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UK HPR1000 GDA Project

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Pre-Construction Safety Report

Chapter 18

External Hazards

Text within this document that is enclosed within brackets '{…}' contains Sensitive Information and has been removed.

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18.1 List of Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
BDA	Emergency Diesel Generator Building A
BDB	Emergency Diesel Generator Building B
BDC	Emergency Diesel Generator Building C
BDU	SBO Diesel Generator Building for Train A
BDV	SBO Diesel Generator Building for Train B
BEJ	Extra Cooling System and Fire-fighting Water Production System Building
BEX	Equipment Access Building
BFX	Fuel Building
BNX	Nuclear Auxiliary Building
BPX	Personnel Access Building
BRX	Reactor Building
BSA	Safeguard Building A
BSB	Safeguard Building B
BSC	Safeguard Building C
BWX	Radioactive Waste Treatment Building
DBC	Design Basis Condition
DBE	Design Basis Earthquake
DiD	Defence in Depth
ECS	Extra Cooling System [ECS]
EHR	Containment Heat Removal System [CHRS]
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPW	Explosion Pressure Wave
EUF	Containment Filtration and Exhaust System [CFES]
EUR	European Utility Requirement

FCG3	Fangchenggang Nuclear Power Plant Unit 3
GDA	Generic Design Assessment
GIC	Geomagnetic Induced Current
HPR1000	Hua-long Pressurised Reactor
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IEC	International Electrotechnical Commission
LOOP	Loss of Offsite Power
LUHS	Loss of Ultimate Heat Sink
MCR	Main Control Room
NPP	Nuclear Power Plant
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]
RCP	Reactor Coolant System (RCP [RCS])
RGP	Relevant Good Practice
RPE	Nuclear Island Vent and Drain System [VDS]
RRI	Component Cooling Water System [CCWS]
SAP	Safety Assessment Principle (UK)
SEC	Essential Service Water System [ESWS]
SGH	NI Hydrogen Distribution System [HDS (NI)]
SSC	Structures, Systems and Component
TAG	Technical Assessment Guide (UK)
TEG	Gaseous Waste Treatment System [GWTS]
TEP	Coolant Storage and Treatment System [CSTS]

TES	Solid Waste Treatment System [SWTS]
UK HPR1000	UK version of the Hua-long Pressurised Reactor
WENRA	Western European Nuclear Regulators Association

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Component Cooling Water System (RRI [CCWS]).

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 (SSCs) 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 impact the delivery of the fundamental safety functions of the UK version of the Hua-long Pressurised Reactor (UK HPR1000) nuclear power plant.

The present safety case of External Hazards is produced based on the design reference version 2.0, as described in the UK HPR1000 Design Reference Report (Reference [2], Rev. D). The safety assessment results are presented in Chapter 18 and corresponding safety assessment reports. However, all the design changes between DR2.0 and DR2.1 have been assessed from External Hazards point and corresponding insights have been provided to support the determination of these design changes.

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 and inform emergency arrangements.*

a) ***Claim 3.2.1:*** *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.*

The Sub-claim 3.2.1.SC18.1 and its relevant arguments and evidence support the Claim 3.2.1:

a) ***Sub-claim 3.2.1.SC18.1:*** *The individual external hazards and hazard combinations that can potentially cause initiating faults and thus affect nuclear safety are sufficiently identified.*

   1) ***Argument 3.2.1.SC18.1-A1:*** *Identification and screening of individual external hazards is conducted to get a comprehensive list of individual external hazards.*

   - ***Evidence 3.2.1.SC18.1-A1-E1:*** *The methodology of identification and screening of individual external hazards is established considering the Relevant Good Practices (RGPs).*

     The methodology of identification and screening of individual external hazards is shown in Reference [3].

   - ***Evidence 3.2.1.SC18.1-A1-E2:*** *The process and outcome of individual external hazards identification and screening are conducted according to the established methodology.*

     The process and outcome of individual external hazards identification and screening are shown in Sub-chapter 18.5.1 and Reference [4].

   2) ***Argument 3.2.1.SC18.1-A2:*** *Identification and screening of external hazard combinations is developed to get a comprehensive list of external hazard combinations.*

   - ***Evidence 3.2.1.SC18.1-A2-E1:*** *The methodology of identification and* *screening of external hazard combinations is established considering the RGPs.*

The methodology of identification and screening of external hazards combinations is shown in Reference [3].

- ***Evidence 3.2.1.SC18.1-A2-E2:*** *The process and outcome of external hazard combinations are conducted according to the established methodology.*

  The process and outcome of external hazard combinations identification and screening are shown in Sub-chapter 18.5.2 and Reference [4].

The Sub-claim 3.2.2.SC18.1 and its relevant arguments and evidence support the Claim 3.2.2:

b) ***Sub-claim 3.2.2.SC18.1:*** *Design basis external hazards are appropriately assessed to identify requirements on safety functions and safety measures and assess their effectiveness.*

1) ***Argument 3.2.2.SC18.1-A1:*** *Design basis external hazard is appropriately assessed to identify requirements on safety functions and safety measures.*

- ***Evidence 3.2.2.SC18.1-A1-E1:*** *The design basis of natural external hazards is determined with a conservative frequency 10^{-4}/y and the effect of climate change is taken into account.*

  The natural external hazards design basis and related climate change values are shown in Sub-chapter 18.6 and Reference [5].

- ***Evidence 3.2.2.SC18.1-A1-E2:*** *The design basis of man-made external hazards is determined with a conservative frequency 10^{-5}/y or maximum credible event or RGP.*

  The man-made external hazard design basis is shown in Sub-chapter 18.6.

2) ***Argument 3.2.2.SC18.1-A2:*** *Appropriate protection measures required are identified and their effectiveness is appropriately assessed.*

- ***Evidence 3.2.2.SC18.1-A2-E1:*** *The appropriate protection measures against individual external hazards are considered for the UK HPR1000.*

  The protection measures of individual external hazards are shown in Sub-chapter 18.6.

- ***Evidence 3.2.2.SC18.1-A2-E2:*** *The appropriate protection measures against hazard combinations are considered for the UK HPR1000.*

  The hazards combination and their protection measures are shown in

Sub-chapter 18.6 for each external hazard and their evaluation reports which are listed in Table T-18.2-1.

T-18.2-1 Evaluation Reports List

No.	Report Title	Reference No.
1	Earthquake Safety Evaluation Report for Reactor Building (BRX)	Reference [6]
2	Earthquake Safety Evaluation Report for Fuel Building (BFX)	Reference [7]
3	Earthquake Safety Evaluation Report for Safeguard Buildings (BSA/BSB/BSC)	Reference [8]
4	Earthquake Safety Evaluation Report for Nuclear Auxiliary Building and Radioactive Waste Treatment Building (BNX/BWX)	Reference [9]
5	Earthquake Safety Evaluation Report for Extra Cooling System and Fire-fighting System Building (BEJ)	Reference [10]
6	Earthquake Safety Evaluation Report for Personnel Access Building (BPX)	Reference [11]
7	Earthquake Safety Evaluation Report for Emergency Diesel Generator Buildings and SBO Diesel Generator Buildings (BDA/BDB/BDC/BDU/BDV)	Reference [12]
8	External Flooding Safety Evaluation Report	Reference [13]
9	Tornado Safety Evaluation Report	Reference [14]
10	External Explosion Safety Evaluation Report	Reference [15]
11	Meteorological Hazards Safety Evaluation Report	Reference [16]
12	Heat Sink Specific Hazards Safety Evaluation Report	Reference [17]

No.	Report Title	Reference No.
13	Lightning, Electromagnetic Interference and Space Weather Safety Evaluation Report	Reference [18]

- ***Evidence 3.2.2.SC18.1-A2-E3:*** *The effectiveness of protection measures is appropriately assessed for the UK HPR1000.*

  The protection measures are appropriately assessed in external hazards safety evaluation reports which are listed in Table T-18.2-1.

The Sub-claim 3.2.3.SC18.1 and its relevant arguments and evidence support the Claim 3.2.3:

c) ***Sub-claim 3.2.3.SC18.1:*** *Beyond design basis external hazards analysis is carried out to identify further risk reducing measures.*

1) ***Argument 3.2.3.SC18.1-A1:*** *Cliff-edge analysis is performed to ensure the robustness of external hazards protection.*

- ***Evidence 3.2.3.SC18.1-A1-E1:*** *Protection design of SSCs important to safety against external hazards is appropriately conservative to avoid cliff-edge effect.*

  The cliff-edge analysis of external hazards is shown in Sub-chapter 18.6 and external hazard evaluation reports which are listed in Table T-18.2-1.

2) ***Argument 3.2.3.SC18.1-A2:*** *More severe beyond design basis natural external hazards are considered to identify further risk reducing measures.*

- ***Evidence 3.2.3.SC18.1-A2-E1:*** *The suitable protection measures against more severe beyond design basis natural external hazards are considered for the UK HPR1000.*

  The beyond design basis external hazards are considered in the external hazard evaluation reports which are listed in Table T-18.2-1.

- ***Evidence 3.2.3.SC18.1-A2-E2:*** *Administrative procedures are appropriately considered to mitigate the consequence of external hazards.*

  Administrative procedures are shown in Sub-chapter 18.8.

18.2.2 Chapter Structure

This sub-chapter describes the structure of Chapter 18. 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. The individual external hazards and hazard combinations, the safety requirements, design basis, protection measures, and the safety assessment are described in Sub-chapter 18.6. The assessment of hazards combinations is described in Sub-chapter 18.7. 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 in Sub-chapter 18.9 to ensure that the risk of external hazards is reduced to be ALARP.

Chapter 18 of External Hazards is structured as follows:

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

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

b) Sub-chapter 18.2 Introduction:

This sub-chapter gives an overview of Chapter 18, and includes introductions to 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 relevant to external hazards.

d) Sub-chapter 18.4 General Approach:

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

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

This sub-chapter describes the principles and process of identification and screening methodology 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 safety requirements, design basis, protection measures and the safety assessment for those external hazards considered in GDA phase.

g) Sub-chapter 18.7 Assessment of Hazard Combinations:

This sub-chapter provides the assessment of hazard combinations, 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, except for the protection measures introduced in Sub-chapter 18.6 and Sub-chapter 18.7.

i) Sub-chapter 18.9 ALARP Demonstration:

This sub-chapter provides an outline of the ALARP demonstration. Gaps are identified from the RGP, Operating Experience (OPEX), and external hazards assessment. For these potential gaps, optioneering analysis is summarised to show the ALARP demonstration.

j) Sub-chapter 18.10 Concluding Remarks:

This sub-chapter provides the concluding remarks, and summarises the main contents of Chapter 18.

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 Table T-18.2-2.

