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UK HPR1000 GDA Project

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Title:

Pre-Construction Safety Report
Chapter 18
External Hazards

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18.1 List of Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
DBC	Design Basis Condition
DBE	Design Basis Earthquake
DiD	Defence in Depth
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPW	Explosion Pressure Wave
GDA	Generic Design Assessment
GIC	Geomagnetic Induced Current
GNS	General Nuclear System Limited
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
I&C	Instrumentation and Control
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LUHS	Loss of Ultimate Heat Sink
MCR	Main Control Room
NRC	Nuclear Regulatory Commission (US)
ONR	Office for Nuclear Regulation (UK)
OPEX	Operating Experience
PCSR	Pre-Construction Safety Report
PMC	Fuel Handling and Storage System [FHSS]
PSA	Probabilistic Safety Assessment
RGP	Relevant Good Practice
RRI	Component Cooling Water System [CCWS]
SAP	Safety Assessment Principle (UK)

SEC	Essential Service Water System [ESWS]
SSC	Structures, Systems and Components
TAG	Technical Assessment Guide (UK)
UK HPR1000	UK version of the Hua-long Pressurised Reactor
VDA	Atmospheric Steam Dump System [ASDS]
WENRA	Western European Nuclear Regulators Association

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Atmospheric Steam Dump System (VDA [ASDS]).

18.2 Introduction

External hazards are those natural or man-made hazards to a site and facilities that originate externally to both the site and its processes, i.e. the duty holder may have very little or no control over these hazards, Reference [1].

External hazards have the potential to initiate faults and cause common cause failure of Structures, Systems and Components (SSC) that are required to deliver the fundamental safety functions, as follows:

a) Control of reactivity;

b) Removal of heat from the reactor and the fuel store;

c) Confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases.

The main objective of Pre-Construction Safety Report (PCSR) Chapter 18 is to demonstrate that threats from external hazards do not undermine the fundamental safety functions of the UK version of the Hua-long Pressurised Reactor (UK HPR1000) nuclear power plant.

18.2.1 Chapter Route Map

The ***Fundamental Objective*** of the UK HPR1000 is that: *The generic UK HPR1000 could be constructed, operated and decommissioned in the UK on a site bounded by the generic site envelope in a way that is safe, secure and that protects people and environment.*

To underpin this objective, Level 1 Claims and a number of Level 2 Claims are developed and presented in Chapter 1. Chapter 18 supports the ***Claim 3.2.1, Claim 3.2.2, and Claim 3.2.3*** derived from the high level ***Claim 3.2***.

Claim 3*: The design and intended construction and operation of the UK HPR1000* *will protect the workers and the public by providing multiple levels of defence to fulfil the fundamental safety functions, reducing the nuclear safety risks to a level that is as low as reasonably practicable.*

Claim 3.2*: A comprehensive fault and hazard analysis has been used to specify the requirements on the safety measures.*

a) ***Claim 3.2.1:*** *All initiating events with the potential to lead to significant radiation exposure or release of radioactive material, including the effects of internal and external hazards have been identified;*

b) ***Claim 3.2.2:*** *Design basis events have been appropriately assessed to specify requirements on safety functions and on safety measures and assess their effectiveness;*

c) ***Claim 3.2.3:*** *Analysis of Design Extension Conditions and Severe Accident Analysis has been carried out to identify further risk reducing measures and inform emergency arrangements.*

The Sub-claim 1 and its relevant arguments and evidence support the Claim 3.2.1:

a) ***Sub-claim 1:*** *The individual external hazards and hazard combinations that can potentially cause initiating faults and thus affect nuclear safety are sufficiently identified.*

1) ***Argument 1.1:*** *The methodology of identification and screening of individual external hazards is conducted to get a comprehensive list of individual external hazards.*

- ***Evidence 1.1.1:*** *The process and outcome of individual external hazards identification and screening are shown in Sub-chapter 18.5.1 and Reference [2].*

2) ***Argument 1.2:*** *The methodology of identification and screening of external hazard combinations is developed to get a comprehensive list of external hazard combinations.*

- ***Evidence 1.2.1:*** *The process and outcome of external hazard combinations are shown in Sub-chapter 18.6 and Reference [2].*

The Sub-claim 2 and its relevant arguments and evidence support the Claim 3.2.2:

b) ***Sub-claim 2:*** *Design basis external hazards are appropriately assessed to identify requirements on safety functions and safety measures and assess their effectiveness.*

1) ***Argument 2.1:*** *External hazard design basis is determined by a conservative methodology.*

- ***Evidence 2.1.1:*** *The design basis of natural external hazards is determined with a conservative frequency 10^{-4}/yr and the effect of climate change is also taken into account, which is shown in the Sub-chapter 18.4.1 and Sub-chapter 18.6.*

- ***Evidence 2.1.2:*** *The design basis of man-made external hazards is determined with a conservative frequency 10^{-5}/yr or maximum credible event, which is shown in Sub-chapter 18.4.1 and Sub-chapter 18.6.*

2) ***Argument 2.2:*** *Appropriate protection measures required are identified and their effectiveness is appropriately assessed.*

   - ***Evidence 2.2.1:*** *The protection measures of external hazards are shown in Sub-chapter 18.6.*

   - ***Evidence 2.2.2:*** *The effectiveness of protection measures is appropriately assessed in Sub-chapter 18.6.*

The Sub-claim 3 and its relevant arguments and evidence support the Claim 3.2.3:

c) ***Sub-claim 3:*** *Beyond design basis external hazards analysis is carried out to improve robustness of UK HPR1000.*

1) ***Argument 3.1:*** *Cliff-edge analysis is performed to ensure the robustness of external hazards design basis.*

   - ***Evidence 3.1.1:*** *The cliff-edge analysis of external hazards is shown in Sub-chapter 18.6.*

   - ***Evidence 3.1.2:*** *The conservative and elastic design of structure and other protection measures are presented in Sub-chapter 18.6.*

2) ***Argument 3.2:*** *Safety margins are considered to protect against more severe beyond design basis natural external hazards.*

   - ***Evidence 3.2.1:*** *A conservative generic site envelope value is adopted to ensure safety margins of specific site value for external hazards protection design in Sub-chapter 18.6.*

18.2.2 Chapter Structure

For this Sub-chapter, the general principles and the assessment scope in the Generic Design Assessment (GDA) phase are introduced in Sub-chapter 18.4, and then identification and screening of external hazards are shown in Sub-chapter 18.5. For these individual external hazards and hazard combinations, the characteristics of hazards, design basis, protection measures, and the safety assessment are described in Sub-chapter 18.6 and Sub-chapter 18.7. Some administrative procedures are considered to mitigate the consequence of external hazards in Sub-chapter 18.8 and As Low As Reasonably Practicable (ALARP) demonstration results are given to ensure that the risk of external hazards is reduced to be ALARP in Sub-chapter 18.9.

The general structure of this chapter is presented as follows:

a) Sub-chapter 18.1 List of Abbreviations and Acronyms:

This sub-chapter lists the abbreviations and acronyms that are used in PCSR Chapter 18.

b) Sub-chapter 18.2 Introduction:

This sub-chapter gives an overview of this PCSR chapter, and includes introduction of the route map, chapter structure, and the interfaces with other chapters.

c) Sub-chapter 18.3 Applicable Codes and Standards:

This sub-chapter gives applicable codes and standards considered in external hazards protection design of UK HPR1000.

d) Sub-chapter 18.4 General Approach:

This sub-chapter gives an overview of the general considerations for external hazards protection design, and includes general principles, assessment scope and external hazards schedule.

e) Sub-chapter 18.5 External Hazards Identification and Screening:

This sub-chapter describes the principles and process of identification and screening methodologies for external hazards and hazard combinations. According to these principles, the hazards list is derived and forms the basis for Sub-chapter 18.6.

f) Sub-chapter 18.6 Protection against External Hazards:

This sub-chapter explains the external hazards characteristics, design basis, external hazards protection measures and describes the safety assessment for those external hazards considered during the GDA phase.

g) Sub-chapter 18.7 Assessment of Hazard Combinations:

This sub-chapter provides the assessment of hazards combination, and aims to demonstrate that the consequences of the credible hazard combinations are acceptable or minimised by proposed protection measures.

h) Sub-chapter 18.8 Administrative Procedures:

This sub-chapter introduces administrative procedures relevant to external hazards.

i) Sub-chapter 18.9 ALARP Assessment:

This sub-chapter provides an outline ALARP justification approach and a summarised assessment against Relevant Good Practice (RGP) for external hazards, for the purposes of verifying that the external hazards risk are ALARP through RGP analysis.

j) Sub-chapter 18.10 Concluding Remarks:

This sub-chapter provides the concluding remarks, and summarises main context of this chapter.

k) Sub-chapter 18.11 References:

This sub-chapter provides the supporting references.

18.2.3 Interfaces with other Chapters

The interfaces between Chapter 18 and other chapters are listed in T-18.2-1.

T-18.2-1 Interfaces between Chapter 18 and Other Chapters

PCSR Chapter	Interface
Chapter 1 Introduction	Chapter 1 provides the Route Map of Level 1 and Level 2 claim, and Chapter 18 provides sub-claims, arguments and evidences to support Level 1 and Level 2 claims given in Chapter 1.
Chapter 2 General Plant Description	Chapter 18 presents the protection of external hazards through the layout of buildings which is mentioned in Chapter 2.
Chapter 3 Generic Site Characteristics	Chapter 3 presents the list of the external hazards, and the generic site envelope and the values for UK HPR1000 design. Chapter 18 adopts the generic site envelope parameters in Chapter 3 to perform the design.
Chapter 4 General Safety and Design Principles	Chapter 4 provides general safety and design principles, including Defence in Depth (DiD), Fundamental Safety Functions, Safety classification of SSCs, etc. Chapter 18 demonstrates that the safety and design principles have been implemented in the design.
Chapter 5 Reactor Core	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 5 considers earthquake protection design and

PCSR Chapter	Interface
	demonstrates that the protection requirements and protection measures against earthquake have been implemented in the design.
Chapter 6 Reactor Coolant System	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 6 considers these kinds of external hazards and demonstrates that the protection requirements and protection measures against external hazards have been implemented in the design.
Chapter 7 Safety Systems	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 7 provides the safety systems design substantiation of applied external hazard protection design principles, which is used for external hazards assessment.
Chapter 8 Instrumentation and Control	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 8 considers these kinds of external hazards and demonstrates that the protection requirements and protection measures against external hazards have been implemented in the design.
Chapter 9 Electric Power	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements of external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 9 considers these kinds of external hazards and demonstrates that the protection requirements and protection measures against external hazards have been implemented in the design.

PCSR Chapter	Interface
Chapter 10 Auxiliary Systems	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 10 considers these kinds of external hazards and demonstrates that the protection requirements and protection measures against external hazards have been implemented in the design.
Chapter 11 Steam and Power Conversion System	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 11 considers these kinds of external hazards and demonstrates that the protection requirements and protection measures against external hazards have been implemented in the design.
Chapter 12 Design Basis Condition	Chapter 12 presents analysis showing that initiating design basis faults have been identified and fault sequences developed and that it identifies suitable safety measures and sets requirements on their design. Chapter 18 provides the potential faults caused by external hazards and links to Chapter 12 to manage these faults.
Chapter 13 Design Extension Conditions and Severe Accident Analysis	Chapter 13 presents analysis that beyond design basis faults have been identified and shows that analysis of design extension conditions and severe accidents have been carried out to evaluate the effectiveness of protection and mitigation measures. Chapter 18 provides the potential beyond design basis faults caused by external hazards and links to Chapter 13 to manage these faults.
Chapter 14 Probabilistic Safety Assessment	Chapter 18 provides the identified external hazards and design basis value and protection measures to Chapter 14. Chapter 14 shows a balanced design for external hazards.

