Office for Nuclear Regulation

New Reactors Division – Generic Design Assessment

Step 4 Assessment of External Hazards for the UK HPR1000 Reactor

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EXECUTIVE SUMMARY

This report presents the findings of my assessment of the external hazards aspects of the UK HPR1000 reactor design undertaken as part of the Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA). My assessment was carried out using the Pre-Construction Safety Report (PCSR) and supporting documentation submitted by the Requesting Party (RP).

The objective of my assessment was to make a judgement, from an external hazards perspective, on whether the generic UK HPR1000 design could be built and operated in Great Britain, in a way that is acceptably safe and secure (subject to site specific assessment and licensing), as an input into ONR's overall decision on whether to grant a Design Acceptance Confirmation (DAC).

The scope of my GDA assessment was to review the safety aspects of the generic UK HPR1000 design by examining the claims, arguments and supporting evidence in the safety case. My GDA Step 4 assessment built upon the work undertaken in GDA Steps 2 and 3, and enabled a judgement to be made on the adequacy of the external hazards information contained within the PCSR and supporting documentation.

My assessment focused on the following aspects of the generic UK HPR1000 safety case:

- Identification, characterisation and screening of external hazards, including combinations of hazards, to ensure a suitable list of hazards are considered during GDA.
- Adequacy of the UK generic site envelope for GDA.
- Adequacy of the external hazards design input values used for GDA.
- Sampling the linkages between external hazards and engineering disciplines by examining the way external hazards definitions are applied as loading functions.
- Adequacy of the RP's deterministic analysis of hazards and combinations retained in GDA.
- The interface between hazard analyses, protection measures and safety case via the hazards schedule.
- Analysis of cliff-edge effects and beyond design basis events.
- The interface between the deterministic and probabilistic external hazards safety cases.
- Adequacy of the holistic external hazards safety case.
- Regulatory Observations (ROs) relevant to the external hazards safety case.
- Adequacy of modifications proposed by the RP relevant to the external hazards safety case.
- Whether the generic UK HPR1000 design reduces risks from external hazards to be as low as reasonably practicable (ALARP).

The conclusions from my assessment are summarised below:

- The RP has defined an adequate UK generic site envelope within which the plant is designed to operate safely including:
  - A suitable range of external hazards and hazard combinations have been evaluated in GDA, with suitable justification provided for hazards that are screened out.
  - External hazard values for the UK generic site envelope have been defined on a conservative basis as either the bounding value of the

candidate sites that inform the generic site envelope or using best available data.

- The design philosophy for the generic UK HPR1000 design is to select the bounding hazard value from either the Fangchenggang Unit 3 nuclear power plant (FCG3) reference design or the generic site envelope and to use this as the design input for the generic UK HPR1000 design.

  - This approach provides confidence that the generic UK HPR1000 design will likely bound the characteristics of a site on which the technology might be deployed.
  - Demonstrable beyond design basis margin exists where the FCG3 reference design value for a hazard is selected as the UK HPR1000 design input, and bounds the equivalent generic site envelope value.
  - The impact on structures, systems and components has been analysed where the generic site envelope value for a hazard is selected as the UK HPR1000 design input, and is bounding of the equivalent FCG3 reference design value.
  - Any exceptions to this approach have been justified.

- The UK HPR1000 design is shown to be robust against external hazards, hazard combinations and associated effects through a combination of engineering, deterministic and probabilistic analysis approaches. This is achieved by the following means:

  - Measures are provided to protect against the effects of external hazards or items important to safety are qualified to withstand external hazard loadings.
  - External hazards do not adversely affect the functionality or reliability of systems important to safety and defence-in-depth is provided.
  - The design adopts good engineering practice including redundancy, diversity and segregation of safety trains to mitigate common cause effects of external hazards.
  - Optioneering has been undertaken to address gaps identified by the safety evaluation, and modifications incorporated into the design to protect against relevant hazard effects.
  - Analysis demonstrates an absence of cliff-edge effects close to the design basis as expected by the Safety Assessment Principles.
  - The design implements lessons learned from the Fukushima Dai-ichi nuclear power plant accident, including the provision of additional cooling and power systems.
  - The design is aligned with relevant good practice including ONR's Safety Assessment Principles for external hazards.

- Where my assessment has identified shortfalls against relevant good practice, I am satisfied that these do not undermine the generic safety justification for UK HPR1000, and can be addressed by a licensee during site-specific stages.
- The risks from external hazards for the generic UK HPR1000 design, at this stage of design development, have been reduced to ALARP. The UK HPR1000 design will be further developed post-GDA to account for the conditions and hazards at a site selected for deployment of the reactor technology. A final judgement on whether the detailed design reduces risks to be ALARP will be made once these site-specific factors are addressed.

These conclusions are based upon the following factors:

- A detailed and in-depth technical assessment, on a sampling basis, of the full scope of safety submissions at all levels of the hierarchy of the generic UK HPR1000 safety case documentation;
- Independent information, reviews and analysis of key aspects of the generic safety case undertaken by Technical Support Contractors (TSCs); and
- Detailed technical interactions on many occasions with the RP, alongside the assessment of the responses to the substantial number of Regulatory Queries (RQs) and Regulatory Observations (ROs) raised during the GDA.

As a consequence of my assessment, a number of matters remain, which I judge are appropriate for a licensee to consider and take forward in its site-specific safety submissions. These matters do not undermine the generic UK HPR1000 design and safety submissions, but are primarily concerned with the provision of site-specific safety case evidence that will become available as the project progresses through the detailed design, construction and commissioning stages. These matters have been captured in ten Assessment Findings.

Overall, based on my assessment undertaken in accordance with ONR's procedures, the claims, arguments and evidence laid down within the PCSR and supporting documentation submitted as part of the GDA process present an adequate safety case for the generic UK HPR1000 design. I recommend that, from an external hazards perspective, a DAC may be granted.

