review its accident management capabilities. EDF Energy has concluded that it has robust arrangements for Emergency Response. However there are lessons we have learnt during this process which we will consider in order to improve our response.

These can be broadly categorised into three areas:

Facilities – this includes site resilience and multi site support

Technical – communications and supply chain

Procedures – emergency arrangements and procedures taking into account staff welfare

Training and Exercising encompasses all elements as it is only through these functions EDF Energy can ensure continuous improvement and oversight of our arrangements.

Conclusion SZB 6.7: The provision of off-site equipment and support is a maintained and formal process within EDF Energy Nuclear Generation. Following the 2011 emergency in Japan it is recognised that it is possible that the equipment could be enhanced to provide further resilience to the emergency scheme.

Consideration SZB 6.8: Further mitigation against the effects of beyond design basis accidents could be provided by additional emergency back-up equipment. This equipment could be located at an appropriate off-site location close to the station to provide a range of capability to be deployed in line with initial post-event assessment. This equipment may include the following capabilities:

Electrical supplies for plant facilities.

Emergency command and control facilities including communications equipment.

Emergency response/recovery equipment.

Electrical supplies for lighting, control and instrumentation.

Robust means for transportation of above equipment and personnel to the site post-event.

Equipment to provide temporary shielding and deal with waste arisings from the event

6.2 Maintaining the containment integrity after occurrence of significant fuel damage (up to core damage) in the reactor core

The Sizewell B containment is of the large dry type incorporating additional water drainage paths to promote a partially wet cavity.

In addition to the primary containment, a secondary containment boundary is provided which, together with the auxiliary building and fuel building, completely enclose the primary containment boundary. This allows any possible leakages from the primary containment to be collected and filtered prior to discharge and results in very low releases under most accident conditions.

The size and strength of the containment structure provides inherent resistance to potential threats to containment integrity. Design provisions and the severe accident management measures are in place to maintain the integrity of the containment, in the unlikely event of an accident with significant fuel damage. Although severe accident analysis for Sizewell B does not make any claims on operator action post-severe accident, procedures are in place to suggest to operators how the consequences of a severe accident may be mitigated against. The station operating documentation for severe accident mitigation is adopted when indications to the operator are that core damage is inevitable. This documentation contains actions to ensure as far as possible that the containment is prepared for a severe accident, and to restore or improve core cooling in order to limit the damage to the core and to protect pressure vessel integrity.

6.2.1 Elimination of fuel damage/meltdown in high pressure

6.2.1.1 Design provisions

Due to the size and the strength of the primary containment and the geometry of structures in the vicinity of the reactor cavity, the threat to containment integrity from meltdown in high pressure is judged as small. Sizewell B does not include specific depressurisation design provisions dedicated to the elimination of high pressure melt sequences. However, the safety injection system may prevent the loss of pressure vessel integrity altogether by recovering adequate core cooling.

6.2.1.2 Operational provisions

The stations severe accident mitigation documentation includes operator actions which, if performed correctly within required timescales, it may prevent meltdown in high pressure (dependant on availability of control and instrumentation). These actions are aimed at depressurising the primary coolant if other means of mitigating accident progression have proved unsuccessful.

6.2.2 Management of hydrogen risks inside the containment

6.2.2.1 Design provisions, including consideration of adequacy in view of hydrogen production rate and amount

Sizewell B has no specific design provisions for the mitigation of hydrogen generated in severe accident conditions.

Two hydrogen recombiners do exist, however, these were designed for design basis accident generation rates and amounts of hydrogen. Therefore, these recombiners are of limited use during a severe accident in managing the hydrogen concentration, and, consequently, the severe accident analysis does not claim any benefit from these.

The hydrogen purge system, which provides a diverse means of reducing hydrogen concentrations in design basis accidents, provides a means of connection to the emergency exhaust heating, ventilation and air conditioning system and could potentially be used to vent hydrogen from containment under severe accident conditions, however, restrictions on allowed upper hydrogen concentration and the fact that the fluid from the containment atmosphere would contain significant amounts of steam at high temperature and possibly aerosols would significantly limit the use of this route to vent hydrogen from the containment atmosphere during severe accident conditions. This route of hydrogen concentration control is, therefore, not claimed in the severe accident analysis.

6.2.2.2 Operational provisions

As hydrogen presents little risk to containment structural integrity, Sizewell B has no specific hydrogen mitigation provisions applicable to severe accidents.