PCSR Chapter	Interface
Chapter 15 Human Factors	Chapter 18 provides human-related claims in external hazards. Chapter 15 substantiates the claims on operator actions relating to external hazards.
Chapter 16 Civil Works & Structures	Chapter 18 defines external hazards that lead to loads being placed on the civil structures. Chapter 16 presents the design substantiation of civil structures.
Chapter 17 Structural Integrity	Chapter 18 provides relevant external hazards considered for the UK HPR1000. It includes protection requirements for external hazards, the design basis of external hazards, potential protection measures, and external hazards assessment. Chapter 17 considers these external hazards and demonstrates that the protection measures against external hazards have been implemented in the design.
Chapter 19 Internal Hazards	Chapter 18 provides the potential internal hazards caused by external hazards, and Chapter 19 provides protection measures that may be used in response of the resulting internal hazards.
Chapter 20 MSQA and Safety Case Management	The organizational arrangements and quality assurance arrangements set out in Chapter 20 are implemented in the design and production of Chapter 18.
Chapter 23 Radioactive Waste Management	Chapter 23 presents the substantiation of radioactive waste management systems to ensure that the nuclear safety risks are reduced to ALARP, and Chapter 18 gives the external hazards that radioactive waste management systems must consider.
Chapter 24 Decommissioning	Chapter 18 gives the relevant external hazards that Chapter 24 must have considered to meet the decommissioning objective.
Chapter 27 Security	Some man-made external hazards in Chapter 18 covered under security are described in Chapter 27.
Chapter 28 Fuel Route and Storage	Chapter 18 provides the relevant external hazards that have to be considered in the design of the Fuel Handling and Storage

PCSR Chapter	Interface
	System (PMC [FHSS]) in Chapter 28. Chapter 28 covers the demonstration of the Fuel Handling and Storage System (PMC [FHSS]), including the relevant external hazards that are identified in Chapter 18.
Chapter 33 ALARP Evaluation	Chapter 18 provides the ALARP analysis for external hazards protection by applying the ALARP methodology, which supports the overall ALARP demonstration addressed in Chapter 33.

18.3 Applicable Codes and Standards

The applicable codes and standards are provided in this Sub-chapter, which are selected after conformity analysis according to the selection principles and selection process presented in the PCSR Chapter 4 and the Reference [3].

The selection principles from the Reference [3] are applied in the selection process and are briefly introduced as follows:

a) The relevant good practice of international organizations and other countries acknowledged by UK regulators are taken into account sufficiently;

b) The experience used in other GDA projects is considered completely;

c) The latest version of codes and standards are selected with priority;

d) The applicability, adequacy and sufficiency of selected codes and standards are identified and evaluated, etc.

The selection process is presented in the PCSR Chapter 4 and the Reference [3], which includes the steps of collection, screening, assessment, justification and analysis, etc.

According to the selection principles, UK context-specific expectations and RGP are taken into account in the selection process of codes and standards, and the sources of RGP for external hazards are as follows:

a) Approved Code of Practice;

b) Standards issued by British Standard Institute and International Electrotechnical Commission (IEC);

c) International Atomic Energy Agency (IAEA) Safety Standards;

d) Western European Nuclear Regulators Association (WENRA) Reference Levels;

e) Industry/Sector Standards.

In the UK HPR1000 design, the Safety Assessment Principles (SAP), Technical Assessment Guide (TAG) and other documents issued by Office for Nuclear Regulation (UK) (ONR) has also been considered.

Based on above presentation, applicable codes and standards are applied in the requirements, protection design and assessment against external hazards of UK HPR1000.

The following codes, standards and guidance are used in general design of external hazards:

a) IAEA, Site Evaluation for Nuclear Installations, Safety Standards Series No. NS-R-3, 2016;

b) IAEA, Safety of Nuclear Power Plant: Design, Safety Standards Series No. SSR-2/1(Rev.1), 2016;

c) IAEA, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, Safety Standards Series No. NS-G-3.6, 2004;

d) WENRA, Safety Reference Levels for Existing Reactors, September 2014;

e) WENRA, Guidance Document Issue T: Natural Hazards: Head Document, 2016;

f) WENRA, Safety of New Nuclear Power Plant design, March 2013;

g) WENRA, Statement on Safety Objectives for New Nuclear Power Plants, 2010;

h) Swedish Nuclear Inspectorate, Guidance for External Events Analysis, 2003.

The following codes, standards and guidance are used to identify the sources of external flooding and to provide characterization and related protection design experience of extreme wind, tornado, aircraft crash and external explosion.

a) IAEA, External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Standards Series No. NS-G-1.5, 2003;

b) IAEA, Meteorological Events in Site Evaluation for Nuclear Power Plants, Safety Standards Series No. NS-G-3.4, 2002;

c) NRC, Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants, RG 1.76, Revision1, 2007.

The following standards and guidance are used in seismic analysis.

a) IAEA, Seismic Design and Qualification for Nuclear Power Plants, Safety Standards Series No. NS-G-1.6, 2003;

b) IAEA, Evaluation of Seismic Hazards for Nuclear Power Plants, Safety Standards

Series No. NS-G-3.3, 2002;

c) IAEA, Seismic Hazards in Site Evaluation for Nuclear Installations, Specific Safety Guide, No. SSG-9, 2010;

d) WENRA, Guidance Document Issue T: Natural Hazards: Guidance on Seismic Events, 2016.

The following codes, standards and guidance are used in external flooding and meteorological analysis.

a) WENRA, Guidance Document Issue T: Natural Hazards: Guidance on External Flooding, 2016;

b) IAEA, Flood Hazard for Nuclear Power Plants on Coastal and River Sites, Safety Standards Series No. NS-G-3.5, 2002;

c) IAEA, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, Specific Safety Guide, No. SSG-18, 2011;

d) WENRA, Guidance Document Issue T: Natural Hazards: Guidance on Extreme Weather Conditions, 2016.

The following standard is used in man-made hazards analysis.

a) IAEA, External Human Induced Events in Site Evaluation for Nuclear Power Plants, Safety Standards Series No. NS-G-3.1, 2002.

18.4 General Approach

This sub-chapter provides the general principles and requirements for external hazards protection design, the assessment scope including the scope of buildings needed to be considered, and the general safety assessment methodology of external hazards.

18.4.1 General Principles

The general design principles or requirements of hazard protection are provided in Reference [4]. The general principles of external hazards protection design are as follows:

a) DiD concept should be applied in the hazards protection design;

b) Design basis hazards should not result in the failure of any fundamental safety functions of nuclear power plants;

c) Priority should be given to passive barriers, and the integrity of the barrier against individual hazards and hazard combinations should be substantiated. The acceptability of any partial loss of integrity should be assessed;

d) The habitability of the Main Control Room (MCR) should be ensured. The availability and the accessibility of the remote shutdown station should be ensured in case MCR is unavailable;

e) The protection design measures should ensure that there are no cliff-edge effects;

f) The hazards safety assessment should demonstrate that the risk is reduced to be ALARP.

For external hazards, certain specific requirements are considered:

a) Design Basis Natural Hazards

The design basis of natural hazards is determined using a conservative estimate at a frequency of 10^{-4}/yr, in line with the upper values on the hazard curve according to TAG 013, Reference [5].

Climate change is likely to have an impact on many natural external hazards, such as extreme air/water temperatures and external flooding.

The effect of climate change has been appropriately considered, using the data from UK Climate Projections, Reference [6]. There are three emission scenarios to develop climate change projections: High, Medium and Low. These scenarios are based on the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios, Reference [7].

The medium emission scenario in Reference [7] has been selected, as it is deemed that this represents the most realistic approach. The values have been selected at 50% probability for UK HPR1000. Climate change values are shown in Reference [8].

Civil structures important to safety are designed against design basis natural hazards, such as wind, heavy snow and earthquake. SSCs important to safety are designed such that they do not lose functionality in the event of an earthquake or Electromagnetic Interference (EMI).

b) Design Basis Man-Made Hazards

The design basis man-made hazards are defined in one of the following two ways, Reference [5]:

1) Probabilistically, as a best estimate value of hazard severity for all initiating hazards, the frequency of occurrence of man-made hazards is 10^{-5}/yr;

2) Deterministically, as a maximum credible event provided its frequency of occurrence is compatible with the principles of FA.5 in SAP, Reference [1].

During the GDA phase, a maximum credible event is usually adopted as a design basis of man-made hazard, such as design basis external explosion. The design basis will be reviewed once the specific site is determined.

c) Beyond Design Basis External Hazards and Cliff-edge Criteria

There are two aspects of beyond design basis external hazards that will be investigated:

1) Cliff-edge Effects

Cliff-edge effects are examined to ensure that there is no step change response to the hazard and there is no disproportionate increase in radiological risk close to the design basis boundary.

2) External Hazards More Extreme than the Design Basis

For beyond design basis external hazards which can severely challenge the plant safety functions across the site, the most resilient means are identified to ensure that fundamental safety functions are maintained.

18.4.2 Scope

According to Reference [9], this sub-chapter describes the external hazards safety assessment and protection scope of the buildings. The building list for external hazards protection is shown in T-18.4-1:

T-18.4-1 Building List for External Hazards Protection

No.	Building Code	Building Description
1	BDA	Emergency Diesel Generator Building A
2	BDB	Emergency Diesel Generator Building B
3	BDC	Emergency Diesel Generator Building C
4	BDU	SBO Diesel Generator Building for Train A
5	BDV	SBO Diesel Generator Building for Train B
6	BEX	Equipment Access Building
7	BFX	Fuel Building
8	BNX	Nuclear Auxiliary Building
9	BPX	Personnel Access Building
10	BRX	Reactor Building
11	BSA	Safeguard Building A
12	BSB	Safeguard Building B
13	BSC	Safeguard Building C
14	BWX	Radioactive Waste Treatment Building

No.	Building Code	Building Description
15	BEJ	Extra Cooling System and Fire-fighting Water Production System Building

18.4.3 External Hazards Schedule

The external hazards safety assessment process includes the following main steps:

a) Identification of External Hazards Sources

The location and sources of external hazards are identified and captured for a generic site. For example, external flooding may be caused by high sea level, storm surge, precipitation, dam failure, etc.

b) Identification of Affected Items Important to Safety

The affected SSCs important to safety are identified, which helps to define the scope of the external hazards assessment.

c) Quantification of Load (Hazard Specific)

The external hazard design basis is given in this chapter. For example, seismic event parameters are expressed in terms of zero period peak acceleration and a response spectrum. In addition, climate change is considered in the relevant natural hazards.

d) Identification of Unmitigated Consequences

The unmitigated consequences are identified. For most cases, the starting assumption for the unmitigated consequences is loss of SSCs functions due to the effect of external hazards.

e) Identification of Protection Measures

Based on the identified unmitigated consequences and initiating frequency, suitable and sufficient protection measures (including DiD protection measures) are identified for an external hazard event to ensure that the mitigated consequences are acceptable.

The process develops the requirement for redundancy, separation and segregation.

f) Assessment of an External Hazard (Hazard Specific)

The effects of an external hazard on the protection measures (e.g. hazard barriers) are assessed aiming to ensure that the protection measures are not failed to maintain the safety functions. The hazard barriers are designed using a conservative calculation approach for each external hazard (or credible combination).

g) Production of a Hazard Schedule

The purpose of a hazard schedule is to analyse the hazard consequence and propose the protection measures to control the risk and define the category and classification of protection measures.

The external hazard sequence progression and the associated protection measures are captured via the production of a hazard schedule. This provides a summary of the assessment of all external hazard events to give the links between hazard identification, protection measures, and the bounding defined in the Fault Schedule in Reference [10].

18.5 External Hazards Identification and Screening

All natural and man-made external hazards that might affect the SSCs important to safety are identified and screened, including individual hazards and hazard combinations.