LIST OF ABBREVIATIONS

A/m	Amperes per metre
ABWR	Advanced Boiling Water Reactor
AC	Alternating Current
AFI	Area for Improvement (ONR Step 3 Assessment)
ALARP	As Low As Reasonably Practicable
AOD	Above Ordnance Datum
ARN	Autoridad Regulatoria Nuclear (Argentine Republic)
ARE [MFFCS]*	Main Feedwater Flow Control System
ASAMPSA_E	Advanced Safety Assessment Methodologies: extended Probabilistic Safety Analysis
ASCE	American Society of Civil Engineers
ASG [EFWS]	Emergency Feedwater System
ASP [SPHRS]	Secondary Passive Heat Removal System
BDA/B/C†	Emergency Diesel Generator Buildings A, B and C
BDBA	Beyond Design Basis Analysis
BDU/V	Station Black-out Diesel Generator Buildings U and V
BD_X	Diesel Generator Buildings (comprising BDA/B/C/U/V)
BEJ	Extra Cooling and Fire-Fighting Water Supply Building
BEX	Equipment Access Building
BFX	Fuel Building
BMS	Business Management System
BMX	Turbine Building
BNX	Nuclear Auxiliary Building
BPX	Personal Access Building
BRX	Reactor Building
BS	British Standard
BSA/B/C	Safeguard Buildings A, B and C
BSI	British Standards Institution
BS_X	Safeguard Buildings (comprising BSA/B/C)
BWX	Radioactive Waste Building
C&I	Control and Instrumentation
CAE	Claims-Arguments-Evidence
CCF	Common Cause Failure
CGN	China General Nuclear Power Corporation Ltd
CIBSE	Chartered Institution of Building Services Engineers

* The UK HPR1000 items important to safety are coded using the format YYY [ZZZ] where: YYY is a unique trigram and [ZZZ] is the abbreviated name of the item important to safety in English.
† UK HPR1000 buildings (structures) are assigned a trigram in the format BYY, where YY is a unique identifier for each building.

cm^2/s	square centimetres per second
DAC	Design Acceptance Confirmation
DBA	Design Basis Analysis
DC	Direct Current
DCL [MCRACS]	Main Control Room Air Conditioning System
DEE	Design Extension Event (Levels 1 or 2)
DEL [SCWS]	Safety Chilled Water System
dia.	Diameter
DMGL	Delivery Management Group Lead
DVD [DBVS]	Diesel Building Ventilation System
DVL [EDSBVS]	Electrical Division Safeguard Building Ventilation System
DWN [NABVS]	Nuclear Auxiliary Building Ventilation System
ECS [ECS]	Extra Cooling System
e.g.	For example
EHR [CHRS]	Containment Heat Removal System
EMI	Electromagnetic Interference
EN	Europäische Norm
EN-6	National Policy Statement for Nuclear Power Generation Volume 6
EPW	Explosion, pressure wave
EUR	European Utilities Requirements
FCG3	Fangchenggang Nuclear Power Plant Unit 3
g	Gravitational Acceleration
GB	Great Britain (England, Scotland and Wales)
GDA	Generic Design Assessment
GNI	General Nuclear International Ltd.
GNSL	General Nuclear System Ltd.
GSE	Generic Site Envelope
HBSC	Human Based Safety Claims
HSE	Health and Safety Executive
HVAC	Heating, Ventilation and Air Conditioning
i.e.	In other words
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
JPI [NIFPS]	Nuclear Island Fire Protection System
kA	Kiloampere
kg	Kilogram
kJ/kg	Kilojoules per kilogram
km^2	Square kilometre
kN	Kilonewton

kN/m^2	Kilonewton per square metre
kPa	Kilopascal
kPa/s	Kilopascals per second
KDS [DAS]	Diverse Actuation System
LAA/B/C/D [NIDCPS]	Nuclear Island 220V Direct Current Power Supply and Distribution System (2 hour) (trains A, B, C and D)
LAP/Q [NIDCPS]	Nuclear Island 220V Direct Current Power Supply and Distribution System (24 hour) (trains P and Q)
LCU	Local Cooling Unit
LOOP	Loss of Off-site Power
LPZ	Lightning Protection Zone
LUHS	Loss of Ultimate Heat Sink
m	Metre
m^2	Square metre
m^3	Cubic metre
m/s	Metre(s) per second
mbar	Millibar
mbar/s	Millibars per second
MCR	Main Control Room
MDEP	Multinational Design Evaluation Programme (within OECD-NEA)
MeV	Mega-electronvolt
Min(s)	Minute(s)
mm	Millimetre
MSQA	Management for Safety and Quality Assurance
NEA	Nuclear Energy Agency (within OECD)
NEI	Nuclear Energy Institute
NNR	National Nuclear Regulator (Republic of South Africa)
NNSA	National Nuclear Safety Administration (People's Republic of China)
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
nT/min	Nanoteslas per minute
OECD	Organisation for Economic Cooperation and Development
ONR	Office for Nuclear Regulation
PCSR	Pre-construction Safety Report
PIE	Postulated Initiating Event
PGA	Peak Ground Acceleration
PSA	Probabilistic Safety Analysis
PSR	Preliminary Safety Report (includes security and environment)
PTR [FPCTS]	Fuel Pool Cooling Treatment System
PWR	Pressurised Water Reactor

RCP(s)	Representative Concentration Pathway(s)
RCP [RCS]	Reactor Coolant System
RGP	Relevant Good Practice
RHWG	Rector Harmonization Working Group (of WENRA)
RIS [SIS]	Safety Injection System
RO	Regulatory Observation
RP	Requesting Party
RPV	Reactor Pressure Vessel
RRI [CCWS]	Component Cooling Water System
RSS	Remote Shutdown Station
RQ	Regulatory Query
SAA	Severe Accident Analysis
SAP(s)	Safety Assessment Principle(s)
SBO	Station Blackout
SDM(s)	System Design Manual(s)
SEC [ESWS]	Essential Service Water System
SEO [SSS]	Station Sewage System
SFP	Spent Fuel Pool
SG(s)	Steam Generator(s)
SoDA	Statement of Design Acceptability (Environment Agency)
SRES	Special Report on Emission Scenarios
SSCs	Structures, Systems and Components
TAG(s)	Technical Assessment Guide(s)
TESG	Technical Expert Subgroup
TLACP	Total Loss of Alternating Current Power
TSC(s)	Technical Support Contractor(s)
UK	United Kingdom of Great Britain and Northern Ireland
UKCP09	UK Climate Projections 2009
UKCP18	UK Climate Projections 2018
UO_2	Uranium Dioxide
US	United States of America
VDA [ASDS]	Atmospheric Steam Dump System
VVP [MSS]	Main Steam System
W/m^2	Watts per square metre
WENRA	Western European Nuclear Regulators' Association
yr.	Year
°C	Degrees Celsius

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1 INTRODUCTION

1.1 Background

1. This report presents my assessment conducted as part of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA) for the generic UK HPR1000 design within the topic of external hazards.

2. The UK HPR1000 is a pressurised water reactor (PWR) design proposed for deployment in the UK. General Nuclear System Ltd (GNSL) is a UK-registered company that was established to implement the GDA on the UK HPR1000 design on behalf of three joint requesting parties (RP), in other words: China General Nuclear Power Corporation (CGN), EDF S.A., and General Nuclear International Ltd (GNI).