6.2.3 Prevention of overpressure of the containment

6.2.3.1 Design provisions, including means to restrict radioactive releases if prevention of overpressure requires steam/gas relief from containment

Overpressure of containment is prevented if the energy deposited in the containment is controlled by existing cooling systems. In the extremely unlikely event of a severe accident, Sizewell B has design features which to some extent limit the occurrence of overpressure of the containment. The reactor building provides a large strong containment with a large free air volume; the building has cooling and sprays systems whose main purpose is to remove heat from the containment atmosphere thereby limiting reactor building pressurisation.

The reactor building is also fitted with a fire suppression spray facility which can be used in case of loss of integrity of the pressure vessel to delay any likelihood of containment overpressure. The spray also floods the reactor building floor to promote ex-vessel debris cooling.

6.2.3.2 Operational provisions

The main operational provision for preventing overpressure of the containment is the severe accident mitigation documentation. The operating instruction prompts the operator to repeatedly attempt to establish and then maintain the reactor building spray. If this is not possible, after loss of integrity of the pressure vessel, the fire protection spray system can be initiated to delay containment overpressure and enhance ex-vessel debris cooling.

6.2.4 Prevention of re-criticality

6.2.4.1 Design provisions

In-vessel re-criticality is judged as extremely unlikely to happen because un-borated water would not normally be injected into the pressure vessel. Any water injected through the safety injection system to the pressure vessel is from a storage tank containing refuelling water. This water is highly borated thereby preventing in-vessel re-criticality.

In the extremely unlikely event where there is a composition of corium and moderator in the reactor cavity, there is the potential to promote re-criticality in certain configurations. Re-criticality is not considered a concern because of the optimised geometry of the core, low uranium enrichment, negative void coefficient and burnable poisons incorporated into the fuel matrix. Water present in containment is normally borated and hence increases the margin to criticality. Similarly any melting of the core region which occurs during a severe accident will decrease the chance of criticality.

6.2.4.2 Operational provisions

As the risk of In-vessel re-criticality is judged to be extremely remote, there are no operational provisions which directly mitigate the risk of re-criticality.

6.2.5 Prevention of basemat melt through

6.2.5.1 Potential design arrangements for retention of the corium in the pressure vessel

The severe accident analysis assumes that fuel melt will progress to loss of pressure vessel integrity. There is no formal in-vessel retention strategy adopted for Sizewell B.

The potential design/operational arrangements that may help to retain the corium (fuel containing material) in the pressure vessel include depressurisation of the coolant, in-vessel cooling provided by a number of safety injection systems, a robust primary circuit and ex-vessel cooling from cavity flooding using the building spray or fire suppression systems.

6.2.5.2 Potential arrangements to cool the corium inside the containment after reactor pressure vessel rupture

In the extremely unlikely situation of a severe accident scenario, it is important not only to remove heat to provide protection against containment over-pressurisation but also, in the case of core melt resulting in loss of pressure vessel integrity, to provide a means of cooling the ex-vessel debris, so as to minimise basemat attack. The floor drainage design is such that under severe accident conditions the reactor cavity would always be partially flooded before this occurs. This water would increase the likelihood of quenching any corium entering the cavity, resulting in a coolable debris bed, thus protecting the basemat.

Additional (non-borated) water required to maintain corium cooling can be injected into containment using the building fire suppression system which is diverse from the engineered safety systems. Initiation of this fire suppression system has been adopted as an accident management measure in the severe accident mitigation documentation.

6.2.5.3 Cliff edge effects related to time delay between reactor shutdown and core meltdown

The analysis of severe accident progression does not make any assumptions as to the function of equipment or operator intervention during the time from reactor shutdown to core meltdown.

Hence there are no cliff edges in the current severe accident analysis associated with the delay between reactor shutdown and core meltdown, since short term recovery actions are not claimed.

6.2.6 Need for and supply of electrical AC and DC power and compressed air to equipment used for protecting containment integrity

6.2.6.1 Design provisions

The equipment used for protecting containment integrity is the cooling and spray systems in the reactor building. These rely on electrical supplies from the essential electrical system. Support systems are also needed in order to provide a heat rejection route for these systems. The support systems are also powered from the essential electrical system. Following loss of offsite power, essential diesel generators supply the safeguards loads.