T-18.2-2 Interfaces between Chapter 18 and Other Chapters

PCSR Chapter	Interfaces
Chapter 1 Introduction	PCSR Chapter 1 provides the Route Map of Level 1 and Level 2 claim. Chapter 18 provides sub-claims, arguments and evidences to support Level 1 and Level 2 claims given in PCSR Chapter 1.
Chapter 2 General Plant Description	Chapter 18 presents the protection against external hazards. The layout of buildings mentioned in PCSR Chapter 2 is one kind of method to protect against external hazards to avoid common cause failure.
Chapter 3 Generic Site Characteristics	PCSR Chapter 3 presents the list of the external hazards, the generic site envelope and the values for the UK HPR1000 design. Chapter 18 adopts values for the UK HPR1000 design to perform the assessment.
Chapter 4 General	PCSR Chapter 4 provides general safety and design

PCSR Chapter	Interfaces
Safety and Design Principles	principles, including Defence in Depth (DiD), Safety classification of SSCs, etc. Chapter 18 demonstrates that the safety and design principles have been implemented in the external hazards protection design.
Chapter 5 Reactor Core	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 5 provides fuel system design applying external hazard protection design principles, which is used for external hazards safety assessment.
Chapter 6 Reactor Coolant System	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 6 provides the Reactor Coolant System (RCP [RCS]) design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 7 Safety Systems	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 7 provides the safety systems design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 8 Instrumentation and Control	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 8 provides the instrumentation and control systems design applying external hazard protection design principles, which is used for external hazards assessment.

PCSR Chapter	Interfaces
Chapter 9 Electric Power	PCSR Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 9 provides the electric power systems design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 10 Auxiliary Systems	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 10 provides the auxiliary systems design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 11 Steam and Power Conversion System	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 11 provides the steam and power conversion system design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 12 Design Basis Condition	PCSR Chapter 12 presents the list of Design Basis Condition (DBC) which is identified from the postulated initiating events. Chapter 18 provides the potential DBC caused by external hazards and provides protection measures.
Chapter 13 Design Extension Conditions and Severe Accident Analysis	PCSR Chapter 13 presents the list of design extension conditions and severe accidents. Chapter 18 provides the potential design extension conditions caused by external hazards and provides protection measures.
Chapter 14 Probabilistic	Chapter 18 provides the identified external hazards and design

PCSR Chapter	Interfaces
Safety Assessment	basis value and protection measures to Chapter 14. PCSR Chapter 14 evaluates the risk of external hazards and provides risk insights to support the design of external hazards.
Chapter 16 Civil Works & Structures	Chapter 18 defines external hazards that lead to loads being placed on the civil structures. PCSR Chapter 16 presents the design substantiation of civil structures against external hazards.
Chapter 17 Structural Integrity	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR 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	PCSR Chapter 19 provides internal hazards list for the consideration of combination with external hazards. Chapter 18 provides combined hazards of external hazards with their consequential internal hazards.
Chapter 23 Radioactive Waste Management	Chapter 18 provides list of external hazards, relevant design principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 23 provides the radioactive waste management systems design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 24 Decommissioning	Chapter 18 presents the list of external hazards and the hazards protection principles. PCSR Chapter 24 identifies the potential external hazards protection measures needed to be considered during decommissioning.
Chapter 28 Fuel	Chapter 18 provides list of external hazards, relevant design

PCSR Chapter	Interfaces
Route and Storage	principles, design basis and safety assessment to identify potential risk information, and the ALARP demonstration from the external hazards point of view. PCSR Chapter 28 provides the Fuel Handling and Storage System (PMC [FHSS]) design applying external hazard protection design principles, which is used for external hazards assessment.
Chapter 29 Interim Storage of Spent Fuel	Chapter 18 provides the hazards protection principles for spent fuel interim storage design. External hazards topic area participates in the spent fuel interim storage safety assessment.
Chapter 33 ALARP Evaluation	Chapter 18 provides the ALARP demonstration for external hazards protection by applying the ALARP methodology, which supports the overall ALARP demonstration addressed in PCSR Chapter 33.

18.3 Applicable Codes and Standards

The applicable codes and standards are provided in this sub-chapter, which are selected following suitability and compliance analysis according to the selection principles and selection process presented in PCSR Sub-chapter 4.4 and Reference [19].

The general selection principles from Reference [19] are applied in the selection process and are briefly introduced as follows:

a) The RGPs of international organisations 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 general selection process is presented in the PCSR Chapter 4.4 and the Reference [19], 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) documents;

e) Nuclear Regulatory Commission (NRC) documents;

f) Industry/sector standards.

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

Based on the above description, the suitability analysis of the codes and standards is performed in Reference [20]. Through suitability analysis, applicable codes and standards are selected. The selected codes and standards in general design of external hazards are listed below:

a) IAEA, Site Evaluation for Nuclear Installations, Safety Standards Series No. SSR-1, 2019;

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

c) IAEA, Site Survey and Site Selection for Nuclear Installations, Safety Standards Series No. SSG-35, 2015;

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

e) WENRA, Guidance Document Issue T: Natural Hazards: Head Document, 2015;

f) WENRA, Safety of New Nuclear Power Plant Designs, 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 provide characterisation and related protection design experience of man-made external hazards (including aircraft crash, external explosion, etc.):

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

b) IAEA, External Human Induced Events in Site Evaluation for Nuclear Power

Plants, Safety Standards Series No. NS-G-3.1, 2002;

c) IAEA, Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations, Safety Report Series No. 86, 2017;

d) IAEA, Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures, Safety Report Series No. 87, 2018;

e) IAEA, Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment, Safety Report Series No. 88, 2017.

The following standards and guidance are used in natural hazards (including seismic events, external flooding, extreme wind, tornado, etc.):

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

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

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

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

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

g) IAEA, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, Safety Standards Series No. SSG-18, 2011;

h) WENRA, Guidance Document Issue T: Natural Hazards: Guidance on Extreme Weather Conditions, 2016;

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

To ensure that the design requirement and method of each selected codes and standards through suitability analysis can be applied adequately, after selecting suitable codes and standards, compliance analysis is performed to provide confirmation and justification of design rules of the selected codes and standards, including where they have been used and the compliance between the codes and standards with the design of the UK HPR1000 with respect to external hazards.

The compliance analysis for the codes and standards identified in Reference [20] is performed in Reference [21]. It shows that the external hazards protection design of the UK HPR1000 is compliant with most requirements listed in the codes and standards. The parts not applicable or partially compliant are related to detailed site investigation. As specific site investigation will be performed in the nuclear site licensing phase, these requirements listed in the codes and standards will be considered at that time.

18.4 General Approach

This sub-chapter provides the general principles and requirements for the external hazards protection design, the assessment scope 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 [22]. The general principles of external hazards protection design are as follows:

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

b) 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;

c) 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;

d) The protection design measures should ensure that there is no cliff-edge effect;

e) The concept of DiD should be applied in the hazards protection design;

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 should be determined using a conservative estimate at a frequency of 10^{-4}/y, Reference [23].

The effect of climate change should be appropriately considered, using the data from UK Climate Projections, Reference [24] and [25]. For the past decade UK Climate Projections 2009 (UKCP09) has been used for applying climate change allowances for natural hazards (such as temperature, rainfall, etc.). This is being superseded by UK Climate Projections 2018 (UKCP18) in Reference [26]. The detailed data related to the projections (such as the probabilistic projections, global projections, etc.) are not yet fully available. UKCP09 is still used and relevant consideration for UKCP18 has been addressed in PCSR Sub-chapter

3.5.1.

b) Design Basis Man-made Hazards

The design basis man-made hazards should be defined in either of the following ways, Reference [23]:

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

2) Deterministically, as a maximum credible event when the frequency of occurrence is not available, Reference [1].

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

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

1) Cliff-edge Effects

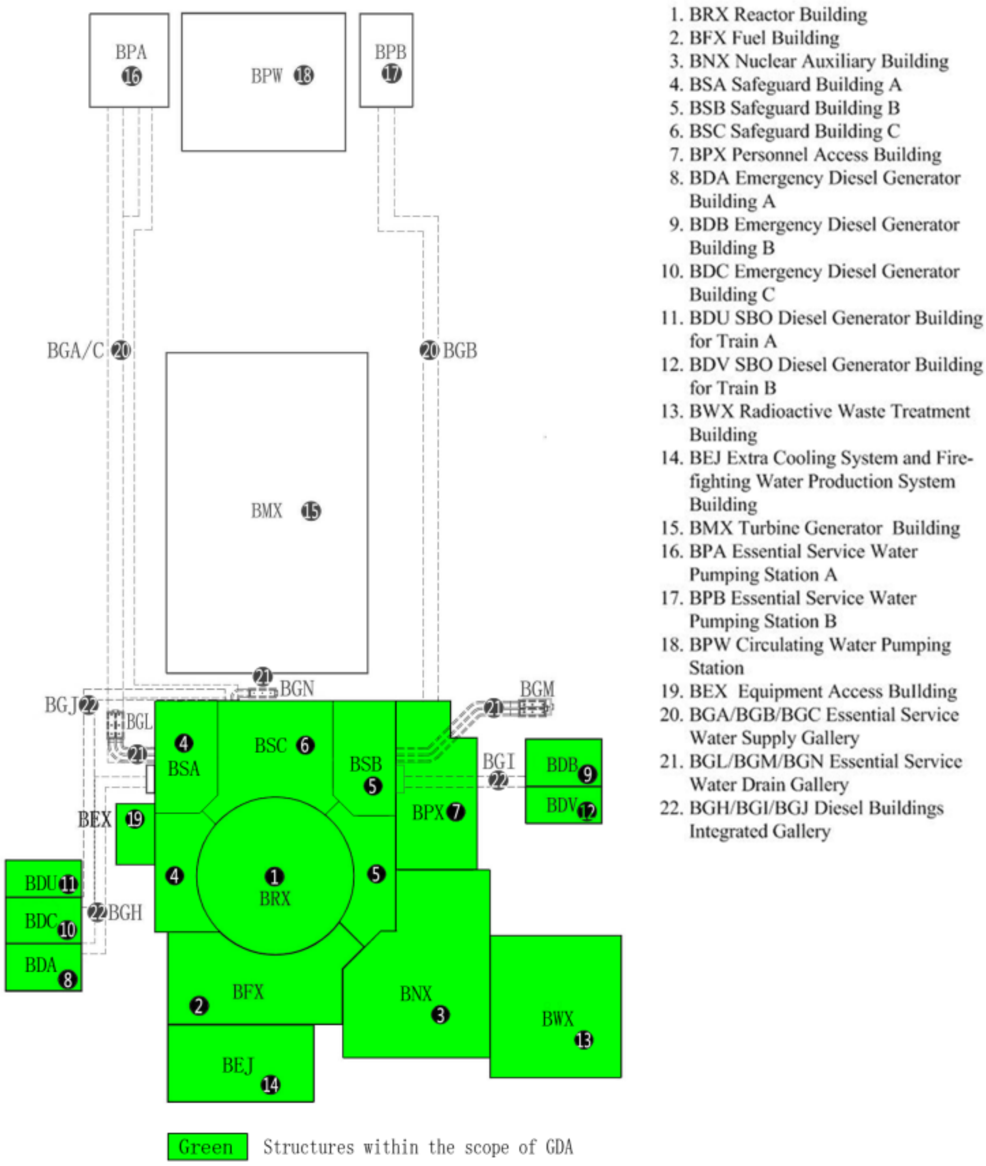
Cliff-edge effects should be examined to ensure that there is no step change response to the hazard and there is no disproportionate increase in radiological risk close to the design basis boundary.