3. GDA is a process undertaken jointly by the ONR and the Environment Agency. Information on the GDA process is provided in a series of documents published on the joint regulators' website (www.onr.org.uk/new-reactors/index.htm). The outcome from the GDA process sought by the RP is a Design Acceptance Confirmation (DAC) from ONR and a Statement of Design Acceptability (SoDA) from the Environment Agency.

4. The GDA for the generic UK HPR1000 design followed a step-wise approach in a claims-arguments-evidence (CAE) hierarchy, which commenced in 2017. Major technical interactions started in Step 2, which focused on an examination of the main claims made by the RP for the UK HPR1000. In Step 3, the arguments which underpin those claims were examined. The Step 2 reports for individual technical areas, and the summary reports for Steps 2 and 3 are published on the joint regulators' website. The objective of Step 4 was to complete an in-depth assessment of the evidence presented by the RP to support and form the basis of the generic safety and security cases.

5. The full range of items that form part of my assessment is provided in ONR's GDA Guidance to Requesting Parties (Ref. 1). These include:

- Consideration of issues identified during the earlier Step 2 and 3 assessments.
- Judging the design against the Safety Assessment Principles (SAPs) (Ref. 2) and whether the proposed design ensures risks are As Low As Reasonably Practicable (ALARP).
- Reviewing details of the RP's design controls and quality control arrangements to secure compliance with the design intent.
- Establishing whether the system performance, safety classification, and reliability requirements are substantiated by a more detailed engineering design.
- Assessing arrangements for ensuring and assuring that safety claims and assumptions will be realised in the final as-built design.
- Resolution of identified nuclear safety and security issues, or identifying paths for resolution.

6. The purpose of this report is therefore to summarise my assessment in the external hazards topic, which provides an input to the ONR decision on whether to grant a DAC, or otherwise. This assessment was focused on the submissions made by the RP throughout GDA, including those provided in response to the Regulatory Queries (RQs) and Regulatory Observations (ROs) raised by ONR. Any ROs issued to the RP are published on the GDA's joint regulators' website, together with the corresponding resolution plans.

1.2 Scope of this Report

7. This report presents the findings of my assessment of the external hazards of the generic UK HPR1000 design undertaken as part of GDA. I carried out my assessment using the Pre-construction Safety Report (PCSR) (Ref. 3, Ref. 4) and supporting documentation submitted by the RP. My assessment was focused on considering whether the generic safety case provides an adequate justification for the generic UK HPR1000 design, in line with the objectives for GDA.

1.3 Methodology

8. The methodology for my assessment follows ONR's guidance on the mechanics of assessment, NS-TAST-GD-096 (Ref. 5).

9. My assessment was undertaken in accordance with the requirements of ONR's How2 Business Management System (BMS). ONR's SAPs (Ref. 2), together with supporting Technical Assessment Guides (TAGs) (Ref. 6, Ref. 7, Ref. 8), were used as the basis for my assessment. Further details are provided in section 2. The outputs from my assessment are consistent with ONR's GDA Guidance to RPs (Ref. 1).

2 ASSESSMENT STRATEGY

10. The strategy for my assessment of the external hazards aspects of the UK HPR1000 design and safety case is set out in this section. This identifies the scope of the assessment and the standards and criteria that have been applied.

2.1 Assessment Scope

11. A detailed description of my approach to this assessment can be found in assessment plan ONR-GDA-UKHPR1000-AP-19-008 (Ref. 9). The purpose of my assessment is based on ONR's 'Generic Design Assessment Technical Guidance' (Ref. 10) relevant to external hazards and is to:

- Ensure that the effects of external hazards are minimised and adequate protection against them has been provided for in the design.
- Ensure that external hazards do not adversely affect the functionality or reliability of systems important to safety.
- Potential common cause failure (CCF) effects of external hazards have been adequately addressed.
- Ensure items important to safety (in other words safety systems and safety related systems) are either qualified to withstand the effects of external hazards or protected against the hazards through appropriate use of measures, redundancy, diversity, separation or segregation.

12. I considered the main submissions within the remit of my assessment scope, to various degrees of breadth and depth. I chose to concentrate my assessment on those aspects that I judged to have the greatest safety significance, or where the hazards appeared least well controlled. My assessment was also influenced by the claims made by the RP, my previous experience of similar systems for reactors and other nuclear facilities, and any identified gaps in the original submissions made by the RP. A particular focus of my assessment has been the RQs, and ROs I raised as a result of my on-going assessment, and the resolution thereof.

2.2 Sampling Strategy

13. In line with ONR's guidance (Ref. 5), I chose a sample of the RP's submissions to undertake my assessment. Sampling is used to limit the areas scrutinised, and to improve the overall efficiency of the assessment process whilst still delivering the overall purpose (sub-section 2.1). Sampling is undertaken in a focused, targeted, and structured manner with a view to revealing any topic-specific or generic weaknesses in the safety case.

14. The following guidance and information were considered in developing my sampling strategy:

- Relevant good practice (RGP) for external hazards.
- ONR SAPs, including those SAPs relevant to external hazards.
- ONR's TAG for external hazards (NS-TAST-GD-013) (Ref. 6).
- ONR GDA guidance (Ref. 10, Ref. 1).
- Review of outputs from previous steps of the GDA including my Step 3 external hazards assessment note (Ref. 11) and associated areas for improvement and open points (Annex 3).
- ROs relevant to external hazards.
- Input from the project stakeholders including experience from previous GDA projects.
- The claims and arguments made in the RP's safety case relevant to external hazards.

15. Where appropriate I have also engaged with my fellow ONR inspectors in relation to multi-disciplinary topics to ensure that my samples are aligned with their assessments. For example, I have engaged with the ONR Civil Engineering Inspector to understand the civil structures they were sampling in detail to inform my own sampling strategy.

16. The main areas sampled are presented in my Step 4 assessment plan (Ref. 9) and summarised below, along with a justification as to why each aspect is sampled:

- Identification, characterisation and screening of external hazards, including combinations of hazards, to ensure a suitable list of hazards are considered during GDA.

  - Justification: ONR expects relevant external hazards and combinations of hazards that could affect the safety of the plant to be identified, characterised and screened. For the purposes of GDA this should consist of those external hazards and combinations that can be considered on a generic basis, are relevant to the UK context, and could affect nuclear safety.

- Adequacy of the Generic Site Envelope (GSE) for GDA.