In addition to these systems, the reactor building fire suppression spray is also used to protect containment integrity. This fire suppression system does not need electrical power (apart from the dedicated diesel engine starting batteries). If the essential electrical system is unavailable the spray system can be started and injection into containment started by the manual operation of isolating valves.

For the protection of containment integrity none of the associated systems are reliant on a compressed air supply for successful initiation/operation during accident conditions.

6.2.6.2 Operational provisions

The essential electrical system operates autonomously in supplying these electrical loads and will start up and load the essential diesel generators if required.

In the extremely unlikely event of a severe accident scenarios which involve station blackout, battery charging diesel generators will have to be manually started and loaded by operators such that battery backed supplies remain unaffected.

6.2.7 Measuring and control instrumentation needed for protecting containment integrity

The equipment used for protecting containment integrity are associated with the reactor building cooling and spray systems and their ability to reduce temperature and pressure inside the containment. For these systems the control and instrumentation is powered from the essential electrical system, or during station blackout scenarios, by battery charging diesel generators.

No instrumentation is claimed specifically for the severe accident analysis apart from the ability to monitor containment pressure. The containment pressure indication is judged to be functional post severe accident provided low voltage essential power is available. Survivability of other instrumentation post-severe accident should be reviewed as part of a review of the severe accident mitigation procedure.

6.2.8 Measures which can be envisaged to enhance capabilities to maintain containment integrity after occurrence of severe fuel damage

The size and strength of the containment structure provides inherent resistance to potential transient threats to containment integrity. For important groups of severe accidents where all containment cooling is lost, the containment integrity could eventually be compromised by either overpressure or basemat failure.

For severe accidents it is important not only to remove heat to provide protection against containment over-pressurisation but also, in the case of core melt resulting in loss of pressure vessel integrity, to provide a means of cooling the ex-vessel debris, so as to minimise basemat attack.

Conclusion SZB 6.8: The robustness of the plant against design basis accident is considered to be appropriate; in considering the robustness to beyond design basis accidents, several areas have been identified where enhancement could be considered.

Consideration SZB 6.9: Further mitigation against the effects of beyond design basis accidents could be provided by reviewing the feasibility of enhancing the plant design. These enhancements may include the following measures:

Installing a filtered containment venting system (FVC).

Installing passive autocatalytic hydrogen recombiners to mitigate against hydrogen risk especially post-RB failure (or prior to containment venting).

Installing quick hook-up points on the containment building fire suppression system to allow a flexible solution of containment water injection into containment.

Consideration SZB 6.10: Consideration should be given to providing further mitigation against the effects of beyond design basis accidents by the provision of additional emergency back-up equipment. This equipment could provide additional diverse means of ensuring robust, long-term, independent supplies to the sites. This equipment could be located at an appropriate off-site location close to the station to provide a range of capability to be deployed in line with initial post-event assessment. This equipment may include the following capabilities:

Equipment to enable containment cooling.

Equipment to enable steam generator feedwater.

Electrical supplies for primary circuit make-up.

Equipment to enable fuel pond cooling.

Emergency command and control facilities including communications equipment.

Emergency response/recovery equipment.

Electrical supplies for lighting, control and instrumentation.

Water supplies for cooling from non-potable sources.

Robust means for transportation of above equipment and personnel to the site post-event.

Consideration SZB 6.11: Once a strategy for back-up equipment has been finalised consideration should be given to a review of the severe accident operational instructions.

In light of the events at the Fukushima Daiichi plant, as responsible operators EDF Energy have carried out reviews at each of the sites as a requirement of the Board. The findings of the Severe Accident Management aspects are discussed below

Scope

The beyond design basis review ensured that documentation, training and plant associated with response to beyond design basis events were reviewed, along with the adequacy of the emergency response organisation. Due to the nature of the questions asked as part of the reviews, this was primarily a paper-based exercise with workshops between station and central support engineers where appropriate. Equipment provided specifically for response to beyond design basis events was also physically inspected to ensure that the condition of the plant was as expected.

Summary of Findings

At Sizewell B, a series of station operating instructions are designed to manage the plant during the faults identified above by monitoring the Critical Safety Functions of the plant. In addition, the severe accident mitigation operating instruction is specifically designed for the management of events beyond design basis following an event where core damage has already occurred.