18.5.1 Individual External Hazards

The aim of this sub-chapter is to briefly describe the methods and processes for the identification and screening of individual external hazards. The identification and screening process of individual external hazards is presented in Reference [2], and includes the following steps:

a) Listing all the individual external hazards;

b) Grouping;

c) Screening.

18.5.1.1 Listing All the Individual External Hazards

The first step is to develop a complete list of potential external hazards, which includes all identified natural and man-made hazards. Additionally, all the hazards are included in the list, regardless of their potential to cause damage to plant equipment or otherwise affect safety functions.

The applicable codes, standards and guidance are used as references to obtain the complete list of individual external hazards. The method and results of listing individual external hazards are shown in Reference [2].

18.5.1.2 Grouping

Grouping of various types of external hazards is useful for structuring the information presented, and makes it possible to perform a complete check of the identified hazards. Duplicate hazards can be removed from the process, and similar hazards can be subsumed into a same group to produce a comprehensive unscreened list. For example, rainfall can result in external flooding and storm surge can also result in external flooding, so they can be put in the same group of external flooding. The hazard groups presented below refer to Reference [8]:

a) Earthquake;

b) Hydrological;

c) Biological Phenomena;

d) Man Made and Industrial Hazards;

e) Meteorological Conditions;

f) Meteorological incorporating Climate Change;

g) Geological;

h) Landscape Change.

18.5.1.3 Screening

Based on the complete list of individual external hazards identified, several screening criteria are applied to determine which external hazards should be considered during the GDA phase and which external hazards should be considered in nuclear site licensing phase. More detailed information on the screening criteria and screening process is shown in Reference [2]. The primary screening criteria are listed as follows:

a) The hazard frequency is below cut-off frequency (lower than 10^{-7}/yr);

b) The hazard produces a sufficiently low consequence;

c) The hazard effect on the plant is similar or less severe than another hazard, and it can be bounded by the other hazard.

After screening, the relevant hazards are reviewed and categorised as GDA phase or nuclear site licensing phase considering whether the hazards depend on the site specific information or not. The individual hazards considered for the UK HPR1000 GDA phase are listed as follows:

a) Earthquake;

b) External Flooding;

c) Meteorological Conditions (includes extreme wind, extreme wind generated missile, tornado, extreme temperature, extreme hail, sleet snow and icing, lightning);

d) Man-made and Industrial Hazards (includes accidental aircraft crash, external explosion and off-site missiles);

e) EMI and Space Weather;

f) Heat Sink Specific Hazards.

18.5.2 Hazard Combinations

Hazard combinations are defined as a combination of hazards (both internal and external), and it also includes the combination of hazards and design conditions.

Hazard combinations can be divided into the following categories:

a) Consequential hazards;

b) Correlated hazards;

c) Independent hazards;

d) Combination of external hazards and design conditions.

The identification process for hazard combinations applies an appropriate combination of engineering judgment, deterministic and probabilistic method, after that all credible hazard combinations have been determined.

a) Consequential Hazards Identification and Screening

Consequential hazards are defined as the occurrence of a secondary hazard that is directly caused by a primary hazard. An external hazard could result in a consequential internal hazard or a consequential external hazard.

Protection against most external hazards is provided by building structure design, except the earthquake and EMI. Earthquake can give rise to internal flooding due to the break of non-seismic classified pipes and collapsed load impact due to the falling of non-seismic classified equipment. The consequential internal hazards resulting from earthquake have been considered in the seismic safety assessment. Further information is in Sub-chapter 18.6.1.

This sub-chapter only considers external hazards resulting from the occurrence of other external hazards.

The identification and screening process for consequential external hazards is as follows:

1) Identifying the cause of each external hazard;

2) Identifying which primary external hazard could result in this case;

3) Screening consequential hazards according to their frequency and impact on the plant.

For example, earthquake, extreme wind, snow and icing can give rise to external flooding. The credible consequential external hazards are described in the sub-chapters of each individual external hazard in Sub-chapter 18.6. The preliminary list of consequential external hazards is presented in Reference [2].

b) Correlated Hazards Identification and Screening

Some external hazards which are associated with meteorological or climate conditions, intrinsically involve a combination of several phenomena.

For example, more than one hazard can occur from the same meteorological conditions, a tropical cyclone may induce high wind, extreme rainfall and high waves.

The identification and screening process for correlated external hazards identification is as follows:

1) Identifying the cause of each external hazard;

2) Identifying external hazards that may have the same cause;

3) Screening consequential hazards according to their frequency and impact on the plant.

The preliminary list of correlated external hazards is presented in Reference [2].

c) Independent Hazards Identification and Screening

Independent hazards are defined as the simultaneous occurrence of two or more external hazard events which have no causal relationship between them. ‘Simultaneous’ means that the second hazard occurs before the previous hazard has been completely mitigated.

The identification and screening process is as follows:

1) Determining the frequency of each external hazard;

2) Calculating the frequency of two or more independent hazards occurring simultaneous;

3) Comparing the frequency of two or more independent hazards occurring with the cut-off frequency;

4) Analysing whether the consequences of two or more independent external hazards could be bounded by individual external hazard or not. It will be carried out according to the preliminary assessment and engineering judgement.

According to previous experience, for some external hazards, the higher frequency at which the hazard occurs, the lower severity of the consequence and impact to the plant. For the independent external hazard combinations with the high frequency and low impact, the consequence is covered by the individual external hazard safety assessment, and the plant safety is ensured through the existing protection measures for individual external hazards. For other external hazards with a low frequency and severe consequences, the frequency of two or more independent hazards occurring simultaneously is generally lower than the cut-off frequency.

The preliminary list of independent external hazard combinations which are considered as the physical process has been presented in Reference [2].

d) Combination of External Hazards and Design Conditions

Generally, the design basis external hazards are assumed to occur under the normal operating conditions, some external hazards could result in design conditions, including Loss of Offsite Power (LOOP) and Loss of Ultimate Heat Sink (LUHS), which are considered in Chapter 12 Design Basis Condition and Chapter 13 Design Extension Conditions and Severe Accident Analysis respectively.

18.6 Protection against External Hazards

The safety requirements, the design basis of external hazards, protection measures, and safety assessment are considered in this sub-chapter. Detailed characteristics for each external hazard are also provided.

18.6.1 Earthquake

18.6.1.1 Safety Requirements

Following a Design Basis Earthquake (DBE), the objective of protection measures is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.1.2 Design Basis

18.6.1.2.1 Earthquake Characterisation

The following earthquake characteristics are considered:

a) Near fault effects

Near fault effects will be assessed during nuclear site licensing phase, and is not considered in this chapter.

b) Surface faulting

The main or secondary fault ruptures may induce surface faulting, and this effect is considered during the nuclear site licensing phase.

c) Vibratory ground motion

Ground shaking waves, including long period waves and short period waves, due to the propagation of earthquake from both far and near field fault rupture process.

Free field vibratory ground motion may be amplified or attenuated due to site effects shown below:

1) Variations in the site specific shear wave velocity profile from seismic bedrock to the surface;

2) Site topography;

3) Basin geologic structure.

The ground motion is impacted by site conditions, and is considered in the determination of DBE.

Ground shaking waves may induce the following effects:

1) Slope failure induced by design basis vibratory ground motions, including liquefaction;

2) Sliding of structures on weak foundation materials or materials whose strength may be reduced by liquefaction;

3) Flooding and drawdown of water due to tsunami, seiche or obstructed or changing river channels, water containment failure, or high ground water;

4) Topping of the structure due to tsunamis on coastal site or seiche in reservoirs, earth slides or rock falls into reservoirs, or failure of spillway or outlet works;

5) Overturning of retaining walls;

6) Failure of items in the nuclear power plant, such as falling, toppling and breakage.

The ground shaking phenomena may affect all the items on the nuclear power plant, and the quantification of ground motion is defined as a DBE in Sub-chapter 18.6.1.2.2.

The ground shaking effects on SSCs are considered during GDA phase, and the effects on maritime work are considered during the site licensing phase.

18.6.1.2.2 Definition of Design Basis Hazards

During the GDA phase, considering the generic site envelope, the peak ground acceleration from an earthquake resulting in a UK HPR1000 safety shutdown has been selected as 0.3g, which is greater than the site-specific value calculated at most EN-6 sites in the UK, and the design adopts the certified seismic design response spectra. The zero period horizontal peak ground acceleration adopts 0.3g as the DBE.

18.6.1.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

1) Earthquake could give rise to consequential effects due to break of items, so internal flooding, internal explosion are taken into consideration;

2) Earthquake could give rise to external flooding (includes tsunami).

b) Correlated Hazards

None.

c) Independent Hazards

Some extreme weather hazards, such as, high wind and snow, may potentially act alongside an earthquake. In the design of structures, the load combinations of wind and snow with earthquake are considered.

d) Combination of External Hazards with Design Conditions

1) For the design of the reactor containment, the inner structure and the reactor internals within the pressure vessel, the load combination of DBE load and Loss of Coolant Accident (LOCA) are considered;

2) The safety systems consider the load combination of DBE and Design Basis Condition (DBC) 2 to DBC4. This ensures the ability of equipment to withstand loads during DBC long after a DBE.

18.6.1.3 Protection Measures

According to Reference [11], the protection concept shall ensure that the fundamental safety functions are fulfilled for the DBE, and all secondary effects that may adversely affect the plant are also take account, such as flooding. The protection measures for earthquake are developed in the following ways:

a) Structures design

Structures important to safety e.g. Reactor Building, are designed to withstand the DBE load defined above. The seismic analysis adopts the response spectra method and equivalent static method to determine the seismic response of structures in an earthquake. Further detailed information is provided in Chapter 16.

b) Seismic classification

All items in the building are affected by earthquake. Therefore, for the protection of SSCs against seismic load, seismic classification is an important factor.

During the seismic classification process, deterministic methods are used to specify the performance of the SSCs which have a function to bring the plant to a safe state and maintain it during or after a DBE. Seismic categorisation defines two seismic categories: Seismic Category 1 (SSE1) and Seismic Category 2 (SSE2).

1) SSCs are classified in terms of their importance to safety during or after an earthquake. The seismic category for Safety Class 1 and Class 2 and parts of Class 3 items required by the safety analysis of the seismic event is SSE1;

2) During or after an earthquake, if any consequential internal hazards caused by failure of a non-SSE1 SSC may affect SSE1 SSCs, these SSCs are defined as SSE2, which can withstand seismic load and will not affect the SSE1 SSCs. The consequential internal hazards are shown as follows:

   - Mechanical interaction with SSE1 equipment (e.g. fall or topple on SSE1 equipment);
   - Generation of missiles;
   - Effects resulting from failure of high-energy equipment;
   - Flooding resulting from failure of fluid systems;
   - Fire.

Different requirements are associated with different SSCs which may have different safety functions during a seismic event. Generally, seismic requirements are divided into four categories as follows:

1) Operability (O): Ability of an active component (including all the necessary auxiliary, supporting and energy supply systems) to fulfil its safety functions and thus meet the safety objective;

2) Functional capacity (F): Ability of all parts of components (active and passive) to withstand the specified loadings such that damage occurring to these components is limited such that their safety function is not impaired;

3) Integrity (I): Ability of active and passive components to withstand the specified loadings at the given frequency of occurrence throughout the service life of the component;

4) Stability (S): Ability of an active or passive component to withstand loads those tend to change its orientation or position (for instance, causing it to sway, fall or slide unacceptably, or causing parts to shear).

Generally, SSE1 mechanical equipment must maintain its ‘operability’ and ‘functional capacity’ function during or after a DBE, and SSE1 electrical Instrumentation and Control (I&C) equipment must maintain the ‘operability’ function during or after a DBE.

Design calculation and qualification tests to prove sufficient resistance of SSCs against seismic loads for the SSCs that have to be seismically qualified are favoured in Reference [11], and more details are provided in Chapter 4.