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 should be identified to ensure that fundamental safety functions are maintained.

18.4.2 Scope

According to Reference [4], this sub-chapter describes the scope of buildings for the external hazards safety assessment and protection. The building list for external hazards protection is shown in Figure F-18.4-1and Table T-18.4-1:



F-18.4-1 General Layout of the UK HPR1000

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	BEJ	Extra Cooling System and Fire-fighting Water Production

No.	Building Code	Building Description
		System Building
7	BEX	Equipment Access Building
8	BFX	Fuel Building
9	BNX	Nuclear Auxiliary Building
10	BPX	Personnel Access Building
11	BRX	Reactor Building
12	BSA	Safeguard Building A
13	BSB	Safeguard Building B
14	BSC	Safeguard Building C
15	BWX	Radioactive Waste Treatment Building

18.4.3 General Safety Assessment Approach

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) Quantification of Load (Hazard Specific)

The external hazard design basis is characterised using the general principles in Sub-chapter 18.4.1. For example, seismic event parameters are expressed in terms of zero period peak ground acceleration with frequency of 10^{-4}/y and a response spectrum. In addition, climate change is considered in the relevant natural hazards.

c) Consequence Analysis

External hazards may cause damage to the SSCs, including:

1) Civil Structure (external hazards loads can damage the civil structure);

2) Systems and Components (such as Heating, Ventilation and Air Conditioning (HVAC) systems, Essential Service Water System (SEC [ESWS]), transformer, etc.).

d) Identification of Hazard Protection Measures

Based on the results of the consequences analysis, suitable and sufficient protection measures are identified for external hazards.

e) Substantiation of safety measures

The effects of an external hazard on the protection measures (e.g. hazard barriers) are assessed aiming to ensure that the protection measures do not fail to maintain the safety functions. The hazard barriers include civil structures, exterior doors, etc.

f) Production of a Hazard Schedule

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 external hazard events to give the links between hazard identification, protection measures, and the bounding events defined in the fault schedule in Reference [27].

Detailed information is given in *External Hazards Schedule Report* (Reference [28]).

18.5 External Hazards Identification and Screening

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 [3], and includes the following steps:

a) Listing the potential individual external hazards;

b) Grouping;

c) Screening.

18.5.1.1 Listing the Potential Individual External Hazards

The first step is to develop a list of potential external hazards, which includes identified natural and man-made hazards.

The applicable codes, standards and guidance are used as references to obtain the list of potential individual external hazards. The method and result of listing individual external hazards is shown in Reference [3].

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 check of the identified hazards.

Duplicate hazards can be removed from the process, and similar hazards can be subsumed into the 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 group of external flooding. The hazard groups presented below refer to Reference [29]:

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 list of individual external hazards identified, several screening criteria are applied to determine which external hazard is considered in GDA phase and which external hazard is considered in nuclear site licensing phase. More detailed information about the screening criteria and screening process is shown in Reference [3]. The primary screening criteria are listed as follows:

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

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 in GDA phase or nuclear site licensing phase depending on whether the hazards depend on the site specific information or not. The individual hazards considered in the UK HPR1000 GDA phase are listed as follows:

a) Earthquake;

b) External Flooding (including rainfall);

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) Electromagnetic Interference (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 methods, after which credible hazard combinations are determined.

a) Consequential Hazards Identification and Screening

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

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 may cause external flooding. The list of consequential external hazards is presented in Sub-chapter 18.6.

b) Correlated Hazards Identification and Screening

Correlated hazards may occur simultaneously with the primary hazard as they depend on a common physical process, for example, a storm may give rise to both rain and lightning at the same time, Reference [23].

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 external hazards that may have the same cause;

2) Screening correlated hazards according to their frequency and impact on the plant.

The list of correlated external hazards is presented in Sub-chapter 18.6.

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 may occur before the previous hazard consequences are completely mitigated by protection measures.

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 simultaneously;

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 an individual external hazard or not. It will be carried out according to the assessment and engineering judgement.

For natural external hazards, the higher frequency at which the hazard occurs, the lower severity of the consequence impact to the plant. For 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 external hazards with a low frequency and severe consequence, the frequency of two or more independent hazards occurring simultaneously is generally lower than the cut-off frequency.

The list of independent external hazard combinations which are considered as the physical process has been presented in Sub-chapter 18.6.

d) Combination of External Hazards and Design Conditions

Generally, the design basis external hazards are assumed to occur under the normal operating modes, and external hazards may result in design conditions, including Loss of Offsite Power (LOOP) and Loss of Ultimate Heat Sink

(LUHS), which are considered in PCSR Sub-chapter 12.4 and PCSR Sub-chapter 13.4 respectively. The design conditions caused by external hazards are described in Sub-chapter 18.6.

18.6 Protection against External Hazards

After external hazards identification and screening, a hazards list is derived for GDA phase, and relevant safety requirements, the design basis of external hazards, protection measures, and safety assessment are considered for each external hazard and hazard combinations. Detailed characteristics for each external hazard are also provided.

Hereafter, the mentioned hazard means design basis hazard except when there is special description, such as, earthquake means design basis earthquake.

18.6.1 Earthquake

18.6.1.1 Safety Requirements

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

18.6.1.2 Design Basis

18.6.1.2.1 Earthquake Characterisation

According to Reference [30], earthquake shows several characteristics, including:

a) Near fault effects;

b) Surface faulting from the main or secondary faults ruptures;

c) Site effects, including free field vibratory ground motion amplification / deamplification;

d) Vibratory ground motion.

As near fault effects, surface faulting and site effects are site specific, they are not considered in GDA phase. The vibratory ground motion due to earthquake can impact the nuclear power plant no matter which site is selected, so the vibratory ground motion is considered in GDA phase.

The vibratory ground motion 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.

18.6.1.2.2 Definition of Design Basis Hazards

The design basis value for earthquake is taken at a frequency of 10^{-4}/y, in GDA phase, considering the generic site envelope, and the zero period peak ground acceleration for the UK HPR1000 has been selected as 0.3g according to Reference [29].

The European Utility Requirement (EUR) spectra are adopted as DBE input motion for the seismic analysis, and the zero period peak ground horizontal and vertical ground accelerations of DBE are 0.30g and 0.20g respectively. The spectra are shown in *Generic Design Parameters for Civil Engineering* (Reference [31]).

18.6.1.2.3 Hazard Combinations

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

a) Consequential Hazards

1) Earthquake could cause internal flooding and internal explosion;

2) Earthquake could cause falling and toppling of non-seismically classified items;

3) Earthquake could cause external flooding (including tsunami).

b) Correlated Hazards

None.

c) Independent Hazards

Meteorological conditions, such as high wind, snow or outside air temperature, may potentially occur simultaneously to an earthquake. In the design of structures, the load combinations of earthquake with wind, snow or outside air temperature are considered.

d) Combination of External Hazards with Design Conditions

The load combination of DBE and Design Basis Condition (DBC) 2 to DBC4 has been considered in the design of safety systems. This is to ensure the ability of equipment to withstand DBC loads which would occur during or after a DBE.

18.6.1.3 Protection Measures

According to Reference [30], the protection concept shall ensure that the fundamental safety functions are fulfilled under the DBE, and secondary effects that may adversely affect the plant are also taken into account, such as flooding. The protection measures for earthquake are developed in the following ways:

a) Structures design

Structures important to safety, such as the Reactor Building, are designed to withstand the DBE load defined above. The seismic analysis adopts the response spectra method and the equivalent static method to determine the seismic response of structures in an earthquake. Further detail is provided in PCSR

Sub-chapter 16.5.

b) Seismic categorisation

Seismic categorisation is an important and effective measure against seismic load. During the seismic categorisation process, a deterministic method is 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 DBE. The seismic category for 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 a DBE, the failure of non-SSE1 SSCs may cause consequential internal hazards (including mechanical interaction with SSE1 equipment, flooding resulting from failure of fluid systems, explosion, etc.). 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 do not affect the SSE1 SSCs.

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. If the consequential effects cannot be eliminated by proper layout, physical protection or seismic classification change are considered to eliminate the impacts on items important to safety.

18.6.1.4 Safety Assessment

Regarding required safety assessments, the following analyses are performed to ensure nuclear safety during or after a DBE:

a) Design Basis Earthquake Safety Assessment

An earthquake safety assessment considers the consequential hazards induced by a DBE, and the safety assessment methodology of consequential hazards is provided in Reference [32].

The design basis earthquake safety assessments are performed for each building in GDA scope according to the methodology report, including:

1) *Earthquake Safety Evaluation Report for Reactor Building (BRX)*, Reference [6];

2) *Earthquake Safety Evaluation Report for Fuel Building (BFX),* Reference

[7];

3) *Earthquake Safety Evaluation Report for Safeguard Buildings (BSA/BSB/BSC)*, Reference [8];

4) *Earthquake Safety Evaluation Report for Nuclear Auxiliary Building and Radioactive Waste Treatment Building (BNX/BWX)*, Reference [9];

5) *Earthquake Safety Evaluation Report for Extra Cooling System and Fire-fighting System Building (BEJ)*, Reference [10];

6) *Earthquake Safety Evaluation Report for Personnel Access Building (BPX)*, Reference [11];

7) *Earthquake Safety Evaluation Report for Emergency Diesel Generator Buildings and SBO Diesel Generator Buildings (BDA/BDB/BDC/BDU/BDV)*, Reference [12].

In the earthquake safety evaluation reports, earthquake induced global effects (including internal flooding and internal explosion) and local effects (including toppling and falling of non-seismically classified items) are considered, and the consequences are shown as follows:

1) Internal flooding

The flooding volumes caused by items that cannot maintain their integrity in a DBE are shown in Table T-18.6-1.

T-18.6-1 Flooding Volume in the Buildings

Building	**Flooding Volume (m^3)**
BRX	5.03
BFX	63.21
BSA/BSB/BSC	0.00
BEJ	0.00
BNX	6202.72
BWX	5511.58
BDA/BDB/BDC/BDU/BDV	0.00

Building	Flooding Volume (m^3)
BPX	830.79

- For BSA/BSB/BSC/BEJ/BDA/BDB/BDC/BDU/BDV, there are no non-seismically classified flooding sources in GDA scope, so there is no flooding risk in these buildings, and the flooding consequence is considered to be acceptable;
- For BRX/BFX, there is flooding caused by items which cannot maintain their integrity during a DBE. According to the layout of items in those buildings, safety related items are not impacted by the released water, so the flooding consequence is considered to be acceptable;
- For BNX/BWX, there are no SSCs important to safety installed in those buildings, and the flooding is contained in the buildings, so the flooding consequence is considered to be acceptable;
- For BPX, there is approximately 830.79m^3 water released. As boundary doors and penetrations of BPX are not watertight, water is released to the site, but the released water does not affect SSCs important to safety.