There is the opportunity to improve the documentation and training provided for severe accident management using the experiences of the people in the Tokyo Electric Power Company (operators of the Fukushima Daiichi plant) as this is one of the very few events where such documentation has been used in a real situation.

Conclusion SZB 6.9: There is the opportunity to improve the documentation and training provided for severe accident management using the experiences of the people in TEPCO, as this is one of the very few events where such documentation has been used in a real situation.

Consideration SZB 6.12: Review the severe accident mitigation procedure against best practice for Westinghouse plants and benchmark against severe accident procedures for French PWRs, specifically in terms of consistency of the procedure, priority of recovery actions and their feasibility of operation.

6.3 Accident management measures to restrict the radioactive release

6.3.1 Radioactive releases after loss of containment integrity

6.3.1.1 Design provisions

There are currently no design provisions which directly mitigate the risk of radioactive releases after the loss of containment integrity.

6.3.1.2 Operational provisions

Emergency planning and actions will be put into effect and will have a major role to mitigate the consequences of a radioactive release.

Loss of containment integrity would mean that there is a high probability of increased radiation levels off-site. Throughout an off-site nuclear emergency EDF Energy Nuclear Generation and independent experts will be utilising the information they receive to produce advice that will protect the public. The methodology for producing this advice is as follows. Emergency Reference Levels are part of the Health Protection Agency – Centre for Radiation Chemical and Environment guidance. This agency provides guidance on introducing countermeasures in the early stages of an emergency and the emergency reference levels show what dose to an individual could be averted if the countermeasure is taken. These levels are based on dose saving and do not take into account the dose already accrued. There are different risks associated with each countermeasure depending on:

- The site – location.
- The type of installation.
- Conditions at the time of the accident.
- For this reason, there are ranges of dose for the introduction of each countermeasure.

The Lower Emergency Reference Level

The Health Protection Agency – Centre for Radiation Chemical and Environment guidance recommends that countermeasures are not justified below this dose level. If the estimated averted dose exceeds the lower emergency reference level, then countermeasures would be justified but are not essential.

The Upper Emergency Reference Level

The upper emergency reference levels are set to avoid the deterministic (non-stochastic) effects of radiation. The Health Protection Agency recommends that, every effort must be made to introduce the countermeasure to avert the doses above the upper emergency reference level.

The most important exposure route after a release of radioactivity from a reactor is inhalation from radionuclide in the plume. It is not possible to measure directly what inhalation dose will result from a particular release in order to make a comparison with the relevant emergency reference level. Consequently, EDF Energy Nuclear Generation has derived simple, initial action levels – Derived Emergency Reference Levels based on the measurement of the concentration of activity in the air. These action levels enable EDF Energy Nuclear Generation to advise on, and implement, countermeasures as the lower emergency reference level of a countermeasure is exceeded. In the early stages of the response to a release, the Emergency Control Centre or Central Emergency Support Centre Health Physicist will use the EDF Energy action levels to advise on countermeasures.

The action levels are based on the total beta/gamma activity of air samples counted by equipment in off-site vehicles. Effective countermeasures are taken to protect the public. The basic principle of countermeasures is that they should be introduced if they are expected to achieve more good than harm in terms of radiation exposure averted versus the hazards associated with introducing the countermeasure. However EDF Energy Nuclear Generation takes a precautionary approach to protecting the public and agreement has been established with local Health Authorities authorising the Emergency Controller to advise the public to take potassium iodate tablets. The countermeasures of sheltering and taking of potassium iodate tablets will be automatically advised and introduced throughout the Detailed Emergency Planning Zone on the declaration of an off-site nuclear emergency.

The company will provide expert advice to the Strategic Coordination Centre, but the ultimate decision regarding implementation will be made by the Strategic Co-ordinating Group, who will be independently advised by the Government Technical Adviser.

Potassium iodate tablets are an effective countermeasure for releases involving radioiodine and can offer significant benefits even if they are taken after exposure. However, potassium iodate tablets are only relevant to the thyroid radiation exposure, and are only useful if the thyroid is not already saturated with iodine. Stable iodine will not replace radioiodine that is already in the thyroid, but acts to dilute further uptake. Each nuclear power station holds stocks of tablets for staff and contractors. Tablet manufacturers and the National Health Service also carry reserve stocks on behalf of EDF Energy. As well as the pre-distributed tablets to the public living in the Detailed Emergency Planning Zone the local Health Authority holds stocks of tablets for the public and they are responsible for arranging distribution of potassium iodate tablets to the public.