For the design of equipment, the floor response spectrum should be considered. Spectra are calculated at frequencies sufficiently close to produce accurate response spectra. Time history analysis method is used to generate the floor response spectra, and more details are available in Chapter 16.

c) Layout

For those SSCs that are not important to safety but can potentially affect SSE1 items, if proper layout can avoid the consequential effects of the failure of such SSCs, it is not necessary to design them as SSE2. They can be installed in a room containing no items important to safety.

18.6.1.4 Safety Assessment

Regarding required safety assessments, the following analysis are performed to ensure safety during an earthquake:

a) Design Basis Earthquake Safety Assessment

An earthquake safety assessment mainly considers the consequential hazards induced by an earthquake, and the safety assessment methodology of consequential hazards is performed as part of Reference [12].

b) Cliff-edge Effects Analysis

The cliff-edge effects of earthquake will be analysed in the following ways:

1) The certified seismic design response spectra will be adopted. During the nuclear site licensing phase, the safety margin between the generic site seismic response spectra and the specific site seismic response spectra can be identified. There will be no cliff-edge effects in earthquake protection design;

2) Appropriate classification principles and equipment layout contribute to ensuring that the SSCs important to safety are not affected by failure of non-seismic items, and the consequences of simultaneous failure of non-seismic items will not affect the delivery of safety functions;

3) The safety assessment methodology is conservative. For example, the simultaneous failures of all non-seismic items are considered, and double-ended guillotine break is considered in Reference [12].

18.6.2 External Flooding

18.6.2.1 Safety Requirements

Following a design basis external flooding event, the objective of the protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.2.2 Design Basis

The areas around the site are evaluated to determine the potential external flooding due to the following sources according to References [13] and [14]:

a) Rainfall at the site;

b) Runoff of water from off-site rainfall;

c) Snow melt (seasonal);

d) Failure of water retaining structures (hydrological, seismic and from faulty operation);

e) Failure of an existing natural obstruction created by landslides, ice, log or debris jams or volcanism (lava or ash);

f) Sliding of avalanches and/or landslides into water bodies;

g) Rising of upstream water level due to stream obstructions;

h) Changes in the natural channel for a river;

i) Storm surge;

j) Tsunamis;

k) High tides;

l) Groundwater;

m) Wind induced waves.

Coastal flooding is usually a result of a combination of different factors, such as sea water levels, storm surge, extreme rainfall, and so on. Many flooding sources mentioned above are site specific, and a site specific survey will be carried out in nuclear site licensing phase. During the GDA phase, the following factors are considered to contribute to external flooding:

a) Extreme sea level;

b) Waves;

c) Extreme Rainfall;

d) Groundwater;

e) Tsunamis.

The external flooding from the sea is considered with a frequency of 10^{-4}/yr.

18.6.2.2.1 Extreme Sea Level

The extreme sea level is a combination of high tide and weather induced storm surges and slow rising in sea level due to the climate change during the life of the plant.

Tides are periodic variations in the surface water level that result from the mutual gravitational attraction of the Earth, Sun, and Moon, their times and heights can be predicted by the tidal harmonic variables. The storm surge is caused by low atmospheric pressure effect on the open water, which can lead to sea level several meters higher than the tide alone. The slow increase in sea level depends on the greenhouse gas emissions and many other uncertainties. Combination of these factors can lead to extreme sea levels.

18.6.2.2.2 Waves

Waves are generated by wind acting on the sea surface and transfer wind energy to the water. The wave height and length depend on the wind speed, the duration over which the wind action exists, and the available fetch. The maximum wave height condition is considered.

18.6.2.2.3 Extreme Rainfall

According to Reference [8], the design basis rainfall is 163mm (1h)/228mm (24h) with a frequency of 10^{-4}/yr, and when considering climate change, these values become 198mm (1h)/294mm (24h). For the UK HPR1000 design, the bounding parameter considered for design basis rainfall is 326mm (1h)/1320mm (24h) according to PCSR Chapter 3.

18.6.2.2.4 Groundwater

The groundwater is characterised by the elevation of the water table and the speed of change. The structures important to safety may be affected by the buoyancy effect of the groundwater, and the infiltration of groundwater may affect the systems and components housed inside the structures. As the groundwater is site specific, the actual value will be compared to the site platform value once the site is nominated.

18.6.2.2.5 Tsunamis

The occurrence of underwater and near shore seismic or volcanic activity in the site region is an indication of the occurrence of local tsunamis at the site according to Reference [5]. The long waves of a tsunami are compressed into shorter waves with substantial crest height when they approach the coastline. When the waves eventually break, it may destroy natural and artificial sea defences or change their state profoundly.

18.6.2.2.6 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate external flooding hazard combinations that have been identified are listed below:

a) Consequential Hazards

External flooding could give rise to internal flooding.

b) Correlated Hazards

1) External flooding is correlated with heavy rainfall;

2) External flooding is correlated with high ground water level;

3) External flooding is correlated with massive clogging.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) External flooding could give rise to LOOP;

2) External flooding could give rise to LUHS;

3) External flooding could give rise to LOOP and LUHS.

18.6.2.3 Protection Measures

The SSCs important to safety are adequately protected against the effects of external flooding. The general protection measures may include:

a) Setting the nuclear power site platform sufficiently high;

b) Placing systems and components important to safety at sufficient elevation where practicable;

c) Designing a suitable water drainage system;

d) Designing seawalls for protection;

e) Designing water sealing for penetrations and doors in boundary of buildings;

f) Designing waterproof buildings housing systems and components important to safety;

g) Selecting appropriate material to counter the erosive effects of water.

18.6.2.3.1 Volumetric Protection

The Volumetric Protection is a watertight volume of protection against external flooding events which ensures no water ingress into the rooms which house systems and components important to safety. All the civil structures important to safety can withstand the design basis external flooding. Above the ground, watertight doors and sealed penetrations of structures important to safety are designed to resist a 2m depth of water. Watertight doors and sealed penetrations underground, on the boundary of structures important to safety are designed to resist 10m depth of water. And the ground floor elevation is 0.3m higher than site elevation. So there is 2.3m margin above the site ground elevation.

18.6.2.3.2 Drainage System

The design of the drainage system is based on extreme rainfall, which includes the effects of climate change that increase the intensity of rainfall. The ground design is determined and the drainage system features the required number of pipes of sufficient diameter to allow unimpeded draining of water to the underground drainage system or to storm drains. Building roofs feature sufficient guttering and drainage to prevent collection of water on rooftops.

18.6.2.3.3 Groundwater Protection

Structures important to safety are designed to ensure they can resist the infiltration of normal groundwater up to the site platform and the buoyancy effect produced by the groundwater.

18.6.2.4 Safety Assessment

This sub-chapter describes the approach to be taken for the external flooding safety assessment, which demonstrates the robustness of the design.

a) Design Basis External Flooding Safety Assessment

   For the design basis conditions, the following aspects are assessed to ensure that the items important to safety are not affected by external flooding. The external flooding safety assessment methodology is performed in Reference [15].

   1) Evaluation of site ground elevation, ground floor elevation;

   2) Evaluation of possible flood flow paths from penetrations and doors at the boundaries of buildings (except for building roofs);

   3) Evaluation of possible flood flow paths from holes and doors on building roofs;

   4) Evaluation of possible flood flow paths from interfaces between the buildings and the galleries.

b) Cliff-edge Effects Analysis

   The cliff-edge effects of external flooding are analysed in the following ways:

1) Watertight doors and sealed penetrations are designed to resist water levels of 2m or 10m according to their location, so that there is a margin against external flooding on the site;

2) The drainage system is conservatively designed to cope sufficiently with severe precipitation;

3) The structures are conservatively designed to withstand additional buoyancy effects due to the extreme groundwater levels and the flood water on the site platform;

4) Seawalls will be conservatively designed against sea water levels and waves once the specific site is known.

For external flooding, some administrative measures are also considered as follows:

1) Weather forecasting and warning systems can provide enough time for operators to shut down the reactor or implement emergency procedures;

2) Mobile protection devices may be used if their effectiveness has been demonstrated, such as sandbags, temporary pumps.

18.6.3 Meteorological Conditions

Meteorological phenomena can cause several hazards that independently, or in combination, could affect the safety of nuclear installations.

Meteorological conditions considered during the GDA phase include extreme wind, wind generated missiles, tornado, extreme air/water temperature, extreme hail, sleet, snow and icing and lightning.

18.6.3.1 Extreme Wind

18.6.3.1.1 Safety Requirements

Following design basis extreme wind conditions, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.3.1.2 Design Basis

18.6.3.1.2.1 Extreme Wind Characterisation

Wind comes from many forms and is influenced by many factors, including location, altitude, direction and topography. Sources of extreme wind include:

a) Cyclones;

b) Tornadoes;

c) Sustained high winds.

Extreme wind can affect the structural integrity and the pressure differential could affect the ventilation system functions. Reference [13] notes that operating experience in nuclear power plants shows that extreme wind mainly affects the power supply and availability of the electricity grid. Damage caused by extreme wind may result in LOOP.

Wind generated missiles are considered in Sub-chapter 18.6.3.2, and tornado is considered individually in Sub-chapter 18.6.3.3.

18.6.3.1.2.2 Definition of Design Basis Hazards

According to Reference [8], an effective wind speed value of 58 m/s is derived for the generic site envelope value of the wind speed. However, the design value of 80m/s in Chapter 3 which is more conservative is adopted to provide greater margin.

The complex concurrent atmospheric and oceanic effects lead to little or uncertain changes in the frequency and intensity of storms over the UK, Reference [6]. For this reason, no climate change value has been incorporated into the derived wind speed value.

18.6.3.1.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

   1) Extreme wind could give rise to external missiles;

   2) Extreme wind could give rise to external flooding.

b) Correlated Hazards

   Extreme wind is correlated with extreme snow.

c) Independent Hazards

   None.

d) Combination of External Hazards with Design Conditions

   1) Extreme wind could give rise to LOOP;

   2) Extreme wind could give rise to LUHS;

   3) Extreme wind could give rise to LOOP and LUHS.

18.6.3.1.3 Protection Measures

To meet the safety requirements, the protection measures aim to resist the load caused by extreme wind.

Systems and components important to safety inside the buildings are protected against wind load by the civil structures of buildings as mentioned in Sub-chapter 16.6 of Chapter 16. Systems and components important to safety outside the buildings are designed to withstand extreme wind load, such as the Atmospheric Steam Dump System (VDA [ASDS]) silencers which are located on the roof of the Safeguard Building.

18.6.3.1.4 Safety Assessment

a) Design Basis Extreme Wind Safety Assessment

The safety assessment of extreme wind is to demonstrate that the plant has sufficient protection to ensure the fulfilment of safety functions in case of this hazard. The main steps of the assessment are shown below:

1) Assessment scope identification

The assessment scope contains the buildings important to safety and buildings which, if damaged, may affect the surrounding buildings important to safety, which is shown in the scope of Sub-chapter 18.4.2.

2) Assessment items identification

Based on the assessment scope, the assessment items contain the structures above ground and the openings on the boundaries.

3) Availability assessment of protection measure

The protection measures will be assessed to ensure that they can deliver their required function in case of design basis extreme wind and protect the systems and components important to safety inside the building.

4) Design iteration

If the assessment result shows that the protection measures are not available or sufficient, additional measures will be added or a design modification will be carried out.

b) Cliff-edge Effects Analysis

The conservative design is used to demonstrate that under design basis extreme wind there is no cliff-edge effect:

1) The design basis wind speed used for the UK HPR1000 design is conservative and is much higher than the generic site envelope value;

2) The structure of buildings important to safety and the dampers of Heating Ventilation and Air Conditioning (HVAC) system important to safety are

designed with sufficient margin.