  - Justification: The RP should specify a GSE within which the UK HPR1000 is designed to operate safely, to demonstrate that the plant can be constructed, operated and decommissioned on a variety of sites within Great Britain (GB). The definition of the GSE should be adequately conservative, and bounding of the sites selected by the RP to represent the generic site. The RP should also demonstrate that an effective process has been applied to identify potential environmental changes such as climate change, which may affect sites in GB. Foreseeable variations in external hazards during the expected lifetime of the plant should be identified and taken into account.

- Adequacy of the external hazards inputs to the design of the UK HPR1000 for GDA.

  - Justification: It is necessary to demonstrate that the selected external hazards inputs to the design of the UK HPR1000 are adequately bounding of the GSE and to understand the margins inherent in the design.

- Sampling the linkages between external hazards and engineering disciplines by examining the way external hazards definitions are applied as loading functions. This focused on:

  - Civil structures due to the widespread use of external hazard loading functions.
  - Heating, Ventilation and Air Conditioning (HVAC) systems due to their contribution to the overall risk profile of the plant as indicated by the Probabilistic Safety Analysis (PSA) analysis and previous GDA experience.

  - Justification: To demonstrate that the RP's approach to deriving design inputs for the UK HPR1000 from the site-wide hazard values is consistent with RGP and will lead to a conservative design.

- Adequacy of the RP's deterministic analysis of hazards and combinations retained in GDA. This focused on:

  - Those hazards that contribute significant risk (e.g. seismic and flooding).
  - Those hazards where there is potentially limited margin between the Fangchenggang Nuclear Power Plant Unit 3 (FCG3) reference design and the GSE values (e.g. air temperatures).
  - Hazards that may be poorly controlled due to limited RGP (e.g. space weather).
  - Hazards for which potential design shortfalls are identified either by the RP's analysis or my assessment (e.g. aircraft impact).
  - Hazards that can lead to design conditions (e.g. loss of off-site power (LOOP) or loss of ultimate heat sink (LUHS)).

  - Justification: ONR expects the RP to adequately analyse the potential effects of external hazards and combinations on the generic UK HPR1000 design to ensure the effects are minimised and adequate protection is provided for in the design. External hazards and combinations of hazards should not adversely affect the functionality or reliability of Structures, Systems and Components (SSCs) important to safety and which are required to perform essential safety functions. It is also necessary for the RP to demonstrate that potential CCFs resulting from external hazards or combinations of hazards have been adequately addressed.

- Interface between the hazard analysis, protection measures and safety case via the external hazards schedule.

  - Justification: The RP should clearly identify measures providing protection against external hazards. Items important to safety (in other words, safety systems and safety related systems) should be either designed (qualified) to withstand the effects of external hazards or protected against the hazards (e.g. by redundancy, segregation and protection measures). The RP should also capture the safety functional requirements associated with external hazards for both items important to safety and the protection measures. It is good practice for external hazards to be included in either a fault or hazards schedule, which provides the links between hazards, protection measures and requirements.

- Analysis of cliff-edge effects and beyond design basis events. This focused on:

  - Those hazards that are more significant risk contributors to the overall risk profile of the plant (e.g. seismic and flooding).
  - Those hazards where there is potentially small margin between the selected design input values and the GSE values (e.g. air temperatures).
  - Design conditions resulting from external hazards (in other words, LOOP or LUHS).

  - Justification: The sensitivity of the design to the magnitude of external hazards should be well understood and the RP should demonstrate both an absence of cliff-edge effects just beyond the design basis and that adequate margins exist beyond the design basis to the point(s) where safety functions would no longer be achieved. The RP should understand the failure mechanisms. It is also necessary for the RP to consider lessons learned from the Fukushima Dai-ichi nuclear power plant (NPP) accident that are applicable to the external hazards area.

- The interface between the deterministic and probabilistic external hazards safety cases.

    - Justification: The external hazards safety case will provide inputs to the probabilistic safety case, and it is important the information is consistent between the safety cases, where appropriate. The probabilistic hazards assessment will also provide a view of the risk contribution from external hazards to the overall risk profile of the generic UK HPR1000 design.

- Adequacy of the holistic external hazards safety case for a specific nuclear island structure.

    - Justification: To demonstrate on a holistic level that the RP's external hazards safety case has analysed all relevant external hazards for a single building and that the analysis meets ONR's expectations as defined in the SAPs and Technical Guidance. The Fuel Building (BFX) is selected as the sample to enable an interface with the ONR Civil Engineering discipline and because of its safety significance.

- ROs relevant to the external hazards safety case including, but not limited to:

    - RO-UKHPR1000-0002 Demonstration that the UK HPR1000 Design is Suitably Aligned with the Generic Site Envelope (Ref. 12).
    - RO-UKHPR1000-0007 Aircraft Impact Safety Case for UK HPR1000 (Ref. 13).
    - RO-UKHPR1000-0009 Geotechnical Design Parameters (Ref. 14).
    - RO-UKHPR1000-0039 Performance Analysis of UK HPR1000 Heating Ventilation and Air Conditioning Systems (Ref. 15).
    - RO-UKHPR1000-0055 Consequential Internal Hazards Resulting from Seismic Events (Ref. 16).

    - Justification: The ROs are directly relevant to, or impact on, the external hazards safety case for the UK HPR1000 generic design. ROs represent potential regulatory shortfalls in the RP's initial safety case documentation. It is necessary to assess these aspects to ensure that the RP adequately addresses the identified gaps and reduces the associated risk to be ALARP.

- Adequacy of modifications proposed by the RP relevant to the external hazards safety case.

    - Justification: To demonstrate the adequacy of the RP's arrangements to address shortfalls in the design against external hazards and to assess whether the proposed modifications reduce the risks from external hazards to be ALARP.

- Whether the UK HPR1000 design reduces risks from external hazards to be ALARP.

    - Justification: This is a key element of the GDA process and issuing a DAC.

2.3 Out of Scope Items

17. The following items were outside the scope of the RP's safety case submissions:

- Site-specific aspects such as the detailed assessment of external hazard values for a target site.
  - Justification: Such matters will be assessed by ONR in site-specific phases.
- Assessment of those hazards screened into site-specific stages.
  - Justification: Hazards screened-out of GDA, with suitable justification, will be assessed by ONR during site-specific stages for a target site selected for deployment of the UK HPR1000 reactor technology.
- Limits and conditions for safe operation related to external hazards.
  - Justification: The definition of limits and conditions related to external hazards has been defined as out of scope of GDA by the RP (Ref. 17). ONR will assess the definition of limits and conditions relevant to external hazards during site-specific stages and once site-specific data is available that may influence their definition. This is normal business for a licensee.