In conclusion, SSCs important to safety are not impacted by internal flooding caused by DBE, and the consequence is acceptable.

2) Internal explosion

The safety evaluation of internal explosion considers the explosion risk due to explosive gas (hydrogen) leakage caused by earthquake.

According to the earthquake safety evaluation reports, systems containing explosive gas are Containment Filtration and Exhaust System (EUF [CFES]), Nuclear Island Vent and Drain System (RPE [VDS]), Gaseous Waste Treatment System (TEG [GWTS]), Coolant Storage and Treatment System (TEP [CSTS]), Solid Waste Treatment System (TES [SWTS]) and NI Hydrogen Distribution System (SGH [HDS (NI)]), and these systems are seismically classified to maintain their integrity, or the hydrogen concentration in those systems is lower than the explosion limit (4%-75.6%). The systems containing explosive gas are listed in Table T-18.6-2.

T-18.6-2 Systems Containing Explosive Gas

System	Design	System	Design
EUF [CFES]	Concentration	SGH [HDS (NI)])	Seismically classified

System	Design	System	Design
RPE [VDS]	of hydrogen is lower than 4%	TEG [GWTS]	Partially seismically classified and partially with hydrogen concentration lower than 4%
TEP [CSTS]			
TES [SWTS]			

In conclusion, there is no explosion risk caused by earthquake.

3) Local effects

The falling and toppling of non-seismically classified items are considered as local effects, and non-seismically classified items are considered to fail at the same time, including:

- Pipelines;
- Ventilation ducts;
- Mechanical equipment, including pumps, tanks, heat exchangers, heaters, filters, etc.;
- Steel structures;
- Instrumentation and Control (I&C) and Electrical cabinets and boxes;
- Ordinary doors;
- Masonry.

Local effect analysis is based on the layout of the UK HPR1000.

According to the results of safety evaluation reports listed in a), the falling and toppling of non-seismically classified items do not impact seismically classified items. In conclusion, the local effects caused by earthquake are acceptable in GDA phase.

b) Cliff-edge Effects Analysis

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

1) The UK HPR1000 design incorporates ductile features allowing inelastic absorption of the hazard load, providing a margin and ensuring that there is no cliff-edge effect;

2) The safety assessment methodology is conservative. For example, non-seismically classified SSCs are considered to fail at the same time.

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.

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 [33] and [34]:

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. In GDA phase, the following factors are considered to contribute to external flooding:

a) Extreme high sea level;

b) Waves (including storm surge);

c) Extreme Rainfall;

d) Groundwater;

e) Tsunamis.

The external flooding from the sea and rainfall on the site is considered with a frequency of 10^{-4}/y.

18.6.2.2.1 Extreme High Sea Level

The extreme sea level includes extreme high sea level and extreme low sea level. Extreme low sea level cannot cause external flooding, so attention is paid to extreme high sea level. The extreme high 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, and 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 high sea level.

18.6.2.2.2 Waves

Waves are generated by wind acting on the sea surface and transferring wind energy to the water. Wave height depends on multiple factors including wind speed, fetch, bathymetry, and so on.

18.6.2.2.3 Extreme Rainfall

According to Reference [29], the generic site envelope rainfall values in UK are 163mm (1h)/228mm (24h) with a frequency of 10^{-4}/y, and when considering climate change, these values become 198mm (1h)/294mm (24h). For the UK HPR1000 design, the design basis of rainfall is 200mm (1h)/300mm (24h) according to PCSR Sub-chapter 3.6.

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.

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 [23]. 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 significantly.

18.6.2.2.6 Hazard Combinations

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

a) Consequential Hazards

External flooding could cause internal flooding.

b) Correlated Hazards

1) External flooding is correlated with wind;

2) External flooding is correlated with lightning.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) External flooding could cause LOOP;

2) External flooding could cause LUHS. However, as the buildings, SEC ([ESWS]) system located in, are designed to withstand external flooding, the failure of SEC ([ESWS]) function due to external flooding is not assumed.

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 exterior building structures;

f) Designing waterproof building structures housing systems and components important to safety.

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. The ground floor elevation is 0.3m higher than site elevation for the UK HPR1000. The exterior 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.

18.6.2.3.2 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 flooding 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 [35].

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

2) Evaluation of possible flood flow paths from exterior penetrations and doors of buildings;

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.

The external flooding safety assessment is performed for all the buildings whose failure may challenge nuclear safety according to the methodology report, which is presented in Reference [13].

The external flooding safety assessment result is as follows:

1) BRX is surrounded by BNX/BSA/BSB/BSC/BFX, which means it has no doors or penetrations connected directly to the outside of the buildings. Systems contained in BEX and BPX are not important to safety, but their connections with other buildings are set as watertight, which prevents water from flowing into the other buildings;

2) Watertight doors and penetrations set on the boundary structure of BNX, BSA/BSB/BSC, BDA/BDB/BDC/BDU/BDV, BWX and BPA/BPB, can guarantee 2m head pressure for the water tightness above the ground, and 10m head pressure underground, to prevent the water from getting into the buildings;

3) Watertight doors and penetrations set on the boundary structure of the BFX are the same function as 2), except one penetration set as 0.85m above the ground, which is used to relieve overpressure inside the building;

4) Watertight doors and penetrations set on the boundary structure of BEJ are the same function as 2), except the penetrations used to install the fans, which are 0.8m above the ground.

Under design basis external flooding, the Volumetric Protection, which is a watertight volume of protection against external flooding events, ensures that there is no water ingress into the buildings important to safety. The ground floor elevation of the buildings important to safety is set at 0.3m according to the design reference plant. So Volumetric Protection can ensure the plant’s safety under design basis flooding. Thus, there is no access for water to get into the buildings important to safety. Systems and components important to safety are located inside the buildings, and these buildings can provide sufficient protection against external flooding. So there is no risk identified in external flooding evaluation in GDA phase.

b) Cliff-edge Effects Analysis

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

1) The ground floor elevation of the buildings important to safety is set 0.3m higher than the platform to keep the SSCs out of impact from external flooding;

2) The rainfall on the site may be drained into the sea through the plant drainage system, or via intercepting flood ditch and plant drainage channels;

   The design of the plant drainage system is site specific, detailed evaluation will be implemented once the site is determined;

3) The drain pipes of the roof drainage system in the UK HPR1000 are designed to discharge the water under the condition of the design basis rainfall. It is the gravity flow that is adopted in the roof drainage system design;

4) Even if there is water accumulated on the ground gradually, watertight doors and sealed penetrations are designed to resist a hydraulic pressure of 2m above the ground, and 10m hydraulic pressure underground. As the mechanical penetrations on BEJ are set as 0.8m, the water of external

flooding has no access to get into the building structure until the water accumulation reaches 0.8m above the ground;

5) The building structures are designed with waterproof measures, so the underground water cannot penetrate into the buildings.

Emergency management measures are adopted, considering the beyond design basis external flooding as Defence in Depth measures:

1) Long-term weather forecasting and storm forecasting will be conducted, so there is enough time to take protection measures;

2) Temporary flooding protection measures can be used, such as sandbags, pumps.

External flooding is site specific, and detailed evaluation and substantiation of the above measures will be justified comprehensively in nuclear site licensing phase.

18.6.3 Meteorological Conditions

Meteorological conditions could affect the safety of nuclear installations independently or in combination.

Meteorological conditions considered in 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.

18.6.3.1.2 Design Basis

18.6.3.1.2.1 Extreme Wind Characterisation

Extreme wind can increase the load on the structures and affect the structure integrity. Reference [33] shows that extreme wind can affect 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.

18.6.3.1.2.2 Definition of Design Basis Hazards

An effective wind speed value 41.66m/s is derived for the generic site envelope value of the wind speed. However, the design value of 80m/s (3 seconds gust, 10m above ground) in PCSR Sub-chapter 3.6 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 winds over the UK, Reference [24]. 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 identified are listed as follows:

a) Consequential Hazards

Extreme wind could cause missiles.

b) Correlated Hazards

1) Extreme wind is correlated with extreme snow;

2) Extreme wind is correlated with heavy rainfall;

3) Extreme wind is correlated with lightning.

c) Independent Hazards

High wind may potentially act alongside an earthquake. In the design of structures, the load combinations of wind with earthquakes are considered.

d) Combination of External Hazards with Design Conditions

Extreme wind could cause LOOP.

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 performing Category 1 and Category 2 functions inside the buildings are protected against wind load by the civil structures of buildings as mentioned in PCSR Sub-chapter 16.6.

18.6.3.1.4 Safety Assessment

a) Design Basis Extreme Wind Safety Assessment

SSCs performing Category 1 and Category 2 functions located in buildings are protected by the civil structures against extreme wind, and the design basis wind load is considered as one kind of the structural loads in the design of the civil structures in Reference [16]. Openings of buildings containing SSCs performing Category 1 and Category 2 functions have been designed to resist extreme wind load.

b) Cliff-edge Effects Analysis

The conservative design is used to demonstrate that under design basis extreme wind there is no cliff-edge effect, Reference [16]:

The design basis wind speed used for the UK HPR1000 design is conservative, which is much higher than the generic site envelope value.

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.

18.6.3.2.2 Design Basis

18.6.3.2.2.1 Extreme Wind Generated Missiles Characterisation

Missiles generated by extreme wind may destroy the integrity of the items performing safety functions. They are similar to tornado missiles, which are discussed in Sub-chapter 18.6.3.3.

18.6.3.2.2.2 Definition of Design Basis Hazards

As stated in Reference [22], wind generated missiles are considered by expert judgement to be bounded by tornado missiles in GDA phase.

18.6.3.2.2.3 Hazard Combinations

a) Consequential Hazards

Wind generated missiles could cause internal flooding[1].

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) Wind generated missiles could cause LOOP;

2) Wind generated missiles could cause LUHS. However, as the buildings, SEC ([ESWS]) system located in, are designed to withstand wind generated missiles, the intake of all three trains of SEC ([ESWS]) system is not

[1] Internal flooding sources are the tanks located on the site, but outside the buildings, so wind generated missiles may damage the tanks and give rise to internal flooding. The layout of the tanks outside the buildings is not in GDA scope and the tanks are usually non-classified items. So they are not designed against design basis external hazards and the consequence caused by these tanks will be analysed in nuclear site licensing phase.

assumed to be clogged by three kinds of missiles caused by wind and tornado in GDA phase.