18.6.3.2 Extreme Wind Generated Missiles

18.6.3.2.1 Safety Requirements

Following a design basis extreme wind generated missile, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.3.2.2 Design Basis

18.6.3.2.2.1 Extreme Wind Characterisation

Extreme wind can give rise to missiles which could affect the performance of SSCs important to safety. It should be noted that tornado missiles are discussed in Sub-chapter 18.6.3.3. This sub-chapter only discusses the missiles generated by cyclones and high winds.

18.6.3.2.2.2 Definition of Design Basis Hazards

As stated in Reference [8], wind generated missiles are considered by expert judgement to be bounded by tornado missiles.

18.6.3.2.2.3 Hazard Combinations

Wind generated missiles are bounded by tornado missiles, thus, the hazard combinations of wind generated missiles is also bounded by the hazard combinations of tornado missiles which is described in Sub-chapter 18.6.3.3.2.3.

18.6.3.2.3 Protection Measures

As mentioned in Sub-chapter 18.6.3.2.2, wind generated missiles are bounded by tornado missiles. According to Sub-chapter 16.6.2.3 of Chapter 16, the civil structure is designed to resist the load caused by tornado missiles, and the openings of HVAC systems important to safety are protected by tornado-protection dampers. Therefore, no additional protection measures, beyond those for tornado events, are required to protect against wind generated missiles.

18.6.3.2.4 Safety Assessment

Wind generated missiles are bounded by tornado missiles. The safety assessment is shown in Sub-chapter 18.6.3.3.4.

18.6.3.3 Tornado

18.6.3.3.1 Safety Requirements

Following a design basis tornado, the objective of the protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.3.3.2 Design Basis

18.6.3.3.2.1 Tornado Characterisation

Tornadoes are generally described as violently rotating columns of air, usually associated with a storm. A tornado is a source of missiles and rain in Reference [16], and this sub-chapter concentrates on the tornado loads and tornado-generated missiles; the rain effect is covered under Sub-chapter 18.6.2.

According to Reference [16], if a tornado strikes plant buildings or structures, damage may be caused by the following effects:

a) The battering effect of high winds;

b) The sudden pressure drop which accompanies the passage of the centre of a tornado;

c) The impact of tornado-generated missiles on plant structures and equipment.

18.6.3.3.2.2 Definition of Design Basis Hazards

According to Reference [8], the tornado wind speed, pressure drop and pressure drop rate for the UK HPR1000 generic site envelope are as follows:

a) Tornado wind speed: 60m/s;

b) Pressure drop: 3.1kPa;

c) Pressure drop rate: 0.94kPa/s.

The adopted design basis tornado parameters are shown in Chapter 3 according to RG 1.76, Reference [17], which provides additional design margin for the design of the UK HPR1000:

a) Tornado wind speed: 89m/s;

b) Pressure drop: 6.3kPa;

c) Pressure drop rate: 2.5kPa/s.

The design basis tornado parameters are greater than the UK HPR1000 generic site envelope value, and the design basis tornado missiles adopted for UK HPR1000 are shown in T-18.6-1, according to RG 1.76 in Reference [17].

T-18.6-1 Design Basis Tornado Missiles

Missile Type	**Dimensions(m)**	**Mass(kg)**	**Speed(m/s)**	**Height(m)**
Automobile	5×2×1.3	1810	34	9.14

Missile Type	Dimensions(m)	Mass(kg)	Speed(m/s)	Height(m)
Schedule 40 pipe	0.168(dia)×4.58(long)	130	34	Any height
Solid steel sphere	0.0254(dia)	0.0669	7	Any height

18.6.3.3.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

Tornados could give rise to external missiles.

b) Correlated Hazards

A tornado event is correlated with rain.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) Tornados could give rise to LOOP;

2) Tornados could give rise to LUHS;

3) Tornados could give rise to LOOP and LUHS.

18.6.3.3.3 Protection Measures

A tornado and any generated missiles may affect SSCs important to safety. The protection measures are as follows:

a) All the civil structures which contain the systems and components important to safety are designed to resist design basis tornado loads and the design basis tornado missiles;

b) The pressure drop and missiles caused by a tornado may enter the buildings through the openings of civil structures (such as the opening of ventilation systems and doors). If SSCs important to safety are at risk, protection measures are to be proposed, such as installation of tornado-protection dampers which can close automatically to protect against the effects of tornado;

c) Systems and components important to safety outside the buildings are designed to withstand the design basis tornado load and tornado-induced missiles, such as the VDA [ASDS] silencers which are located on the roof of safeguard buildings;

d) Tornados can affect the power supply and availability of grid. This may result in LOOP, and the systems dealing with LOOP are protected from tornado loads, such as emergency power supply systems;

e) Tornados may cause LUHS, and so alternative cooling systems (such as the Extra Cooling System (ECS [ECS])) are to be available in the event of a tornado.

18.6.3.3.4 Safety Assessment

a) Design Basis Tornado Safety Assessment

Each SSC will be assessed according to their safety function category according to Reference [18]. This task includes an examination of the openings of the structure and an assessment of civil structures.

The safety assessment ensures that SSCs can deliver their required function. For example, the dampers for HVAC systems important to safety perform their functions under design basis tornado loads.

b) Cliff-edge Effects Analysis

The cliff-edge effects for tornados are analysed in the following ways:

1) The structures of buildings important to safety are designed to accommodate extreme loads such as those resulting from aircraft impacts or earthquake. Such structures can withstand loadings resulting from tornado wind pressure and missiles with sufficient margin;

2) The tornado-protection dampers and the protection measures of the openings can withstand a maximum overpressure of 20kPa, presenting significant margin to the design basis tornado pressure;

3) The inverse ‘L’ civil structures which open towards the ground can withstand tornado-generated missiles with enough margins.

18.6.3.4 Extreme Temperature

18.6.3.4.1 Safety Requirements

Following a design basis extreme temperature event, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.3.4.2 Design Basis

18.6.3.4.2.1 Extreme Temperature Characterisation

Extreme ambient temperatures (air and sea) include extreme high or low temperatures. Extreme temperature can potentially challenge the electrical and instrumentation equipment important to safety and also the cooling systems.

18.6.3.4.2.2 Definition of Design Basis Hazards

According to Reference [8], the maximum air temperature value is 41.5℃ for the UK HPR1000 Generic Site Envelope. A maximum air temperature climate change value of 5.4℃ has been selected from Reference [6].

The minimum air temperature value has also been obtained from Reference [8]. The minimum air temperature is -22℃ for the UK HPR1000 Generic Site Envelope. A climate change value has not been calculated for minimum air temperature, as Reference [6] indicates that temperatures in the UK will rise during the next 60 years. The value presented is therefore deemed conservative.

The maximum water temperature value is 28℃ based on Reference [8], and a climate change value of 4℃ is considered according to Reference [6]. The minimum water temperature value of -2℃ is selected as this is the lowest temperature of salt water before freezing.

T-18.6-2 Generic Site Envelope Temperature Values

Parameter	Proposed Generic Site Envelope Value	Climate Change Consideration
Maximum Air Temperature (Dry bulb)	41.5℃	+5.4℃
Minimum Air Temperature (Dry bulb)	-22℃	---
Maximum Sea Water Temperature	28℃	+4℃
Minimum Sea Water Temperature	-2℃	---

18.6.3.4.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, the appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

   1) Extreme low temperatures could give rise to icing;

   2) Extreme high temperatures could give rise to fire.

   3) Extreme high temperatures could give rise to low water level.

b) Correlated Hazards

   None.

c) Independent Hazards

   None.

d) Combinations of External Hazards with Design Conditions

1) Extreme temperatures could give rise to LOOP;

2) Extreme temperatures could give rise to LUHS;

3) Extreme temperatures could give rise to LOOP and LUHS.

18.6.3.4.3 Protection Measures

To achieve the safety requirements, the protection measures aim to ensure that those items important to safety can fulfil their functions over the range of temperatures considered as the design basis conditions for the UK HPR1000.

The HVAC system design will take the extreme air temperatures and climate change into consideration and will maintain the ambient temperature of equipment important to safety to within the appropriate operating range. Further information is shown in Chapter 10.

The civil structures of buildings important to safety are designed to withstand extreme high and low air temperatures. As stated in Sub-chapter 16.6 of Chapter 16, extreme temperature values are used to calculate the thermal effect of the civil structures based on the temperature gradient.

Extreme high water temperatures may affect the heat removal function of cooling systems, particularly with regards to the Essential Service Water System (SEC [ESWS]) and Component Cooling Water System (RRI [CCWS]). The designs of the SEC [ESWS] and RRI [CCWS] will consider the effects of extreme high water temperature, and will ensure their ability to remove heat from the plant is sufficient, further information is presented in Sub-chapter 10.4 of Chapter 10.

Icing induced by extreme low water temperature may affect the water intake of cooling systems. The water intake shall be located deep enough to avoid freezing. Other protection measures to protect the water intakes against ice formation are covered in Sub-chapter 18.6.6.

18.6.3.4.4 Safety Assessment

a) Design Basis Extreme Temperature Safety Assessment

The extreme temperature safety assessment is required to demonstrate that the plant has sufficient protection to ensure the fulfilment of safety functions in the event of extreme temperature conditions. The main steps of the assessment are shown as follows:

1) Assessment Scope Identification

The assessment scope contains the buildings important to safety and buildings which, if damaged, may affect surrounding buildings important to safety, which is part of the scope of Sub-chapter 18.4.2.

2) Assessment Items Identification

Based on the assessment scope, items assessed include the HVAC systems and cooling systems important to maintaining safety functions.

3) Availability Assessment for Protection Measures

The HVAC systems shall be assessed to ensure that they can maintain the indoor temperature in the event of extreme temperatures. The cooling systems shall be assessed to ensure that they can remove the heat in case of extreme temperature conditions.

4) Design Iteration

If the assessment results show that the protection measures are not available or sufficient, additional measures will be added or design modifications will be carried out to ensure sufficient protection is available.

b) Cliff-edge Effects Analysis

Conservative design is used to demonstrate that under design basis extreme temperature there is no cliff-edge effect:

1) The design basis temperatures used for the UK HPR1000 design is conservative. The generic site envelop value is chosen to be the design basis and a temperature increase caused by climate change is added to determine the design basis extreme high temperature;

2) The weather forecast has the potential to alert the operators that an extreme temperature event will occur and inform the decision on whether to shut down the reactor;

3) The design of the HVAC systems and cooling systems important to safety will operate with sufficient margin during extreme temperatures.

18.6.3.5 Extreme Hail, Sleet, Snow and Icing

18.6.3.5.1 Safety Requirements

During and following Design Basis extreme hail, sleet, snow and icing, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.3.5.2 Design Basis

18.6.3.5.2.1 Extreme Hail, Sleet, Snow and Icing Characterisation

The effects of extreme hail, sleet, snow and icing include structure loading, damage to the heat sink and plant flooding. The blockage of the water intake by ice is considered in Sub-chapter 18.6.6. Sleet and snowmelt may cause flooding and this is considered under Sub-chapter 18.6.2.

18.6.3.5.2.2 Definition of Design Basis Hazards

Ground snow loading for the UK HPR1000 Generic Site Envelope is determined under Reference [8]. Hail and sleet values have not been selected as they are deemed to be bounded by snow load.

The design basis value for snow load is taken at a frequency of 10^{-4}/yr. The ground snow level value is selected as 1.5kPa as a design basis load. A climate change value has not been incorporated into snow loads, as climate change predictions indicate that temperatures are increasing, therefore the value presented is deemed to be conservative.

To conclude, the snow load is considered to be uniform and a design basis of 1.5kPa is determined.

18.6.3.5.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

Extreme hail, sleet, snow and icing could give rise to external flooding.