18. The out-of-scope items are consistent with previous GDA projects. I expect a licensee to consider the above items during future site-specific phases.

2.4 Standards and Criteria

19. The relevant standards and criteria adopted within this assessment are principally the SAPs (Ref. 2), TAGs (Ref. 6, Ref. 7, Ref. 8), relevant national and international standards, and RGP, informed by existing practices adopted on nuclear licensed sites in GB. The key SAPs and any relevant TAGs, national and international standards and guidance are detailed within this sub-section. RGP, where applicable, is cited within the body of the assessment.

2.4.1 Safety Assessment Principles

20. The SAPs (Ref. 2) constitute the regulatory principles against which ONR judge the adequacy of safety cases. The SAPs applicable to external hazards are included within Annex 1 of this report.

21. The key SAPs applied within my assessment are presented in Annex 1 and include SAPs EHA.1, EHA.2, EHA.3, EHA.4, EHA.5, EHA.6, EHA.7, EHA.8, EHA.9, EHA.10, EHA.11, EHA.12, EHA.14, EHA.18 and EHA.19.

2.4.2 Technical Assessment Guides

22. The following Technical Assessment Guides were used as part of this assessment:

- NS-TAST-GD-005, ONR Guidance on the Demonstration of ALARP (Ref. 7).
- NS-TAST-GD-013, External Hazards (Ref. 6).
- NS-TAST-GD-051, The Purpose, Scope and Content of Nuclear Safety Cases (Ref. 8).

2.4.3 National and International Standards and Guidance

23. The following standards and guidance were used as part of this assessment:

International Atomic Energy Agency (IAEA)

- Fundamental Safety Principles, Safety Standards Series No. SF-1 (Ref. 18).
- Safety of Nuclear Power Plants: Design, Specific Safety Requirements Series No. SSR-2/1 (Ref. 19).
- Site Evaluation for Nuclear Installations, Specific Safety Requirements, Safety Standards Series No. SSR-1 (Ref. 20).
- External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Guide, Safety Standards Series No. NS-G-1.5- (Ref. 21).
- Seismic Design and Qualification for Nuclear Power Plants Safety Guide, Safety Guide, Safety Standards Series No. NS-G-1.6 (Ref. 22).
- External Human Induced Events in Site Evaluation for Nuclear Power Plants, Safety Guide, Safety Standards Series No. NS-G-3.1 (Ref. 23).
- Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants, Safety Guide, Safety Standards Series Guide No. NS-G-3.6 (Ref. 24).
- Seismic Hazards in Site Evaluaiton for Nuclear Installations, Specific Safety Guide, Safety Standards Series No. SSG-9 (Ref. 25).
- Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, Specific Safety Guide, Safety Standards Series No. SSG-18 (Ref. 26).
- Safety Standards Series – Volcanic Hazards in Site Evaluation for Nuclear Installations – SSG- 21 (Ref. 27).
- Safety Aspects of Nuclear Power Plants in Human Induced External Events: General Considerations, Safety Reports Series No. 86 (Ref. 28).
- Safety Aspects of Nuclear Power Plants in Human Induced External Events: Assessment of Structures, Safety Reports Series No. 87 (Ref. 29).
- Safety Aspects of Nuclear Power Plants in Human Induced External Events: Margin Assessment, Safety Reports Series No. 88 (Ref. 30).

Western European Nuclear Regulators Association (WENRA) Reactor Harmonisation Working Group (RHWG)

- Reactor Safety Reference Levels (Ref. 31).
- Safety Objectives for New Power Reactors (Ref. 32).
- Statement on Safety Objectives for New Nuclear Power Plants (Ref. 33, Ref. 34).
- Safety of New Nuclear Power Plant Designs (Ref. 35).
- Guidance Document Issue TU: External Hazards - Head Document: Guidance for the WENRA Safety Reference Levels for External Hazards (Ref. 36).
- Guidance Document Issue TU: External Hazards - Guidance on Seismic Events (Ref. 37).
- Guidance Document Issue TU: External Hazards - Guidance on External Flooding (Ref. 38).
- Guidance Document Issue TU: External Hazards - Guidance on Extreme Weather Conditions (Ref. 39).

Other National and International Guidance

- United States Nuclear Regulatory Commission (US NRC), Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants, Regulatory Guide 1.76 (Ref. 40).
- Nuclear Energy Institute (NEI), Methodology for Performing Aircraft Impact Assessments for New Plant Designs, NEI 07-13 Revision 8P (Ref. 41).

- European Utility Requirements (EUR), European Utility Requirements for LWR Nuclear Power Plants, Volume 2 - Generic and Nuclear Island Requirements, Chapter 4 Design Basis (Ref. 42).
- British Standards Institute (BSI), Lightning Protection Standard, British Standard (BS) Europäische Norm (EN) / International Electrotechnical Commission (IEC) 62305 (Ref. 43).

2.5 Use of Technical Support Contractors

24. It is usual in GDA for ONR to use Technical Support Contractors (TSCs) to provide access to independent advice and experience, analysis techniques and models, and to enable ONR's inspectors to focus on regulatory decision making.

25. Table 1 defines the areas where I used TSCs to support my assessment. I required this support to provide additional capacity to enable the sampling of additional topics, and access to independent advice and experience.

26. Whilst the TSC undertook detailed technical reviews, this was undertaken under my direction and close supervision. The regulatory judgment on the adequacy, or otherwise, of the generic UK HPR1000 safety case in this report has been made exclusively by ONR.

Table 1: Work packages undertaken by the TSC

Number	Description
1	Independent technical review of the external hazards safety case (excluding aircraft impact). This comprised: ■ Identification and screening of hazards, including detailed examination of hazard combinations. ■ Characterisation of hazards and combinations including the selection and processing of source data, and the detailed examination of the application of climate change projections. ■ Adequacy of the GSE for a UK generic site, and the selection of design inputs for external hazards. ■ Analysis of hazards screened into GDA. ■ Detailed examination of methods used to translate site-wide hazard values into load functions for use in the civil design. ■ Detailed examination of the external hazards safety case pertaining to a nuclear safety significant building to demonstrate a logical and systematic flow of CAE. ■ Detailed examination of claims pertaining to hazards that may impact SSCs with little margin between the GSE and design input: • High-air temperature • Enthalpy • Lightning • Space weather ■ Detailed examination of the evidence for cliff-edge effects and beyond design basis events. ■ Examination of the links between hazards, protection measures and safety case via the hazard schedule. The details of this assessment are presented in my TSC's report (Ref. 44).