18.6.3.2.3 Protection Measures

As mentioned in Sub-chapter 18.6.3.2.2.2, wind generated missiles are bounded by tornado missiles. According to PCSR Sub-chapter 16.6.2, the civil structures are designed to resist the load caused by tornado missiles.

The openings of HVAC systems performing Category 1 and Category 2 functions are protected by the inverse “L” structure. 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

Extreme 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.

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. Tornado could cause missiles and is correlated with rain in Reference [36], and this sub-chapter concentrates on the tornado loads and tornado-generated missiles; the rain effect is covered in Sub-chapter 18.6.2.

According to Reference [36], 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

The adopted design basis tornado parameters are shown in PCSR Sub-chapter 3.6 according to RG 1.76 in Reference [37], 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 the UK HPR1000 are shown in Table T-18.6-3.

T-18.6-3 Design Basis Tornado Missiles

Missile Type	**Dimensions(m)**	**Mass(kg)**	**Speed(m/s)**	**Height**
Automobile	5×2×1.3	1810	34	Less than 9.14m
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 identified are listed as follows:

a) Consequential Hazards

Tornados could cause external missiles.

b) Correlated Hazards

Tornado is correlated with rain.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) Tornado could cause LOOP;

2) Tornado could cause LUHS. However, as the buildings, SEC ([ESWS]) system located in, are designed to withstand tornado and tornado generated missiles. The intake of all three trains of SEC ([ESWS]) system is not assumed to be clogged by three kinds of missiles caused by tornado in GDA phase.

18.6.3.3.3 Protection Measures

The main protection measures adopted in the design of the UK HPR1000 are as follows:

a) Civil Structures above the Ground

The design basis tornado wind loads, tornado differential pressure loads and tornado generated missiles loads are considered in the design of civil structures. Systems and equipment important to safety in the buildings are protected by civil structures.

b) Exterior Doors

Exterior doors mean the doors installed in the boundary of the buildings connecting to the outside. For buildings important to safety, the exterior doors can withstand tornado generated missiles loads.

c) The Explosion Pressure Wave (EPW) Damper

EPW dampers can withstand 20kPa of both positive and negative differential pressure. When the differential pressure caused by the tornado reaches 2.5kPa, the damper can automatically close, and when the differential pressure returns below 2.5kPa, the damper can automatically open.

Intakes and exhausts of HVAC systems performing Category 1 and Category 2 functions have been protected by EPW dampers from sudden pressure drop caused by tornado.

d) Inverse “L” Structure

Inverse “L” structure is a special civil structure configuration opened toward the ground, and they are designed to protect the openings of HVAC systems on the building boundary from design basis tornado generated missiles.

e) Pressure Relief Device

Pressure relief device is designed to prevent the room overpressure caused by pipe rupture from affecting structure in the room. The pressure relief device can withstand 20kPa pressure from outside. It can protect the opening on the building boundary from design basis tornado differential pressure.

18.6.3.3.4 Safety Assessment

The following safety assessment is performed to ensure the delivery of fundamental safety functions during tornado:

a) Design Basis Tornado Safety Assessment

The safety assessment methodology of tornado is performed according to

Reference [38].

Buildings in GDA scope are considered in the design basis tornado safety assessment. SSCs performing Category 1 and Category 2 functions located in buildings are protected by civil structures, and the intakes and exhausts of HVAC systems performing Category 1 and Category 2 functions are protected by EPW dampers and inverse "L" structures. The following measures are analysed in Reference [14]:

1) Civil structures of buildings including SSCs performing Category 1 and Category 2 functions have been designed to resist tornado;

2) Exterior doors of buildings including SSCs performing Category 1 and Category 2 functions have been designed to resist tornado;

3) Intakes and exhausts of HVAC systems performing Category 1 and Category 2 functions have been protected by EPW dampers and inverse "L" structures to perform their functions during design basis tornado.

Gaps identification has been finished, the optioneering process is under progress.

b) Cliff-edge Effects Analysis

The following aspects of the UK HPR1000 protection design can avoid the cliff-edge effects and risk of beyond design basis tornado:

1) The design basis values are larger than generic site values, and the protection design of tornado has adequate margin, which is shown in Table T-18.6-4;

T-18.6-4 Compare Design Basis Value with Generic Site Value

Parameter	Design Basis Value	Generic Site Value
Tornado Wind Speed	89m/s	60m/s
Pressure Drop	6.3kPa	3.1kPa
Pressure Drop Rate	2.5kPa/s	0.94kPa/s

2) The EPW dampers can withstand maximum overpressure of 20kPa, which can withstand tornado wind pressure loads with margin.

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.

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 function of cooling systems, electrical and instrumentation equipment important to safety.

18.6.3.4.2.2 Definition of Design Basis Hazards

According to Reference [29], the maximum air temperature value is 41.5℃ for the UK HPR1000 Generic Site Envelope, and a maximum air temperature climate change value of 5.4℃ has been selected.

The minimum air temperature value has also been obtained from Reference [29]. The minimum air temperature is -22℃ for the UK HPR1000 Generic Site Envelope.

According to Reference [29], the maximum water temperature value is 28℃, and a climate change value of 4℃ is considered. The minimum water temperature value of -2℃ is selected as this is the lowest temperature of salt water before freezing.

A climate change value has not been calculated for minimum air/water temperature, as Reference [24] indicates that temperatures in the UK may rise during the next 60 years. The values presented are therefore deemed conservative.

The generic site envelope temperature values are shown in Table T-18.6-5.

T-18.6-5 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 identified are listed as follows:

a) Consequential Hazards

Extreme low temperatures could cause icing.

b) Correlated Hazards

Extreme low temperatures are correlated with snow.

c) Independent Hazards

None.

d) Combinations of External Hazards with Design Conditions

1) Extreme temperatures could cause LOOP;

2) Extreme temperatures could cause LUHS;

3) Extreme temperatures could cause LOOP and LUHS.

18.6.3.4.3 Protection Measures

To achieve the safety requirements, the protection measures aim to ensure that 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 systems are designed to maintain the ambient temperature of equipment important to safety to within the appropriate operating range, and the extreme air temperatures and climate change are taken into consideration in the design of HVAC systems. More information is shown in PCSR Sub-chapter 10.6.

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

Extreme water temperatures may affect the heat removal function of cooling systems, particularly with regards to SEC [ESWS] and Component Cooling Water System (RRI [CCWS]). The effects of extreme high water temperature are considered in the design of SEC [ESWS] and RRI [CCWS], and more information is presented in PCSR Sub-chapter 10.4.

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

Systems and equipment important to safety in the buildings are protected by HVAC systems from the impact of environmental temperature outside the buildings, and the design basis extreme air temperature is considered in the design of HVAC systems. The design basis air temperature is also considered in the design of civil structures.

The impact of the design basis extreme water temperature is considered in the design of SEC [ESWS] and RRI [CCWS] system. Measures such as offshore deeper water intake, alarm signal, specific water intake tunnel and forebay design could be taken to avoid the risk of freezing caused by extreme low water temperature. The details of the measures depend on the site characteristics.

Gaps identification has been finished, the optioneering process is under progress.

Details of temperature safety assessment are shown in Reference [16].

b) Cliff-edge Effects Analysis

Conservative design is used so that under design basis extreme temperatures there is no cliff-edge effect:

1) The HVAC systems, SEC [ESWS] and RRI [CCWS] systems important to safety are designed to operate with sufficient margin during extreme temperatures;

2) Climate change predictions indicate that temperatures are increasing. The design basis extreme low air/water temperatures used for the UK HPR1000 design are conservative as the climate change value has not been incorporated into the extreme low air/water temperatures.

18.6.3.5 Extreme Hail, Sleet, Snow and Icing

18.6.3.5.1 Safety Requirements

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.

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 in 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 in Reference [29]. 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}/y, and 1.5kPa is adopted as the design basis ground snow load. A climate change value has not been incorporated into snow loads, as climate change predictions indicate that temperatures are increasing, the value presented is deemed to be conservative.

18.6.3.5.2.3 Hazard Combinations

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

a) Consequential Hazards

Snow melt could cause external flooding.

b) Correlated Hazards

1) Extreme snow is correlated with extreme wind;

2) Extreme snow is correlated with extreme low temperature.

c) Independent Hazards

Extreme snow may potentially act alongside an earthquake. In the design of structures, the load combinations of snow with earthquakes are considered.

d) Combination of External Hazards with Design Conditions

External hail, sleet, snow and icing could cause LOOP.

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. The snow and icing loads are considered in the design of civil structures important to safety in PCSR Sub-chapter 16.6.2. Systems and components important to safety outside the buildings are designed to withstand extreme snow load. The inverse "L" structure is designed to protect the openings of HVAC systems from clogging caused by snow. The openings on the boundary of the buildings which contain the SSCs important to safety are used for overpressure relief. These openings are protected by the pressure relief devices from being clogged by snow.

18.6.3.5.4 Safety Assessment

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

The design basis snow and icing loads are considered in the design of civil structures.

Measures such as offshore deeper water intake, alarm signal, specific water intake tunnel and forebay design could be taken to avoid clogging caused by icing, and the details of the measures depend on the site characteristics.

The inverse "L" structure is designed to protect the openings of HVAC systems from clogging.

The extreme hail, sleet, snow and icing safety assessment is shown in Reference [16].

b) Cliff-edge Effects Analysis

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

Climate change predictions indicate that temperatures are increasing, and the load of snow may become smaller. The design basis snow load used for the UK HPR1000 design is conservative as the climate change value has not been incorporated into snow loads.

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.

18.6.3.6.2 Design Basis

18.6.3.6.2.1 Lightning Characterisation

According to Reference [33], lightning is a visible electrical discharge 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 is created under certain circumstances produces point discharges and can cause breakdown of insulators.

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

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

a) Electrical fires;

b) Explosion;

c) Loss of SSCs 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 requirement of design basis frequency of external hazard is 10^{-4}/y, and 300kA is determined to be the design basis current value of lightning in the UK HPR1000, Reference [40].

18.6.3.6.2.3 Hazard Combinations

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

a) Consequential Hazards

   1) A lightning strike could cause internal fire or internal explosion;

   2) A lightning strike could cause external fire;

   3) A lightning strike could cause EMI.

b) Correlated Hazards

   1) Lightning is correlated with rainfall;

   2) Lightning is correlated with wind.

c) Independent Hazards

   None.

d) Combination of External Hazards with Design Conditions

   A lightning strike could cause LOOP.

18.6.3.6.3 Protection Measures

The lightning protection measures and the electrical equipment are designed and coordinated with each other such that the influence of lightning strikes on electrical facilities would 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). Buildings are protected by a lightning protection system, appropriate surge arrestors and an earthing system. Systems vulnerable to radio frequency interference are suitably located away from the outside of buildings to minimize the effects of lightning strikes.