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) External hail, sleet, snow and icing could give rise to LOOP;

2) External hail, sleet, snow and icing could give rise to LUHS;

3) External hail, sleet, snow and icing could give rise to LOOP and LUHS.

18.6.3.5.3 Protection Measures

Systems and components important to safety inside the buildings are protected against snow loading by the civil structures of buildings important to safety. The snow and icing loads are considered in the design of civil structures important to safety in Sub-chapter 16.6.2.3 of Chapter 16. Systems and components important to safety outside the buildings are designed to withstand extreme snow load.

18.6.3.5.4 Safety Assessment

a) Design Basis Extreme Hail, Sleet, Snow and Icing Assessment

Snow and icing loads are taken into account for the building structure design. The structures are assessed to ensure their function under snow and icing loads.

b) Cliff-edge Effects Analysis

A conservative design is used to demonstrate that under design basis extreme hail, sleet, snow and icing there is no cliff-edge effect:

1) The design basis snow load used for the UK HPR1000 design is conservative and takes climate change into account;

2) Structures of buildings important to safety are designed to accommodate extreme loads. Such structures can withstand extreme hail, sleet, snow and icing loads with sufficient margin.

18.6.3.6 Lightning

18.6.3.6.1 Safety Requirements

Following a design basis lightning strike, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.3.6.2 Design Basis

18.6.3.6.2.1 Lightning Hazard Characterisation

According to Reference [13], lightning is a visible electrical discharge most commonly produced in thunderstorms, and lightning transients exhibit extremely high voltages, currents and current rise rates. Damage is usually categorised as either direct or induced (indirect) damage. The extreme electric field created under certain circumstances produces point discharges and can cause breakdown in all but the most robust of insulators.

It is not currently possible to predict when and where lightning will strike, statistical information can provide some indication of the areas prone to lightning activity as well as the seasons when such activity is most likely to occur. Lightning is an unpredictable transient phenomenon with characteristics that vary widely from flash to flash and whose measurement is difficult.

The effects of lightning contribute to the consequences, which may be:

a) Electrical fires;

b) Explosion;

c) Loss of SSC safety functions;

d) Breaches of building containment and structural damage, e.g. damage to offsite electricity transmission lines leading to LOOP;

e) Damage due to electrical surges;

f) Electromagnetic pulses generated from close strikes;

g) Damage to telephones, computers and other electronic devices leading to loss of safety function;

h) Conventional health & safety risks to personnel on site.

18.6.3.6.2.2 Definition of Design Basis Hazards

The UK HPR1000 lightning protection design complies with the technical guideline IEC 62305-1(2010), Reference [19]. According to the IEC 62305-1(2010), four lightning protection levels (I to IV) are introduced. The maximum values of lightning current parameters for the different lightning protection levels are given in T-18.6-3, and are used to design lightning protection components.

The design basis value of lightning is Level I, which is the highest of the four levels of protection.

T-18.6-3 Maximum Values of Lightning Parameters

First positive impulse			**Lightning protection levels**			
Current Parameters	symbol	Unit	I	II	III	IV
Peak Current	I	kA	200	150	100	
Impulse Charge	Q_{SHORT}	C	100	75	50	
Specific Energy	W/R	MJ/Ω	10	5.6	2.5	
Time Parameters	T_1/T_2	μs /μs	10/350			
First negative impulse[a]			**Lightning protection levels**			
Current parameters	symbol	Unit	I	II	III	IV
Peak Current	I	kA	100	75	50	
Average Steepness	di/dt	kA/μs	100	75	50	
Time Parameters	T_1/T_2	μs /μs	1/200			
Subsequent impulse			**Lightning protection levels**			
Current parameters	symbol	Unit	I	II	III	IV
Peak Current	I	kA	50	37.5	25	
Average Steepness	di/dt	kA/μs	200	150	100	
Time Parameters	T_1/T_2	μs /μs	0.25/100			

Long stroke			Lightning protection levels			
Current parameters	symbol	Unit	I	II	III	IV
Long Stroke Charge	Q_{LONG}	C	200	150	100	
Time Parameters	T_{LONG}	s	0.5			
Flash			**Lightning protection levels**			
Current parameters	symbol	Unit	I	II	III	IV
Flash Charge	Q_{FLASH}	C	300	225	150	
[a] The use of this current shape concerns only calculations and not testing.						

The design of direct-strike lightning protection and the associated grounding depends on the lightning activity at the plant site and the soil resistivity which can only be determined on a site specific basis once a site has been nominated.

18.6.3.6.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

A lightning strike could give rise to fire and explosion.

b) Correlated Hazards

Lightning is correlated with rainfall.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

A lightning strike could give rise to LOOP.

18.6.3.6.3 Protection Measures

The lightning protection measures and the electrical equipment should be designed and coordinated with each other such that the influence of lightning strikes on electrical facilities will not lead to unacceptable effects on plant safety (e.g. inhibition or spurious activation of protective actions, lightning-induced fires or failure of components required by the protection concept).

Earthing and lightning protection system mainly performs the role of limiting the risks of overvoltage on the electrical systems, reducing the electromagnetic effects of lightning currents and ensuring the safety of personnel and equipment in the power plant.

This system includes external and internal lightning protection systems. For external lightning protection system, it includes air-termination systems, shielding in outer walls of the buildings, down-conductor systems and an interconnected earthing termination system. It is to conduct the lightning current down to the earth safely and disperse it to earth when it is struck by lightning. For internal lightning protection system, it takes some measures such as shielding in inner floors of buildings, cable ducts and outdoor cabling to reduce the electromagnetic effects of lightning currents and protect the internal equipment. The more detailed information is described in Chapter 9 Electric Power. The design of internal and external earthing systems can ensure personnel safety in any possible situation during lightning, and it is also applied to communication systems, process control systems, fire alarm systems, etc. Systems and components important to safety outside the buildings are designed to against lightning.

18.6.3.6.4 Safety Assessment

Lightning strike is related to the specific site, a mapping of potential lightning strikes within the site is performed. This map is required to identify the location of all potential lightning strikes and target equipment which can be struck.

In general, the highest protection level is used for the design, to incorporate margin against a lightning strike. The earthing and lightning protection system will protect the items important to safety.

18.6.4 Man Made and Industrial Hazards

During the GDA phase, the accidental aircraft crash, external explosion and off-site missiles are considered. Other man-made and industrial hazards such as structural failure, gas clouds, etc. are considered until the nuclear site licensing phase.

18.6.4.1 Accidental Aircraft Crash

This sub-chapter concentrates on the accidental aircraft crash hazard. Intentional aircraft crash is not presented in the PCSR due to its security-related nature, and separate documentation is to be provided to address this hazard.

18.6.4.1.1 Safety Requirements

Following a design basis aircraft crash, the objective of the protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.4.1.2 Design Basis

18.6.4.1.2.1 Aircraft Crash Characterisation

The following hazard consequences are considered in line with Reference [13]:

a) The global structural damage of the affected structures, including structure collapse or overturning, excessive structural deformations or displacements which prevent the structure from performing its function;

b) Functional failure of systems and components due to induced vibrations, particularly when items important to safety are located close to the external perimeter of the structures;

c) Localised structural damage due to the effects of missile impact, including penetration, perforation, scabbing and spalling, leading to failure of a structural element or of safety and safety related SSCs as a result of the effects of primary and secondary missiles;

d) The effects of fuel initiated fires and possible explosion on SSCs.

18.6.4.1.2.2 Categorising and Screening of Accidental Aircraft Crash

Aircraft are normally categorised to take account of different characteristics, such as the mass and velocity, and the following five categories of aircraft are typically considered according to Reference [8]:

a) Light aircraft;

b) Helicopters;

c) Small transport aircraft;

d) Large transport aircraft;

e) Military combat aircraft.

The approach for protection against an accidental aircraft crash is deterministic and is based on specific scenarios applied to different categories of aircraft. If one kind of aircraft crash rate is higher than the screening frequency, which is 10^{-7}/yr according to Reference [1], this kind of aircraft is considered. The background crash rate of each category of aircraft is given in Reference [8], which is shown in the T-18.6-4:

T-18.6-4 Aircraft Crash Rate

Aircraft Category	**Background Crash Rate ($km^{-2}yr^{-1}\times10^{-5}$)**
Light aircraft	2.04
Helicopters	1.05
Small transport aircraft	0.26
Large transport aircraft	0.11

Aircraft Category	Background Crash Rate ($km^{-2}yr^{-1}\times10^{-5}$)
Military combat aircraft	0.41
Total	3.87

The crash rate needs to consider UK regulations. Flying within the vicinity of UK nuclear sites is restricted by UK air navigation regulations. All the designated UK nuclear sites have restrictions on aircraft flight within specific vicinity, as described in Reference [20].

Once the crash rates of each accidental aircraft crash are determined, the parameters of the representative aircraft are specified to ensure conservative loadings are developed for the aircraft crash.

18.6.4.1.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

1) Aircraft crash could give rise to external missiles;

2) Aircraft crash could give rise to fire and possible explosion.

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

None.

18.6.4.1.3 Protection Measures

To achieve the safety requirements, the protection measures aim to prevent an aircraft crash from entering into the buildings important to safety.

All of the civil structures that contain systems and components important to safety are designed to resist the impact loads of aircraft crash. Further information is shown in Chapter 16 Civil Works & Structures. The consequential hazards of aircraft crash are considered in the protection measures of aircraft crash.

18.6.4.1.4 Safety Assessment

a) Aircraft Crash Safety Assessment

The assessment methods are undertaken to make sure the SSCs are robust against the effects of accidental aircraft crash, including the following:

1) The global structural damage effect of an aircraft crash and aircraft-induced vibration are conservatively simulated in Reference [21]. Structures are reasonably simplified and selected to build the geometric model. Boundary conditions are determined, and then the computational analysis is performed. The results are checked whether the safety functions are challenged;

2) Fuel-initiated fires from an aircraft are simulated by using the methodology in Reference [21];

3) The calculation of local structural damage is based on empirical formula methods as provided in Reference [22].

b) Cliff-edge Effects Analysis

The following aspects are assessed:

1) Conservative parameters selected for the analysis effect of aircraft crash are used in the modelling;

2) The shell of buildings important to safety are designed against the aircraft crash loads;

3) The protection measures (such as the special structures, fire dampers, fire resistant door, etc.) are used to resist the fire to enter the building.

18.6.4.2 External Explosion

18.6.4.2.1 Safety Requirements

Following a design basis external explosion, the objective of the protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

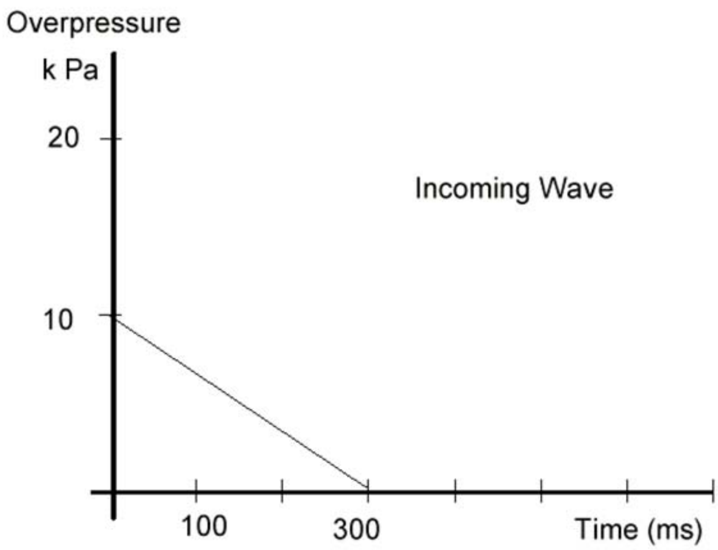
18.6.4.2.2 Design Basis

18.6.4.2.2.1 External Explosion Characterisation

According to Reference [13], an external explosion can affect the entire plant, and it may take the form of a deflagration, which generates moderate pressures, heat or fire, or a detonation which generates high pressures and thermal effects. These effects mainly depend on the explosive substances and the distance from the structure under consideration to the source of the explosion. So external explosion is mainly a site specific hazard, a site specific survey will be carried out once the site is confirmed.