Number	Description
2	Independent technical review of the aircraft impact safety case including: ■ Detailed examination of hazard definitions and derivation of associated load-time functions. ■ Detailed examination of the claims, arguments and evidence relating to the aircraft impact safety case. ■ Interfaces with the civil engineering safety case and design. The details of this assessment are presented in my TSC's report (Ref. 45).

2.6 Integration with Other Assessment Topics

27. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment cannot be carried out in isolation as there are often issues that span multiple disciplines. I have therefore worked closely with a number of other ONR inspectors to inform my assessment. The key interactions were:

- Civil Engineering – I have engaged with the Civil Engineering Inspector in relation to the adequacy of the external hazards load definitions that are applied in the civil engineering safety case. The Civil Engineering Inspector was responsible for assessing the adequacy of the RP's substantiation of the design against relevant load combinations. I have worked closely with the Civil Engineering Inspector to address the potential regulatory shortfalls of relevant ROs. I led the assessment of RO-UKHPR1000-0002 (Ref. 12) and RO-UKHPR1000-0007 (Ref. 13), whilst the ONR Civil Engineering Inspector led the assessment of RO-UKHPR1000-0009 (Ref. 14).
- Mechanical Engineering – I have engaged with the Mechanical Engineering Inspector in relation to the adequacy of the safety and performance requirements of mechanical SSCs against external hazards described in the hazards schedule. The Mechanical Engineering Inspector was responsible for assessing the adequacy of the RP's substantiation of mechanical SSCs against relevant loads including those from hazards, where appropriate. The Mechanical Engineering Inspector led the assessment of RO-UKHPR1000-0039 (Ref. 15) relating to potential regulatory shortfalls with the analysis of the HVAC systems. I have worked closely with them in relation to the adequacy of the external hazards inputs to the analysis.
- Control and Instrumentation (C&I) – I have engaged with the C&I Inspector in relation to the adequacy of the safety and performance requirements of the C&I SSCs against external hazards described in the hazards schedule. The C&I Inspector was responsible for assessing the adequacy of the RP's substantiation of C&I SSCs against relevant loads including those from hazards, where appropriate. I have also worked closely with the C&I Inspector in relation to space weather hazards to address RO-UKHPR1000-0002 (Ref. 12), and also meteorological hazards as part of RO-UKHPR1000-0039 (Ref. 15).
- Electrical Engineering – I have engaged with the Electrical Engineering Inspector in relation to the adequacy of the safety and performance requirements of the electrical SSCs against external hazards described in the hazards schedule. The Electrical Engineering Inspector was responsible for assessing the adequacy of the RP's substantiation of electrical SSCs against relevant loads including those from hazards, where appropriate. In particular, I have collaborated with the Electrical Engineering Inspector with regards to protection against the lightning, electromagnetic interference and space weather hazards as part of RO-UKHPR1000-0002 (Ref. 12), and also

meteorological hazards impacting electrical systems as part of RO-UKHPR1000-0039 (Ref. 15).

- Probabilistic Safety Analysis (PSA) – I have provided input to the hazard screening and definition aspects of the external hazards PSA. I have engaged with the ONR PSA Inspector to understand the risk contribution from external hazards to the overall risk profile of the plant.
- Internal Hazards – I have engaged with ONR Internal Hazards Inspector to assess hazard screening and hazard combinations aspects of the external hazards assessment. The Internal Hazards Inspector was responsible for assessing the deterministic analysis of the design against consequential internal hazards to form a judgement on the adequacy of the RP's safety case with respect to hazard combinations. I have supported the Internal Hazards Inspector with assessment of RO-UKHPR1000-0055 (Ref. 16), which relates to potential regulatory shortfalls associated with consequential internal hazards initiated by earthquake.
- Fault Studies – I have engaged with the Fault Studies Inspector with regards to the classification of safety functional requirements, and the SSCs that are claimed to deliver these functions. I have also collaborated with the Fault Studies Inspector in relation the RP's approach to consider external hazards as fault initiators.

2.7 Overseas Regulatory Interface

28. ONR has formal information exchange agreements with a number of international nuclear safety regulators, and collaborates through the work of the IAEA and the Organisation for Economic Co-operation and Development's Nuclear Energy Agency (OECD-NEA). This enables us to utilise overseas regulatory assessments of reactor technologies, where they are relevant to the UK. It also enables the sharing of regulatory assessments, which can expedite assessment and helps promote consistency.

2.7.1 Multilateral Collaboration

29. As part of my assessment, I participated in and chaired the Hazards Technical Expert Sub-Group (TESG) of the HPR1000 Multinational Design Evaluation Programme (MDEP). This TESG included national regulators from Argentina's Autoridad Regulatoria Nuclear (ARN), China's National Nuclear Safety Administration (NNSA) and South Africa's National Nuclear Regulator (NNR). This provided insight into the design evolution of the HPR1000 following the Fukushima Dai-ichi NPP accident, and the safety systems included to enhance the design's resilience against beyond design basis events, as well as the hazard combinations considered in the design. The HPR1000 design has been accepted by the NNSA, and is currently being constructed at the Fangchenggang NPP site as Units 3 and 4.

3 REQUESTING PARTY'S SAFETY CASE

3.1 Introduction to the Generic UK HPR1000 Design

30. The generic UK HPR1000 design is described in detail in the PCSR (Ref. 46). It is a three-loop PWR designed by CGN using the Chinese Hualong technology. The generic UK HPR1000 design has evolved from reactors which have been constructed and operated in China since the late 1980s, including the M310 design used at Daya Bay and Ling'ao (Units 1 and 2), the CPR1000, the CPR1000$^+$ and the more recent ACPR1000. The first two units of CGN's HPR1000, Fangchenggang NPP Units 3 and 4, are under construction in China and Unit 3 is the reference plant for the generic UK HPR1000 design. The design is claimed to have a lifetime of at least 60 years and has a nominal electric output of 1,180 megawatts.

31. The reactor core contains zirconium clad uranium dioxide (UO_2) fuel assemblies and reactivity is controlled by a combination of control rods, soluble boron in the coolant and burnable poisons within the fuel. The core is contained with a steel Reactor Pressure Vessel (RPV) which is connected to the key primary circuit components, including the reactor coolant pumps, Steam Generators (SGs), pressuriser and associated piping, in the three-loop configuration. The design also includes a number of auxiliary systems that allow normal operation of the plant, as well as active and passive safety systems to provide protection in the case of faults, all contained within a number of dedicated buildings.