The 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 PCSR Sub-chapter 9.7.1. 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.
Appropriate rules of layout, cabling and equipotential bonding network are also adopted to protect the electrical and electronic systems from being affected by 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 should be performed. This map is required to identify the location of 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 can protect the items important to safety.

Gaps identification has been finished, the optioneering process is under progress.

18.6.4 Man-made and Industrial Hazards

Human activities can cause man-made external hazards that could affect the safety of nuclear installations.

Man-made external hazards considered in GDA phase include accidental aircraft crash, external explosion and off-site missiles. SSCs important to safety should be protected against design basis man-made external hazards.

18.6.4.1 Accidental Aircraft Crash

This sub-chapter focuses on the accidental aircraft crash hazard. Malicious aircraft crash is not presented in Chapter 18 as it is related to sensitive nuclear information. The civil structures protection design against physical damage due to the malicious aircraft impact is presented in PCSR Sub-chapter 16.7.2.

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.

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 [33]:

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 inside the buildings due to the 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 effect of missile impact (including secondary missiles), including penetration, perforation, scabbing and spalling, leading to the failure of structural elements or equipment important to safety;

d) The effects of induced fires and possible explosion on SSCs important to safety.

18.6.4.1.2.2 Categorising and Screening of Accidental Aircraft Crash

Aircraft types are normally categorised taking different characteristics into account, such as the mass and velocity, and the following five categories of aircraft are typically considered according to Reference [29]:

a) Light aircraft;

b) Helicopters;

c) Small transport aircraft;

d) Large transport aircraft;

e) Military combat aircraft.

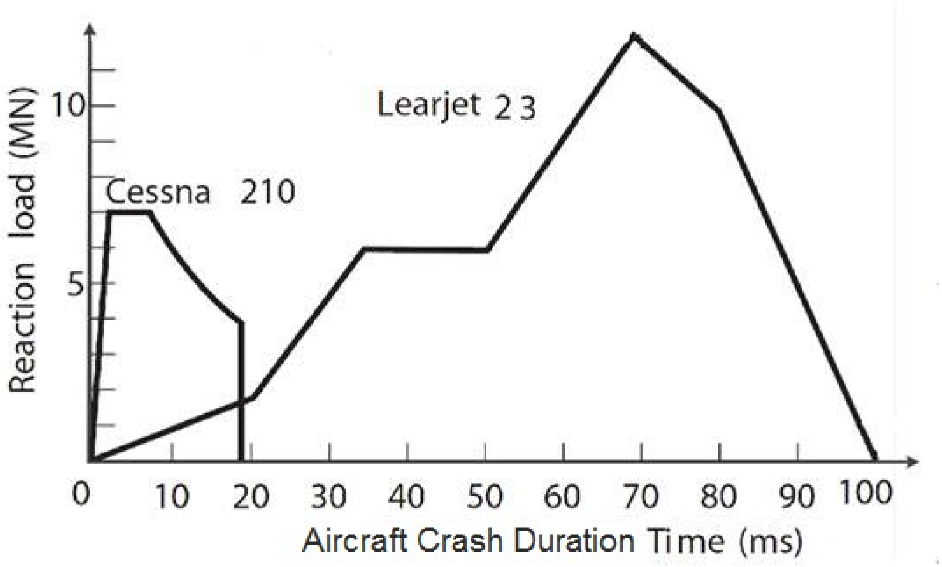
The approach for protection against an accidental aircraft crash is deterministic and based on specific scenarios applied to different categories of aircraft. If one kind of aircraft crash rate is higher than the screening frequency of occurrence, which is 10^{-7}/y according to Reference [1], this kind of aircraft is considered.

For one unit of the UK HPR1000, the total accidental aircraft crash rate is less than 10^{-5}/y based on UK aircraft crash rates in Reference [42]. The crash rate of each accidental aircraft category is presented in Table T-18.6-6.

T-18.6-6 Accidental Aircraft Crash Rate

The accidental aircraft crash rate is lower than the design basis discrete hazards frequency, which is 10^{-5}/y, so accidental aircraft crash belongs to beyond design basis event.

As with the reference design of the Fangchenggang Nuclear Power Plant Unit 3 (FCG3), light aircraft Learjet 23 and Cessna 210 are chosen as design basis aircraft for the UK HPR1000. IAEA No. NS-G-1.5 (Reference [33]) provides the applicable load-time function for the design basis aircraft, which is presented in Figure F-18.6-1.



F-18.6-1 Load-time Function of Design Basis Aircraft Crash

18.6.4.1.2.3 Hazard Combinations

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

a) Consequential Hazards

1) Aircraft crash could cause external missiles;

2) Aircraft crash could cause fire and possible explosion.

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

1) Aircraft crash could cause LOOP;

2) Aircraft crash could cause LUHS.

18.6.4.1.3 Protection Measures

For design basis aircraft crash, civil structures that contain systems and components important to safety are designed to resist the design basis aircraft impact loads according to PCSR Sub-chapter 16.6.2.

For beyond design basis accidental aircraft crash, structure reinforcement primarily applies to the BRX, BSC and BFX according to PCSR Sub-chapter 16.7.2, while the geometrical separation is applied to the layout design of BDA/BDB/BDC/BDU/BDV, and BSA/BSB to avoid common mode failure.

18.6.4.1.4 Safety Assessment

The accidental aircraft crash rate will be reviewed considering specific site conditions and proximity to airports and airfields during nuclear site licensing phase and the safety assessment will be carried out in nuclear site licensing phase. The assessment methods are developed to make sure the SSCs important to safety are robust against the effects of accidental aircraft crash, including the following:

a) The global structural damage effect due to an aircraft crash and aircraft-induced vibration is conservatively simulated following the methodology in Reference [42]. 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 to see whether the safety requirements are challenged, and modifications are proposed for the design of SSCs if necessary;

b) The induced fire from an aircraft crash is simulated by using the methodology in Reference [42];

c) The calculation of local structural damage is based on the empirical formula methods as provided in Reference [43].

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.

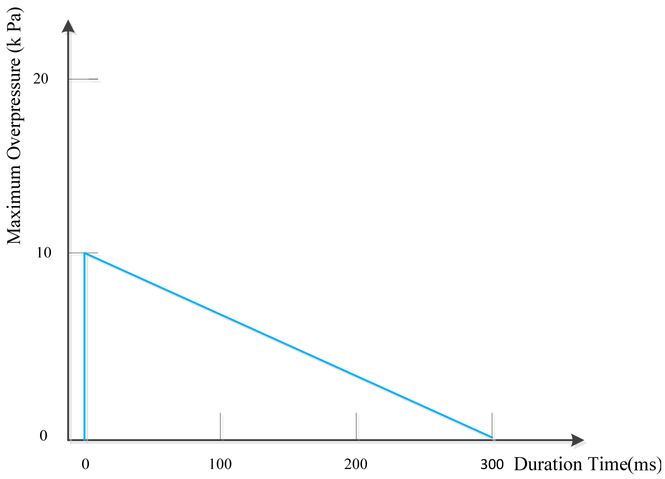
18.6.4.2.2 Design Basis

18.6.4.2.2.1 External Explosion Characterisation

According to Reference [33], an external explosion can affect the entire plant, and it may be in the form of deflagration, which generates moderate pressure, heat or fire, or detonation which generates high pressure 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 in nuclear site licensing phase.

18.6.4.2.2.2 Definition of Design Basis Hazards

According to Reference [22], 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 Figure F-18.6-2).



F-18.6-2 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 2 is applied, that is to say, the maximum overpressure is 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 identified are listed as follows:

a) Consequential Hazards

   1) External explosion could cause external missiles;

   2) External explosion could cause internal and external fire.

b) Correlated Hazards

   None.

c) Independent Hazards

   None.

d) Combination of External Hazards with Design Conditions

   External explosion could cause LOOP.

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 the buildings important to safety. The main protection measures adopted in the design of the UK HPR1000 are as follows:

a) Civil Structures above Ground

   External explosion loads are considered in the design of civil structures. Systems and equipment important to safety in the buildings are protected by civil structures, which can withstand 20kPa pressure wave.

b) Exterior Doors

   Exterior doors mean the doors installed in the boundary of the buildings connecting to the outside. For buildings important to safety, external explosion loads are considered in the design of exterior doors, which can withstand 20kPa pressure wave.

c) EPW Damper

   EPW dampers can withstand 20kPa pressure wave of both positive and negative differential pressure. When the differential pressure reaches 2.5kPa, the damper is automatically closed, and when the differential pressure returns below 2.5kPa, the damper automatically opens.

Intakes and exhausts of HVAC systems important to safety have been protected by EPW dampers.

d) Pressure Relief Device

Pressure relief device is designed to prevent the room overpressure caused by high energy pipe failures from affecting other items in the room. It consists of multiple release devices and can be opened by different overpressures inside. The pressure relief device can withstand 20kPa pressure wave from outside. It protects the opening towards the outside from design basis external explosion.

18.6.4.2.4 Safety Assessment

The following safety analysis is performed to ensure nuclear safety during external explosion:

a) Design Basis External Explosion Assessment

The safety assessment methodology of external explosion is performed according to Reference [44]. The design basis external explosion safety assessment includes every building in GDA scope. SSCs performing Category 1 and Category 2 functions located in buildings are protected by civil structures, and the safety classified HVAC systems intakes and exhausts are protected by EPW dampers. According to Reference [15], the following measures are analysed:

1) Civil structures of buildings including SSCs performing Category 1 and Category 2 functions have been designed to resist external explosion;

2) Exterior doors of buildings including SSCs performing Category 1 and Category 2 functions have been designed to resist external explosion;

3) Intakes and exhausts of HVAC systems performing Category 1 and Category 2 functions have been protected by EPW dampers.

Gaps identification has been finished, the optioneering process is under progress.

b) Cliff-edge Effects Analysis

For civil structures, the UK HPR1000 design incorporates ductile features allowing inelastic absorption of the hazard load, providing a margin and ensuring that there is no cliff-edge effect. The source of external explosion will be identified according to specific site condition. So the cliff-edge effects and beyond design basis analysis of external explosion for the UK HPR1000 protection design will be taken in nuclear site licensing phase.

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.

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 SSCs of the plant. The missiles include:

a) Wind- induced missiles and tornado induced missiles;

b) Man-made missiles from adjacent areas.

Wind-induced missiles and tornado induced missiles are discussed respectively in Sub-chapter 18.6.3.2 and Sub-chapter 18.6.3.3, this sub-chapter focuses on man-made missiles from adjacent areas.

18.6.4.3.2.2 Design Basis

Adjacent area missile may be generated by explosion in adjacent facilities, which is a site specific hazard and cannot be determined in the GDA phase. The specific scenarios will be investigated during the nuclear site licensing phase.

18.6.4.3.2.3 Hazard Combinations

a) Consequential Hazards

None.

b) Correlated Hazards

None.

c) Independent Hazards

None.

d) Combination of External Hazards with Design Conditions

Off-site missiles could cause LOOP.