18.6.4.2.2.2 Definition of Design Basis Hazards

A standard load-time function derived from pressure waves is used as a design basis load. It is a triangular pressure wave with a tight wave front, reaching a maximum overpressure of 10kPa and duration of 300ms (see F-18.6-1).



F-18.6-1 Standard load-time function for Explosion Pressure Wave

While determining the maximum overpressure wave applied on the flat wall, reflection and superimposition effects must be considered. For vertical walls, due to the reflection of the horizontal blast wave, a reflection factor of 2 is applied, that is to say, the maximum overpressure will be equal to 2 times the maximum value of the incident overpressure wave.

18.6.4.2.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

   1) External explosion could give rise to external missiles;

   2) External explosion could give rise to internal and external fire;

   3) External explosion could give rise to internal flooding.

b) Correlated Hazards

   None.

c) Independent Hazards

   None.

d) Combination of External Hazards with Design Conditions

1) External explosion could give rise to LOOP;

2) External explosion could give rise to LUHS.

18.6.4.2.3 Protection Measures

To achieve the safety requirements, the protection measures aim to prevent the blast wave of design basis external explosion from entering into the buildings important to safety.

Systems and components important to safety inside the buildings are protected against external explosion by the civil structures. Systems and components important to safety outside the buildings are designed to withstand explosion pressure load, such as the silencers of VDA [ASDS] which are located on the roof of the safeguard building.

Extreme environmental loads are already considered for the design of civil structures, under tornado pressure load. According to Reference [13], structures that have been designed to accommodate extreme load are capable of withstanding substantial overpressures without compromising the essential functions of the systems important to safety that they house. Thus, civil structures are able to withstand design basis external explosions. Moreover the design basis blast wave is considered in structure design, and further information is shown in Sub-chapter 16.6.2.3 of Chapter 16.

For the openings in the boundaries of buildings important to safety, doors are designed to withstand the blast wave of external explosion. The inlets of HVAC systems important to safety will be protected by Explosion Pressure Wave (EPW) dampers which can automatically close due to the differential pressure. EPW dampers are designed to withstand an overpressure of 20kPa.

18.6.4.2.4 Safety Assessment

a) Design Basis External Explosion Assessment

The safety assessment for external explosion shall demonstrate that the plant has sufficient protection to ensure the fulfilment of safety functions following this hazard. The main steps of the assessment are as follows, and more detailed information is shown in Reference [23]:

1) Assessment Scope Identification

The assessment scope contains the buildings important to safety and buildings which, if damaged, may affect the surrounding buildings important to safety.

2) Assessment Items Identification

Based on the assessment scope, the assessment items contain the structures above ground and the openings on the boundaries.

3) Availability Assessment of Protection Measures

The protection measures will be assessed to ensure that they can prevent the blast wave from entering the relevant building and can protect the systems and components important to safety.

4) Design Iteration

If the assessment results show that the protection measures are not sufficient, additional measures shall be added and/or design modification should be carried out as appropriate.

b) Cliff-edge Effects Analysis

The factors of external explosion will be identified by the specific site conditions. However, for the GDA phase, a conservative design is used to demonstrate that under design basis external explosion there are no cliff-edge effects, including:

1) Even if there is no explosion source outside the site, the external explosive loads are considered in the design with a triangular pressure wave with a tight wave front, reaching a maximum overpressure of 10kPa;

2) Structures of buildings important to safety have been designed to accommodate extreme loads such as aircraft crash impact load, tornado generated missile load or seismic load. Such structures will withstand external explosive loads with enough margin;

3) The EPW dampers and the protection measures of the openings are conservatively designed and will withstand twice the maximum overpressure wave value by considering the reflection from higher buildings.

18.6.4.3 Off-site Missiles

18.6.4.3.1 Safety Requirements

Following a design basis off-site missile event, the objective of the protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.4.3.2 Design basis

18.6.4.3.2.1 Off-site Missile Characterisation

The term ‘missile’ is used to describe a moving object that is capable of striking any component of the plant, including:

a) Wind-induced missiles;

b) Man-made missiles from adjacent areas.

Wind generated missiles and tornado missiles are discussed respectively in

Sub-chapter 18.6.3.2 and Sub-chapter 18.6.3.3, this sub-chapter focuses on missiles from adjacent areas.

18.6.4.3.2.2 Design Basis

Adjacent area missiles may be generated by explosion on adjacent facilities. The design basis is site-specific and cannot be determined during the GDA phase. The specific scenarios will be investigated during the site specific phase.

18.6.4.3.2.3 Hazard Combinations

a) Consequential Hazards

Normally they can be bounded by tornado missiles.

b) Correlated Hazards

Normally they can be bounded by tornado missiles.

c) Independent Hazards

Normally they can be bounded by tornado missiles.

d) Combination of External Hazards with Design Conditions

Normally they can be bounded by tornado missiles.

18.6.4.3.3 Protection Measures

To achieve the safety requirements, the protection measures aim to resist the load caused by missiles from adjacent areas.

Systems and components important to safety inside the buildings are protected against off-site missile load by the civil structures. As mentioned in Chapter 16, the design of the civil structure takes the missile load into consideration. Systems and components important to safety outside the buildings are designed to withstand adjacent area missiles.

In addition, the protection measures for tornado missiles which are mentioned in Sub-chapter 18.6.3.3 are also available to protect against missiles from adjacent areas.

18.6.4.3.4 Safety Assessment

As UK HPR1000 is designed to accommodate the effects of tornado missiles and aircraft crash, the loads caused by missiles generated by an explosion are bounded by the loads exerted by tornado missiles or aircraft crash.

However, such events will be assessed on a site-specific basis, although it is unlikely that such missiles from adjacent areas would be more challenging than the design basis missiles from the design basis tornado scenario.

18.6.5 Electromagnetic Interference and Space Weather

18.6.5.1 Electromagnetic Interference

18.6.5.1.1 Safety Requirements

Following design basis EMI, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.5.1.2 Design Basis

18.6.5.1.2.1 Electromagnetic Interference Hazard Characterisation

EMI is a disturbance that affects an electrical circuit due to electro-magnetic radiation emitted from an external source. The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit. The source may be any object, artificial or natural, that carries rapidly changing electrical currents, includes:

a) Man-made sources: such as radar, radio interference or the telephone network, etc.;

b) Natural sources: such as a result of lightning strikes, extra-terrestrial source (typically the Sun).

The sources of EMI will be identified and characterised during the site specific stage once the site has been determined.

18.6.5.1.2.2 Definition of Design Basis Hazards

EMI can affect the functionality of electronic devices important to safety, and it is not currently possible to predict when and where EMI will happen, especially for man-made sources.

Usual practice is to adopt the bounding case for EMI protection design. EMI from a lightning strike is described in the Sub-chapter 18.6.3.6. EMI from space weather is described in the Sub-chapter 18.6.5.2.

18.6.5.1.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

None.

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

EMI could give rise to faults (caused by malfunction of I&C equipment).

18.6.5.1.3 Protection Measures

An EMI hazard will not prevent the delivery of the safety functions. The protection measures have been taken into consideration in the design of UK HPR1000 as follows:

a) Transferring the EMI sources out of the influence scope if the EMI sources can affect the equipment important to safety;

b) Providing appropriate shielding to equipment important to safety which is sensitive to EMI from outside the site.

Appropriate qualification of equipment is assessed to protect from off-site EMI.

EMI protection is undertaken through the design adhering to appropriate international standards. The Electromagnetic Compatibility (EMC) test is conducted for I&C equipment which described in Chapter 8 Instrumentation and Control.

EMC test is one of tests for the qualification of I&C and it shows that I&C equipment has the capacity to resist EMI caused by ground level enhancements. EMC test includes conducted emission test, radiated emission test, harmonic immunity of alternating current power lines test, conducted susceptibility induced by radio frequency field, electrical fast transient, combination wave, ring wave, test of 0kHz~150kHz immunity to conducted common mode disturbance, radiated susceptibility, power frequency magnetic field immunity, pulsed magnet field immunity, damped magnet field immunity and electro static discharge test. The EMC test is conducted for I&C equipment which are described in Chapter 8 Instrumentation and Control.

18.6.5.1.4 Safety Assessment

The EMC test shows that I&C equipment has the ability to resist the EMI. Actually the I&C equipment located inside the buildings is mainly affected by the internal EMI which is shown in Chapter 19.6, the risk from external EMI is much lower because it is protected by the lightning protection measures.

An electromagnetic field site survey will be carried out at the specific site to verify whether the safety objectives can be achieved in the event of EMI.

18.6.5.2 Space Weather

18.6.5.2.1 Safety Requirements

Following a space weather event, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

18.6.5.2.2 Design Basis

18.6.5.2.2.1 Space Weather Hazard Characterisation

The sun has an approximately 11 year's magnetic activity cycle through changes in the sun spot activity on the Sun's surface. There are related phenomena such as solar flares and fast streams of charged particles. Space weather is concerned with the time varying conditions within these related phenomena. Coronal mass ejection is the most significant threat to engineered systems on Earth.

A coronal mass ejection is an eruption of electrical plasma and magnetic fields from the solar corona. Coronal mass ejection energy and plasma can be efficiently directed into the Earth's environment, including the radiation belts, ionosphere atmosphere and ground (such as ground level particle fluxes of neutron and muon, i.e. ground level enhancements).

The interaction between an appropriately magnetically-aligned coronal mass ejection or fast stream of solar wind and the geomagnetic field induces a secondary magnetic field and a surface electric field in the Earth. Geomagnetic Induced Current (GIC) is induced by the surface electric field in the Earth, which can enter any ground-based network through the earthing points. Ground level infrastructures include electrical power transmission systems are affected by GIC due to their large span.

The effect of space weather is also relevant to I&C systems, with certain materials being particularly susceptible to particle fluxes creating false signals.

18.6.5.2.2.2 Definition of Design Basis Hazards

Space weather may be classified as a low probability but potentially high impact event, and some records such as ground-level geomagnetic record or sunspot record have been conducted. Generally, the frequency and severity of space weather to GIC and I&C systems are difficult to determine because of less of data and validity of the methodology.

The magnitude of GIC will be studied by a conservative methodology according to the characteristic of grid network at the nuclear site licensing phase.

18.6.5.2.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

   Space weather could give rise to EMI (false signals of susceptible I&C due to particle fluxes).

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

Space weather could give rise to LOOP due to GIC.

18.6.5.2.3 Protection Measures

Space weather has been identified as a threat to infrastructure. Nuclear facilities are not specifically highlighted, but the vulnerability of electric grid and susceptible I&C is highlighted.

Electric grid and electrical power transmission will consider the effect of GIC, which will be shown in Chapter 9. These are deems as a site specific factor and will be studied at the nuclear site licensing phase.

The protection measure of lightning, i.e. earthing and lightning protection system which is shown in Chapter 9, is used to protect the electromagnetic effects of lightning currents, that is the system also has capacity to protect susceptible I&C equipment against space weather events.

18.6.5.2.4 Safety Assessment

The earthing and lightning protection system and the EMC test are designed to protect the susceptible I&C equipment important to safety against space weather events to ensure the safety requirements are met.

The effect of GIC caused by the space weather to electric grid and electrical power transmission will be considered at the nuclear site licensing phase.

18.6.6 Heat Sink Specific Hazards

18.6.6.1 Safety Requirements

Following a heat sink specific hazard, the objective of protection is to ensure that the safety functions needed to bring and maintain the plant to a safe state are not affected, and radiological release risk is below the acceptable limit.