32. The Reactor Building (BRX) houses the reactor and primary circuit and is based on a double-walled containment with a large free volume. Three separate Safeguard Buildings (BSA/B/C) surround the BRX and house key safety systems and the Main Control Room (MCR). The Fuel Building (BFX) is also adjacent to the reactor, and contains the fuel handling and short-term storage facilities. Finally, the Nuclear Auxiliary Building (BNX) contains a number of systems that support operation of the reactor. In combination with the Diesel Generator (BDA/B/C/U/V), Extra Cooling and Fire-Fighting Water Supply (BEJ), Personnel Access (BPX) and Equipment Access (BEX) buildings, these constitute the nuclear island for the generic UK HPR1000 design. The generic layout of the UK HPR1000 is shown in Figure 1.

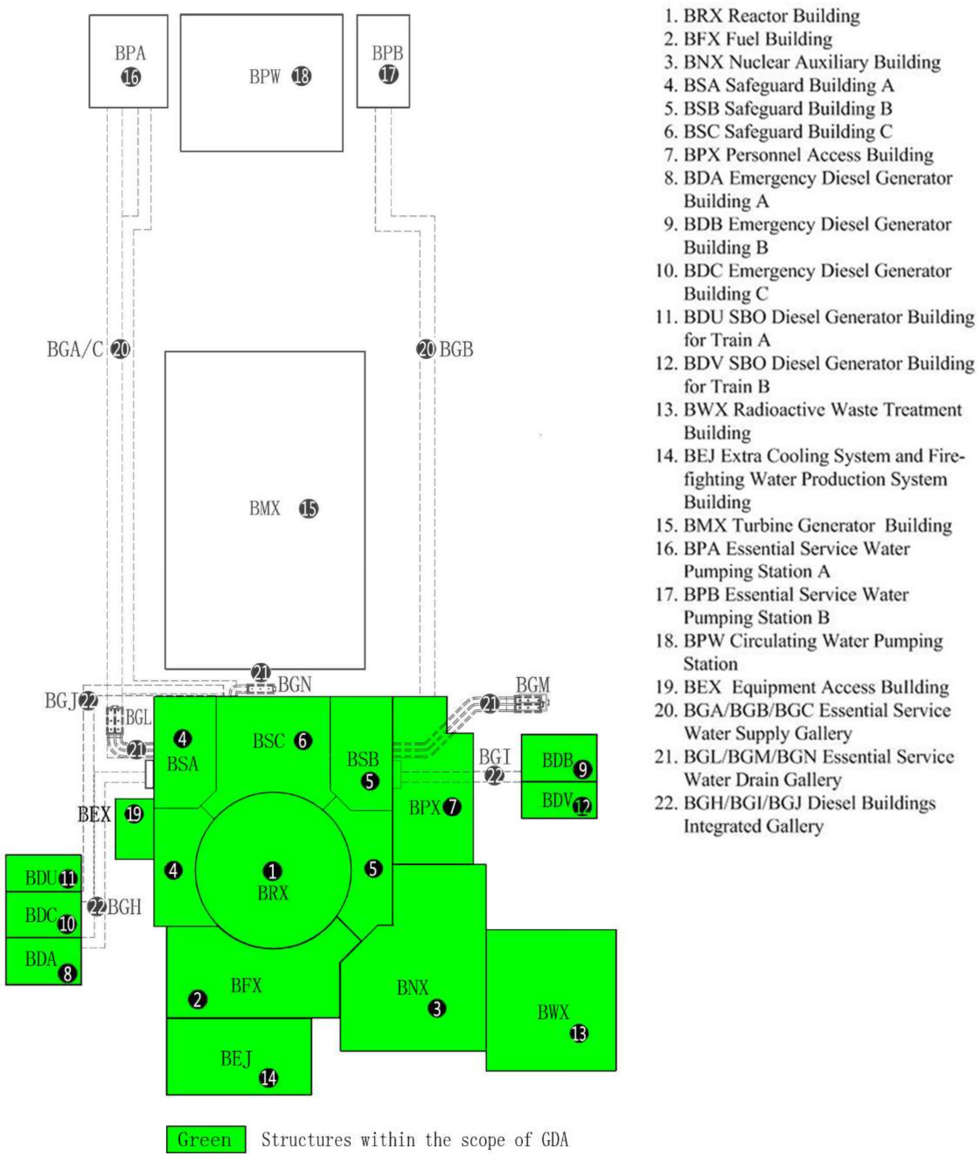

Figure 1: Layout of the UK HPR1000. Structures in GDA scope shown in green. *(Ref. 47)*

3.2 The Generic UK HPR1000 Safety Case

33. In this sub-section I provide an overview of the external hazards aspects of the generic UK HPR1000 safety case as provided by the RP during GDA. This includes a brief description of the external hazards safety case, the key documentation and its architecture. Details of the technical content of the documentation and my assessment of its adequacy are reported in the subsequent sections of my report.

34. The RP’s stated fundamental objective for the UK HPR1000 GDA is to demonstrate that the design: “… 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 the environment.” The RP has developed the safety case, which is summarised in the PCSR, to demonstrate that this fundamental objective is achieved by the design. The RP has adopted a CAE framework for structuring of the safety case for the UK HPR1000. This framework has been applied to those elements of the safety case relevant to external hazards. The document hierarchy for external hazards is shown in Figure 2, and comprises:

- Tier 1 – The PCSR presents the principal claims, sub-claims and arguments related to the safe operation of the UK HPR1000, and provides a summary of the supporting safety case. The PCSR is split into a number of chapters that each deal with a specific aspect of the safety case.
- Tier 2 – Documents that directly underpin the PCSR chapters. Documents in this tier include both methodologies and those providing detailed analysis of the design against external hazards.
- Tier 3a – Documents specific to the UK HPR1000 design that supplement the safety case and address specific issues including topic reports related to RQ and RO responses, and UK-specific system design manuals (SDMs) and plant layout drawings.
- Tier 3b – Documents related to the reference design of FCG3 used to supplement the UK HPR1000 safety case.
- Tier 4 – These documents are not a formal part of the external hazards safety case, but provide supplementary information to support the progress of the GDA programme including responses to my regulatory questions.