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 performing Category 1 and Category 2 functions inside the buildings are protected against off-site missile load by the civil structures, which can resist aircraft crash load. As mentioned in Sub-chapter 18.6.3.3, the design of the safety classified civil structure takes the missile load into consideration, the protection measures for tornado missiles are also available to protect against missiles from adjacent areas. The spatial separation of diesels buildings can avoid common failure caused by missiles from adjacent areas.

18.6.4.3.4 Safety Assessment

a) Design Basis Off-site Missile Assessment

Tornado induced missiles assessment is discussed in Sub-chapter 18.6.3.3.

For missiles generated by an explosion in adjacent facilities, which is a site specific hazard, cannot be determined in GDA phase. So the design basis off-site missiles assessment will be taken during the nuclear site licensing phase.

b) Cliff- edge Effects Analysis

Tornado induced missiles cliff-edge effects analysis is discussed in Sub-chapter 18.6.3.3.

Missiles generated by an explosion in adjacent facilities are a site-specific hazard and thus cannot be determined in GDA phase. So the off-site missiles cliff-edge effects analysis will be taken during the nuclear site licensing phase.

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.

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, including:

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).

In GDA phase, lightning and space weather are considered to be the sources of external EMI. EMI will be identified and characterised during the nuclear site licensing phase 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 happens, especially for man-made sources.

In GDA phase, lightning and space weather are considered to be the sources of external EMI. EMI caused by a lightning strike is described in the Sub-chapter 18.6.3.6. EMI caused by 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

None.

18.6.5.1.3 Protection Measures

The following protection measures have been taken into consideration in the design of the UK HPR1000:

a) Shielding

Electrical equipment and I&C equipment are shielded by cabinet or shell to protect them from the effect of EMI. The cables are shielded by a cable shielding layer to protect them from the effect of EMI.

b) Grounding

Proper grounding of electrical and I&C equipment, cabinets, and cable shields is implemented to enhance the capability against EMI.

c) Electromagnetic Compatibility Test

The Electromagnetic Compatibility (EMC) test is performed on essential electrical equipment and essential I&C equipment so as to ensure the reliability of the equipment.

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 affected by the internal EMI which is shown in PCSR Sub-chapter 19.6, and the risk from external EMI is much lower because it is protected by the lightning protection measures. In GDA phase, the measures of the UK HPR1000 against EMI are considered to be able to protect the safety functions from being affected, and detailed information is shown in Reference [18].

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.

18.6.5.2.2 Design Basis

18.6.5.2.2.1 Space Weather Hazard Characterisation

Space weather is defined as a set of processes originating from solar activity that can affect the near-Earth environment. 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 neutrons and muons, 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 including 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. Hardware may be permanently damaged and memory may be rewritten.

18.6.5.2.2.2 Definition of Design Basis Hazards

The frequency and severity of space weather are difficult to determine because of lack of data and validity of the methodology. A frequency of 10^{-4}/y is adopted for the design basis space weather. As the GIC is site related, the GIC flowing through the neutral point of the unit transformer will be calculated based on the typical earth conductivity structure in UK and the distribution of the ocean around the UK, and then mitigation measures will be defined.

Horizontal magnetic field change rate with a frequency of 10^{-4}/y is considered as 2513nT/min in GDA phase.

The magnitude of GIC will be studied by a conservative methodology according to the characteristic of grid network in 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 identified are listed as follows:

a) Consequential Hazards

   Space weather could cause 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 cause 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.

Larger scale mitigations such as operating procedures of Transmission System Operator, GIC compliant power transformers and deployment of GIC blocking devices may be considered. The GIC flowing through the neutral point of the unit transformer can be calculated based on the typical earth conductivity structure in UK and the distribution of the ocean around the UK, and then mitigation measures will be defined, Reference [18].

The protection measure of lightning, i.e. earthing and lightning protection system which is shown in PCSR Sub-chapter 9.7.1, is used to protect the electromagnetic effects of lightning currents. The system also has capacity to protect susceptible I&C equipment against space weather events.

Electrical and I&C systems important to safety are located inside reinforced concrete buildings. The neutron influence on devices within buildings can be attenuated by the concrete structures surrounding the systems. Electrical control and protection equipment, I&C equipment and the host of communication system are also shielded by cabinet or shell.

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.

The effects of space weather (GIC, solar energetic particles, EMI) are considered and protection measures are identified in the GDA phase. Assessment of space weather is shown in *Lightning, Electromagnetic Interference and Space Weather Safety Evaluation Report* (Reference [18]).

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.

The heat sink design should meet the following safety requirements:

a) Systems for transferring heat should 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 in 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 Heat Sink Specific Hazards 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 that can clog the intake of the pump station, affect the water quality of SEC [ESWS] system and corrode the equipment.

Pump station may be clogged due to:

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

b) Silting;

c) Debris (frazil ice, logs, etc.).

18.6.6.2.1.2 Hydrocarbon Pollution

Hydrocarbon pollution may influence the water quality of cooling systems. During the nuclear site licensing phase, 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. Potential sources 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.

Underwater explosion effects are mainly pressure waves that propagate through water. Underwater explosion will be considered during the nuclear 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 (NPP) 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 related 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 identified are listed as follows:

a) Consequential Hazards

   None.

b) Correlated Hazards

   Massive clogging is correlated with exceptional coastal flooding.

c) Independent Hazards

   None.

d) Combination of External Hazards with Design Conditions

   Heat sink specific hazards could cause 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 hazard sources. A summary of the protection measures against the heat sink specific hazards is as follows:

a) Protection measures against clogging are shown as follows:

Protection measures against clogging are taking offshore deeper water intake measure and using appropriate equipment of SEC [ESWS] (including coarse rack, fine rack and debris filter), which can prevent clogging material from entering the water intakes. The deeper water intake measures are site specific, and more detailed information will be provided in nuclear site licensing phase.

For the frazil ice induced clogging, the protection measure is an offshore deeper water intake to ensure the intake water would not get frozen. In addition, the design modification is carried out for SEC [ESWS] against low water temperature. The recommended option is to return thermal water of the SEC [ESWS] heat exchanger to the SEC [ESWS] pump, and make the mixing of the cold and warm seawater at the inlet suction to enhance the water temperature entering into the heat exchanger.

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

1) Offshore deeper water intake measure;

2) DiD protection measure is monitoring the route to reduce the risk caused by ship collision.

c) Protection measures against potential ship collision are shown as follows:

1) Redundant intakes of SEC [ESWS];

2) Sufficient separation of redundant intakes.

d) Protection measures taken against underwater explosion are shown as follows:

1) Sufficient separation of redundant intakes;

2) DiD protection measures is periodic dredging in the vicinity of water intake.

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

Protection measure against low water level is setting the water intakes offshore in deeper water. In the reference plant design of the FCG3, the design basis low water level is the combination of low astronomical tide and the probably maximum storm surge low level, which is -5.09m, and the design of SEC [ESWS] intake is lower than this low water level, which can provide sufficient cooling for RRI [CCWS].

If the protection measures mentioned above are failed, Extra Cooling System (ECS [ECS]) and Containment Heat Removal System (EHR [CHRS]) can be put into operation to provide extra cooling water to maintain the plant in a stable state. ECS

[ECS] and EHR [CHRS] are located on the nuclear island that cannot be affected by heat sink specific hazards.

18.6.6.4 Safety Assessment

The safety assessment is carried out in the *Heat Sink Specific Hazards Safety Evaluation Report* (Reference [17]).

a) Design Basis Tornado Safety Assessment

Structures (Essential Service Water Pump Station A (BPA) and Essential Service Water Pump Station B (BPB)) and the systems (SEC [ESWS] and RRI [CCWS]) could be affected by heat sink specific hazards. Protection measures are adopted against heat sink specific hazards, which are presented in Sub-chapter 18.6.6.3.

After assessment, the protection measures can effectively reduce the consequences caused by heat sink specific hazards. The most severe consequence of heat sink hazards is total loss of ultimate heat sink. In this situation, the backup heat removal systems ECS [ECS] and EHR [CHRS] can be put into operation because they cannot be affected by heat sink specific hazards due to their layout, so the residual heat of reactor core and spent fuel can be continually removed by ECS [ECS] and EHR [CHRS] that can maintain the plant in stable state.

There are no gaps found in the safety assessment against heat sink specific hazards.

b) Cliff-edge Effects Analysis

The most severe consequence of heat sink specific hazards is LUHS, which is acceptable as stated in the *Heat Sink Specific Hazards Safety Evaluation Report* (Reference [17]). So no cliff-edge effect may happen due to heat sink specific hazards.

18.7 Assessment of Hazard Combinations

The aim of this sub-chapter is to demonstrate that the consequences of the 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 the overall hazard assessment to ensure that the protection measures implemented are suitable and sufficient. Hazard combinations have the potential to be compound or exhibit delayed impacts and, as a result, may exceed the limit of the available protection measures. The safety protection requirements for the hazard combinations are consistent with that for the 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 in the section of hazard combinations in Sub-chapter 18.6.

The effect of a design basis external hazard on internal equipment important to safety is mainly prevented by the appropriate design of the exterior civil structures, doors, dampers, etc., with the exception of earthquake, EMI, space weather, lightning and extreme temperatures. The consequential internal hazards caused by an earthquake are analysed separately in Sub-chapter 18.6.1 and in Reference [32].

LOOP and/or LUHS are typically caused by external hazards. However, these two faults are considered in PCSR Sub-chapter 12.4 and PCSR Sub-chapter 13.4, and the equipment used to address the faults is protected against the relevant design basis external hazards.

Independent hazard combinations may be considered for the purposes of ensuring conservative design, such as the effects of extreme temperatures and earthquakes. The compound effects due to the combination of external hazards are considered as part of the civil structure design and substantiation which is described in PCSR Sub-chapter 16.6.

18.8 Administrative Procedures

Administrative procedures should be developed to prevent the breach of barriers against release or to mitigate consequences caused by the severe external hazards, Reference [23]. Administrative procedures are DiD protection measures against the external hazards and will be produced in the nuclear site licensing phase. The production of administrative procedures must consider the site specific natural hazard conditions. Winds, rainfall and lightning are typical meteorological hazards and need to be considered during the development of administrative procedures.

Following administrative procedures drawn from feedback from existing NPP operations can be considered for the UK HPR1000. 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 forecasting, and a process for obtaining these data;

c) Establishment of warning signals depending on the 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.

18.9 ALARP Demonstration

As part of the ALARP demonstration of the UK HPR1000, the current ALARP demonstration which will be developed throughout the GDA for external hazards protection design is presented in this sub-chapter. The current ALARP demonstration process and results are presented in *ALARP Demonstration Report for External Hazards* (Reference [39]).