6.3.2 Accident management after uncovering of the top of fuel in the fuel pool

There are currently no severe accident mitigation procedures covering severe accidents involving the fuel storage pond. The fuel pond safety case presents evidence demonstrating that the design of ponds, associated plant, and the methods of operation, protect against and mitigate the consequences of faults. These faults can be categorised as either loss of pond water faults or loss of pond cooling faults. The protection and mitigation features allow the ponds to retain the essential functions of cooling and containment of fuel.

6.3.2.1 Hydrogen management

There are no designs or operational provisions in the fuel building for the management of hydrogen generated by Zirconium oxidation due to overheating fuel in the fuel storage pond.

6.3.2.2 Providing adequate shielding against radiation

The pond civil structure should provide significant shielding in the lateral direction, even with the loss of water. However, in the vertical direction (and with shine at an angle) dose rates around the pond area would become very high once the fuel is uncovered.

In order to restore effective radiation shielding, particularly local to the pond area, it is necessary to restore the pond water level. There are a number of engineered means of providing make-up water to the pond, however these may not always be available in the unlikely event of a severe accident scenario. If other make-up routes are inoperable, Sizewell B provides an external make-up pipe which can be connected to a fire tender (or similar) to provide make-up water.

6.3.2.3 Restricting releases after severe damage of spent fuel in the fuel storage pools

A key means of limiting releases would be to restore water cover to the fuel, as this provides both cooling and some containment. Note that if it is not possible to re-fill the ponds, then even a water spray (deluge) would be beneficial.

6.3.2.4 Instrumentation needed to monitor the spent fuel state and to manage the accident

Primary indications for the ponds are of water level and temperature. There are various installed means of indications, which can be manually backed with level markings (visual inspection) and hand held-temperature monitoring. The availability of remote indications from the ponds requires confirmation, especially in the event of significant water loss, high temperatures and dose rates.

Instrumentation to confirm the correct functioning of the fuel building cooling and ventilation system, including filters, would be required to manage the accident, as would be the ability to monitor the local ponds environment for fission product release. For fuel pond severe accidents, it is judged that remote means of visual inspection would be the most versatile means of monitoring the spent fuel

6.3.2.5 Availability and habitability of the control room

Sizewell B does not have a pond control room; all operations related to the fuel storage pond are controlled from the main control room.

Conclusion SZB 6.10: The main control room is located well away from the fuel storage pond, and any shine from the fuel pond would have to travel through the containment including equipment located inside containment in order to reach the main control room. Hence, it is judged that doses rates in the main control room with a dry fuel storage pond should be low. However, radioactive releases from the fuel building may affect main control room heating, ventilation and air conditioning. It would be prudent to investigate whether the main control room could be manned with that in mind.

Consideration SZB 6.13: Consideration should be given to reviewing whether any airborne release from a severe accident in the fuel pond would affect the habitability of the main control room.

6.3.3 Measures which can be envisaged to enhance capability to restrict radioactive release

Measures which can be envisaged to enhance capability to restrict radioactive release are considered below.

Conclusion SZB 6.11: The robustness of the pond against design basis accidents is considered to be appropriate; in considering the robustness to beyond design basis accidents, several areas have been identified where enhancement could be considered.

Consideration SZB 6.14: Consideration should be given to providing further mitigation against the effects of beyond design basis accidents by the provision of additional emergency backup equipment. This equipment could provide additional diverse means of ensuring robust, long-term, independent supplies to the ponds. This equipment could be located at an appropriate off-site location close to the station to provide a range of capability to be deployed in line with initial post-event assessment. This equipment may include the following capabilities:

Equipment to enable fuel pond cooling.

Emergency command and control facilities including communications equipment.

Emergency response/recovery equipment.

Electrical supplies for lighting, control and instrumentation.

Water supplies for cooling from non-potable sources.

Robust means for transportation of above equipment and personnel to the site post-event.

Installation of a radiation hardened camera with infra-red capability in the fuel pond area to aid remote inspection of the fuel pond in fuel pond severe accidents.

It would be appropriate, if this equipment was developed and in any case to capture learning from events in Japan to review and where necessary revise the documentation and training provided for severe accident management in the fuel route plant areas.