The heat sink design should meet the following safety requirements:

a) Systems for transferring heat shall have adequate reliability for the plant states in which they have to fulfil the heat transfer function;

b) Adequate cooling water should be ensured to meet the cooling requirement of the plant;

c) The water quality should meet the system requirements.

18.6.6.2 Design Basis

The heat sink specific hazards considered during the GDA phase include the following categories, and in nuclear site licensing phase, some heat sink specific hazards may be screened out.

a) Clogging;

b) Hydrocarbon pollution;

c) Underwater explosion;

d) Ship collision;

e) Low water level.

18.6.6.2.1 Characterisation

18.6.6.2.1.1 Clogging

Considering the operating experience of the existing nuclear power plant, Clogging is a primary heat sink hazard, and biological fouling and floating debris can clog the intake of the heat sink and affect the water quality.

Heat sink may be clogged due to:

a) Fauna and flora, mainly jellyfish, seaweed and fish;

b) Silting;

c) Frazil ice;

d) Log.

Biological fouling and floating debris may clog the intakes, and impact the flow area of the cooling water systems and corrode the equipment.

18.6.6.2.1.2 Hydrocarbon Pollution

Hydrocarbon pollution may influence the water quality of cooling systems. During the nuclear site licensing phase and system design, hydrocarbon pollution is considered. The main hydrocarbon pollution sources are offshore oil exploitation (release or leak of hydrocarbon), ship collision and fishing activities, etc.

18.6.6.2.1.3 Underwater Explosion

Underwater explosion may be caused by an existing unexploded bomb, transportation, industrial and fishing activities near the intakes. All potential sources lying within the screening distance value shall be taken into consideration.

Typically, there are two kinds of underwater explosion sources:

a) A stationary source, for which the location of the initiating mechanism is fixed, such as for offshore oil facilities;

b) A mobile source, for which the location of the initiating mechanism is not totally constrained, such as for marine transport and fishery activities.

Resulting underwater explosion effects are mainly pressure waves that propagate through water. Underwater explosion will be considered during the site licensing phase, and proper design, protection measures and administrative measures can be taken to avoid underwater explosion effects.

18.6.6.2.1.4 Ship Collision

Ship collision may constitute a particular hazard to the water intake structures of a nuclear power plant and affect the ultimate cooling systems and result in the release of hydrocarbon pollution. The collision of large ships in normal cruising can usually be screened out by the implementation of administrative measures and safeguards.

18.6.6.2.1.5 Low Water Level

Low Water Level only affects very specific plant systems, namely the ultimate heat sink related system, and is not usually considered in the structural integrity evaluation of buildings.

Intake structures for the heat transport systems directly associated with the ultimate heat sink are designed to provide an adequate flow of cooling water during seasonal water level fluctuations, as well as under credible drought conditions.

18.6.6.2.2 Definition of Design Basis Hazards

Heat sink specific hazards are closely connected with site specific characteristics. During the nuclear site licensing phase, specific investigation and surveys will be carried out to verify the situation of the site, such as:

a) The species of marine organisms;

b) The off-shore industries (including fishing);

c) Shipping lane activity.

18.6.6.2.3 Hazard Combinations

According to the principles outlined in Sub-chapter 18.5.2, appropriate hazard combinations that have been identified are listed as follows:

a) Consequential Hazards

None.

b) Correlated Hazards

1) Massive clogging is correlated with exceptional coastal flooding;

2) Massive clogging is correlated with extreme wind.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

Heat sink specific hazards could give rise to LUHS.

18.6.6.3 Protection Measures

To meet the requirements of maintaining the heat sink, protection measures against associated hazards have been considered. Administrative measures are important, and may reduce some of the heat sink specific hazards by controlling or eliminating the hazards source, such as controlling the lane to reduce the risk caused by ship collision hazard. Summary of protection measures against the heat sink specific hazards is as follows:

a) Protection measures against clogging are shown as follows:

1) Use of appropriate seawater filtering equipment of SEC [ESWS] to prevent clogging material from entering the intake;

2) Chemical measures can be taken to deter the marine organism from entering the vicinity of the heat sink or kill the organism;

3) Administrative measures, such as regular inspection and cleaning of filtration systems.

b) Protection measures against hydrocarbon pollution are shown as follows:

1) During the nuclear site licensing phase, the hydrocarbon pollution effects will be considered, controls for the offshore facility and sea-based activities will be proposed and the potential impacts resulting from offshore facilities and sea-based activities will be assessed;

2) Measures can be taken to prevent the events such as offshore oil leak and explosion, ship collision and fishing from occurring within a specific vicinity of the site to prevent consequences on site.

c) Further protection measures against potential ship collision are also considered for the design of the ultimate heat sink intakes, such as:

1) Redundant intakes of the SEC [ESWS];

2) Sufficient separation of redundant intakes.

d) The following measures can be taken to protect against underwater explosion:

Underwater explosions will be considered during the nuclear site licensing phase, and administrative measures, such as controlling the off-shore industrial activities and fishery industry, will be taken to eliminate the potential effects of underwater explosion.

e) The following measures can be taken to protect against low water level

For coastal sites, the ultimate heat sink is seawater, and during the nuclear site licensing phase, the design of ultimate heat sink intakes take effects of low water level into account, to ensure sufficient margin is available during operation and the risks associated with this specific hazard are acceptable.

Although it is not expected that low water level will have a significant impact on the ultimate heat sink, administrative measures are to be taken to ensure sufficient margin.

1) As low water level is not an instantaneous phenomenon, monitoring of the site conditions is an essential activity to warn against the onset of low water level;

2) Pumps associated with non-classified systems that draw water from the water channel, which also acts as the primary source for classified systems, may exacerbate low water levels. To ensure the availability of adequate cooling water for classified systems, during periods of low water levels, the pumps associated with non-classified systems will stop automatically.

18.6.6.4 Safety Assessment

To ensure the plant safety, the capability to transfer heat to an ultimate heat sink is essential for all plant states. As such, systems key to transferring heat will have adequate reliability to fulfil the heat transfer function during heat sink specific hazards.

18.7 Assessment of Hazard Combinations

This sub-chapter is to demonstrate that the consequences of identified credible hazard combinations are acceptable or minimised to an acceptable level through the use of appropriate protection measures. The hazard combinations assessment is considered as part of this overall hazard assessment to ensure that protection measures implemented are suitable and sufficient. Hazard combinations have the potential to be compounded or exhibit delayed impacts and, as a result, may exceed the limit of the available protection measures. The safety requirements for hazard combinations protection are consistent with that for individual external hazards in Sub-chapter 18.6.

The external hazards caused by or correlated with other external hazards are generally linked by a particular characteristic, for example, external flooding considers the combination of waves, storm surge, tsunami, etc. These hazard combinations conditions have been considered under the individual external hazards throughout this chapter.

Internal hazards caused by the external hazards are predominantly considered in the internal hazards protection design in Chapter 19 Internal Hazards. The effect of a design basis external hazard on internal equipment important to safety is prevented by the appropriately-designed outer civil structural, with the exception of during an earthquake. The consequential internal hazards caused by an earthquake are analysed separately in Reference [12].

LOOP and/or LUHS are typically caused by external hazards. However, these two faults are considered in Chapter 12 Design Basis Condition and Chapter 13 Design Extension Conditions and Severe Accident Analysis, and the equipment used to address the faults is protected against the relevant design basis external hazards.

Some independent hazards may be considered for the purposes of ensuring conservative design, such as the effects of extreme temperatures and earthquake. The compounded effects due to the combination of external hazards will be considered as part of the civil structure design and substantiation which is described in PCSR Chapter 16.

18.8 Administrative Procedures

Administrative procedures are developed to prevent the breach of barriers against release or to mitigate consequences caused by the severe external hazards, Reference [5]. Administrative procedures are DiD protection against external hazards and will be produced in site licensing phase. The production of administrative procedures must consider the site specific natural hazard conditions. Extreme winds, extreme rainfall and lightning are frequent hazards and considered during development of administrative procedures.

Some following administrative procedures drawn from feedback from existing nuclear power plant operation are considered for the UK HPR1000, more detailed information will be produced in the nuclear site licensing phase.

a) Establishment of an emergency organisation to provide guidance for severe external hazards;

b) Availability of long-term weather forecasting and storm forecasts, and a process for obtaining these data;

c) Establishment of warning signals depending on severity levels of external hazards, such as rainstorm yellow, orange and red warnings;

d) Availability of additional measures to prevent flood water ingress into buildings, such as dam boards, sandbags, etc.;

e) Availability of emergency equipment to repair damaged systems following a severe external hazard;

f) Availability of staff and workers that can be called upon in response to severe weather warnings for necessary hazard mitigation actions before the weather deteriorates to a level where worker safety becomes an issue;

g) Protection of emergency control centres and access points and associated equipment against external hazards.

18.9 ALARP Assessment

18.9.1 General Description

This sub-chapter gives an overview of ALARP principles to be applied in this Chapter. Chapter 33 presents a generic approach used for demonstrating ALARP for the UK HPR1000 design, and the main steps of the approach in Reference [24] are listed as follows:

a) Presenting a design evolution review of HPR1000 design to demonstrate that safety improvements have been incorporated and Operating Experience (OPEX) has been considered;

b) A systematic review of the UK HPR1000 design against RGP, OPEX and the Probabilistic Safety Assessment (PSA);

c) Identifying and collating the potential improvements;

d) Optioneering, which is the process of generation and evaluation of options;

e) Implementation of all reasonably practicable options until a suitable solution is reached and ALARP justification is given;

f) Iterative holistic review of the UK HPR1000 design.

The external hazards ALARP analysis process follows a generic approach, including the following steps:

a) Identifying and analysing relevant UK RGP and OPEX;

b) Risk assessment;

c) Identifying gaps;

d) Undertaking an optioneering analysis.

18.9.2 Identifying and Analysing the UK RGP and OPEX

Analysis of RGP conformance is the starting point for the ALARP analysis. A thorough review of RGP is undertaken to help identify suitable options to reduce the risk. For the UK HPR1000 External Hazards protection designs, the sources of RGP are described in Sub-chapter 18.3.

Key OPEX from previous GDA experiences is also considered and is integrated into UK HPR1000 external hazards design where suitable.

18.9.3 Risk Assessment

External hazards schedule will be performed to identify high risk areas against external hazards.

18.9.4 Identifying Gaps

Potential gaps have been identified following activities completed under Sub-chapter 18.9.2 and Sub-chapter 18.9.3 (as stated, further work is to be undertaken). These potential gaps are derived from UK RGP and OPEX.

The ALARP analysis for the UK HPR1000 External Hazards protection design follows the steps from 18.9.2 to 18.9.5. Some potential improvements have been identified.

18.9.5 Undertaking an Optioneering Analysis

This process comprises the analysis of potential improvements for identified gaps, and then proposes corresponding improvement schemes for each gap. The options analysis applies the ALARP methodology.

For external hazards protection optioneering, the following aspects are considered:

a) Analysing the potential improvement;

b) Generating risk reduction options;

c) Identifying assessment criteria;

d) Assessing the options against identified criteria.

For the identified potential gaps, the detailed optioneering will be done.

After analysis of the options, all reasonably practicable options are considered and further analysis is implemented until a suitable solution is reached. The final scheme is to close the gaps between UK HPR1000 and UK requirements and context in step 3 and step 4 of GDA.

18.10 Concluding Remarks

The design, analysis and protection will guarantee that external hazards do not compromise the fundamental safety functions. The design is based on a conservative approach which ensures that any design basis external hazard load is unlikely to result in a cliff-edge effect. In addition, measures that aim to prevent the occurrence of hazards, and protect SSCs from the effects of each external hazard are to be incorporated into the design.

Commensurate with the ALARP methodology, the risk from external hazards will be reduced to ALARP.

18.11 References

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