18.9.1 General Approach for ALARP Demonstration

PCSR Chapter 33 and its reference document *ALARP Methodology* [45] present a generic approach used for ALARP demonstration for the UK HPR1000 design. The main steps of the approach are listed as follows:

a) Identifying sources of RGPs;

b) Comparison with RGPs;

c) Identification of potential gaps;

d) Risk assessment, as a way of understanding the significance of the issue to the overall demonstration of ALARP;

e) Evaluation of options (Optioneering);

f) Implementation of reasonably practicable improvements.

18.9.2 Sources of RGPs

A review of the sources of RGPs is undertaken to help to identify suitable options to reduce risk. For the UK HPR1000, the sources of the RGP applied to protect against external hazards are identified. The sources of the RGP predominantly come from the following aspects:

a) IAEA Codes and Standards;

b) WENRA Documents;

c) Other Codes and Standards.

The sources of the RGPs are listed in Table T-18.9-1, T-18.9-2 and T-18.9-3 according to Reference [20] and Reference [21].

T-18.9-1 IAEA Codes and Standards

No.	Title	Source	Remark
1	Site Evaluation for Nuclear Installations, SSR-1, 2019	IAEA	For all external hazards
2	External Human Induced Events in Site Evaluation for Nuclear Power Plants, NS-G-3.1, 2002	IAEA	For external human induced hazards
3	Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, NS-G-3.6, 2004	IAEA	For earthquake
4	Seismic Hazards in Site Evaluation for Nuclear Installations, SSG-9, 2010	IAEA	For earthquake
5	Safety of Nuclear Power Plants: Design, SSR-2/1, 2016	IAEA	For all external hazards
6	External Events Excluding Earthquakes in the Design of Nuclear Power Plants, NS-G-1.5, 2003	IAEA	For external hazards except earthquake
7	Seismic Design and Qualification for Nuclear Power Plants, NS-G-1.6, 2003	IAEA	For earthquake
8	Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, SSG-18, 2011	IAEA	For meteorological and hydrological hazards
9	Site Survey and Site Selection for Nuclear Installations, SSG-35, 2015	IAEA	For all external hazards
10	Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations, Safety Report 86, 2017	IAEA	For external human induced hazards
11	Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures, Safety Report 87,	IAEA	For external human induced hazards

No.	Title	Source	Remark
	2018		
12	Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment, Safety Report 88, 2017	IAEA	For external human induced hazards

T-18.9-2 WENRA Documents

No.	Title	Source	Remark
1	Safety of New NPP Designs, 2013	WENRA	For all external hazards
2	Guidance Document Issue T Natural Hazards (External Flooding), 2016	WENRA	For external flooding
3	Guidance Document Issue T Natural Hazards (Extreme Weather Conditions), 2016	WENRA	For extreme weather
4	Guidance Document Issue T Natural Hazards (Seismic Events), 2016	WENRA	For earthquake
5	Guidance Document Issue T: Natural Hazards: Head Document, 2015	WENRA	For natural hazards
6	Safety Reference Levels for Existing Reactors, September 2014	WENRA	For all external hazards
7	Statement on Safety Objectives for New Nuclear Power Plants, 2010	WENRA	For all external hazards

T-18.9-3 Other Codes and Standards

No.	Title	Source	Remark
1	Design-basis Tornado and Tornado Missiles for Nuclear Power Plants, RG1.76, 2007	NRC	For tornado and missile

No.	Title	Source	Remark
2	Guidance for External Events Analysis, 2003	Swedish Nuclear Inspectorate	For all external hazards

18.9.3 Identification of Potential Gaps

Gaps can be identified through evolution of the Hua-long Pressurised Reactor (HPR1000), compliance with RGP, OPEX review and external hazards safety assessments.

18.9.3.1 Evolution of the HPR1000

The external hazards protection design of Hua-long Pressurised Reactor under construction at FCG3 is based on the successful experiences from a series of Chinese commercial NPPs. More detailed information can be seen in PCSR Sub-chapter 2.3.

Modifications have been made in the evolution of the HPR1000 (FCG3). These modifications take into consideration the reduction of risks and the experience feedback from the accident of other power plants. The typical modifications are listed as follows:

a) For the lessons learned from the Fukushima accident, the beyond design basis external flooding scenario is adopted to check the risk from external flooding. Modifications, such as watertight doors, and sealing of penetrations, are taken for this scenario. The SSCs important to safety are designed to withstand the design basis earthquake (zero period peak horizontal ground acceleration is 0.3g).

b) For the low water temperature, in a northern site of China, one modification option of Hongyanhe NPP is to use hot water from the outlet of SEC [ESWS]/RRI [CCWS]) exchangers at the intake of the SEC [ESWS] pump to heat the intake water so that the water cannot freeze.

c) For the clogging in the water intake of SEC [ESWS], the modification is to set several filtrations before the sea water coming into the forebay.

18.9.3.2 Compliance with RGPs

The compliance analysis between the current design of the UK HPR1000 and the RGPs is shown in *Compliance Analysis of Codes and Standards in External Hazards* (Reference [21]). The analysis result is presented in Sub-chapter 18.3.

18.9.3.3 OPEX Review

The OPEXs of external hazards from Chinese commercial NPPs and the Fukushima accident are reviewed. The feedbacks from these experiences are considered in the

UK HPR1000 design, such as the protection measures of watertight doors, and the sealing of penetrations taken after Fukushima accident.

For the OPEX review from external hazards protection experience feedback in UK, these experiences are suitably considered in the UK HPR1000 design.

a) The combination of earthquake and wind or snow is considered in the civil structure design of the UK HPR1000;

b) The low air temperature is considered for the systems outside the building;

c) For the protection design experience of heat sink specific hazards from the HPC (Hinkley Point C), these hazards are considered in the protection design of the UK HPR1000.

18.9.3.4 External Hazards Safety Assessments

External hazards within GDA scope are evaluated in each external hazard evaluation report. The evaluation results of each hazard are presented in Sub-chapter 18.6 and some gaps are identified in the assessment. The list of gaps completed is shown in Table T-18.9-4.

T-18.9-4 Gaps Identified from External Hazards Safety Assessment

Gap	Sources	Progress
Air temperature	Different values between design basis parameters of the FCG3 and the UK HPR1000 Generic Site Envelope	Complete
Water temperature (minimum temperature)	Different values between design basis parameters of the FCG3 and the UK HPR1000 Generic Site Envelope	Complete
Snow	Different values between design basis parameters of the FCG3 and the UK HPR1000 Generic Site Envelope	Complete
Icing	Different values between design basis parameters of the FCG3 and the UK HPR1000 Generic Site Envelope	Complete
Space weather	Different values between design basis parameters of the FCG3 and the UK HPR1000 Generic Site Envelope	Complete

Gap	Sources	Progress
Seismic (shear wave velocity)	Different values between design basis parameters of the FCG3 and the UK HPR1000 Generic Site Envelope	Complete

18.9.4 Gaps Assessment

The ALARP demonstration process has been finished for the gaps of Air Temperature, Water Temperature, Snow, Icing, Space Weather and Seismic (shear wave velocity).

18.9.4.1 Air Temperature

HVAC systems are impacted by the gaps of air temperature. The modifications of the systems with safety ventilation, cooling or heating functions may be applied in Diesel Building Ventilation System (DVD [DBVS]), Safety Chilled Water System (DEL [SCWS]), Electrical Division of Safeguard Building Ventilation System (DVL [EDSBVS]) and Main Control Room Air Conditioning System (DCL [MCRACS]) systems.

The optioneering has been done for these systems and the recommended option is given, which are presented in *Systems Analysis Report—Site Adaptability Modification in UK HPR1000* (Reference [46]).The implementation of these options for modifying the HVAC system design manuals has been finished. So the gap resolution for HVAC systems is completed.

18.9.4.2 Water Temperature

The maximum seawater temperature used for the design of the UK HPR1000 is the same as the Generic Site Envelope value. So the impact of the seawater temperature difference is mainly due to the low seawater temperature. The gap analysis and optioneering process are shown in *SEC/RRI System Analysis Report* (Reference [47]). The optioneering has been done for SEC/RRI systems and the recommended option is given. The implementation of the recommended option for modifying the SEC [ESWS] system design manual has been finished. So the gap resolution for SEC [ESWS] system is completed.

18.9.4.3 Structural Analysis against Snow and Icing

The snow and icing are new external hazards for the UK HPR1000, they are identified as potential gaps which are analysed in *Structural Analysis and Design Report* (Reference [48]).

The analysis result shows that the combination of actions including icing load and snow load is not the critical combination (the combination of actions including earthquake and abnormal loads is the critical combination). Therefore, the addition of icing and snow load may have no influence on the design of civil structures.

18.9.4.4 Structural Analysis against Shear Wave Velocity

The shear wave velocity is identified as a gap because the shear wave velocity of the candidate site in the UK may be as low as 150m/s. The change in shear wave velocity can lead to the change of structural responses. The gap is analysed in *Seismic Analysis Report for Structure* (Reference [49]).

The analysis result shows that for the very soft soil condition, the calculated reinforcement of the selected members is almost enveloped by the actual reinforcement of the FCG3, which demonstrates that cross sections of members are reliable.

18.9.4.5 I&C System Analysis

The analysis of potential impacts from Solar Energetic Particles (SEP) and EMI to the I&C system are addressed in *Control & Instrumentation System Protection Design against Space Weather Report* (Reference [50]).

The analysis result shows that effective measures have been taken to protect against the SEP and EMI effects of space weather. I&C equipment important to safety is qualified to perform their function under space weather. Based on the current protection measures implemented in I&C design, no design modifications are considered based on the protection measures already implemented for I&C design in GDA phase.

18.9.4.6 Electrical Power System Analysis

The analysis of potential impacts from Geomagnetic Induced Current (GIC), SEP and EMI to electrical systems are addressed in *Electrical Power System Protection Design against Space Weather Report* (Reference [51]). The electrical equipment important to safety, the preferred power system, and the communication system are considered in this report. This report provides the impacts analysis on electrical power systems, gap analysis and the mitigation measures for space weather, which is similar with I&C system analysis.

Gaps in external hazards topic area have been identified and analysed, and other potential gaps may be identified. Potential improvements will be reviewed and implemented with detailed demonstration process to reduce the risk to ALARP in GDA Step 4.

18.10 Concluding Remarks

The design of hazard protection and the safety assessment ensure that the external hazards do not compromise the fundamental safety functions. This is ensured primarily by the conservative design of civil structure against individual and combined external hazard loads, as well as the protection measures used for the items important to safety inside the buildings. Safety assessment of each external hazards considered in GDA phase has been conducted and potential gaps have been identified in GDA Step 3.

In addition, at the current phase, ALARP analysis of the risks identified from external hazards safety assessments are in process. Further analysis will be focused on the assessment of potential improvements in the design to demonstrate that the risk is reduced to ALARP.

It should be noted that design changes made during Step 3 have not been totally reflected in the present version of external hazards safety assessment reports due to the design development progress of the UK HPR1000. The relevant safety assessment reports of external hazards will be updated.

18.11 References

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