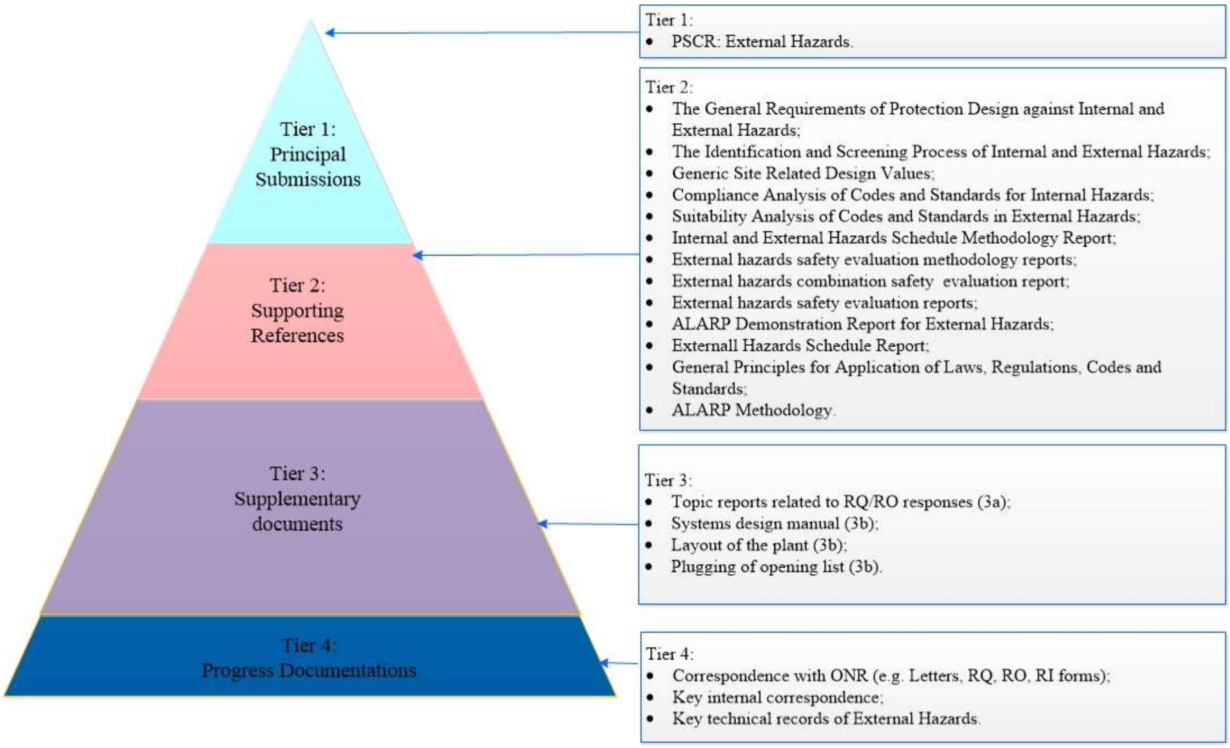

Figure 2: Documentation hierarchy for the external hazards safety case. *(Ref. 48)*

35. The RP's external hazards safety case comprises two elements:

- Definition of a GSE that is used to demonstrate that the UK HPR1000 can be safely constructed and operated in the UK.
- A safety justification of the design against a range of external hazards to demonstrate that adequate protection is provided against the hazards and their effects, and that any residual risk from external hazards is reduced ALARP.

36. The two elements of the external hazards safety case each have a dedicated PCSR chapter (Ref. 3, Ref. 4) and supporting documents based on the RP's CAE framework. The PCSR chapters and supporting documentation are described below. It is important to note that the GSE and hazards analysis elements are inexorably linked, and there is sharing of information between documents. For example, the hazards analysis uses, where appropriate, hazard values defined for the GSE.

37. The RP's definition of the GSE is presented in the tier one PCSR Chapter 3 (Ref. 3), along with the principal claims and arguments relating to its definition and the justification for it being representative of a generic UK site. The claims and arguments relevant to the GSE definition are summarised in Table 2. The GSE is based on three of the sites identified for new nuclear build in the UK National Policy Statement for Nuclear Power Generation (EN-6) (Ref. 49), namely: Bradwell, Sizewell and Hinkley Point. PCSR Chapter 3 (Ref. 3) presents:

- Hazard identification and screening.
- The GSE definitions for screened-in external hazards.
- The selected UK HPR1000 design input values for external hazards.

38. The UK HPR1000 will be designed to withstand relevant UK HPR1000 design input values, which are an input to the hazard analysis and SSC substantiation. The UK HPR1000 design input values are typically selected as the bounding value of either the FCG3 reference design or the GSE, although there are a number of exceptions to this (e.g. rainfall). The GSE values relevant to external hazards defined by the RP are presented in Annex 4 and compared with the FCG3 reference design values and the selected UK HPR1000 design input values.

39. PCSR Chapter 3 (Ref. 3) is underpinned by the 'UK HPR1000 Generic Site Report' (Ref. 50). This report provides the detailed characterisation of hazards and other site properties including geotechnical parameters, population density and distribution, and other environmental parameters. Characterisation data is sourced for the three sites that inform the GSE, as well as being taken from other published data and reports including those from previous GDAs. For relevant hazards, climate change allowances are defined using UK Climate Projections 2018 (UKCP18), where data is available. The Generic Site Report justifies the values used for the GSE. The Generic Site Report references to other underpinning tier two and three documents that provide supplementary evidence in support of hazard characterisation, as well as international and national standards.

Table 2: Claims and arguments relevant to the generic site as stated in PCSR chapter 3

Claim	Description	Summary of Sub Claims and Arguments
1	The generic site characteristics for the UK HPR1000 design reflect a generic UK site that bounds possible locations for deployment of [the] reactor technology.	Site characteristics are identified for the three candidate sites informing the GSE based on RGP and bounding analyses.

40. The safety demonstration of the UK HPR1000 against external hazards is presented in PCSR Chapter 18 (Ref. 4). The claims and arguments in the PCSR are précised in Table 3. The PCSR summarises the information and analysis presented in the underpinning tier two and three documents. The safety case aims to demonstrate that the challenge from external hazards does not impact the delivery of the fundamental safety functions of the UK HPR1000.

41. Figure 3 presents the RP's logic flow of CAE and associated requirements between the tier two documentation forming the external hazards safety case, summarised in PCSR Chapter 18 (Ref. 4). The ability to trace CAE and requirements between documents is important in demonstrating that a safety case is complete and internally consistent.

Table 3: Claims and arguments relevant to external hazards as stated in PCSR Chapter 18

Claim	Description	Sub Claims and Arguments
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 ALARP.	Hazards and combinations have been identified, characterised and screened for GDA using RGP. Screened-in hazards and combinations have been analysed using design basis analysis (DBA), beyond design basis analysis (BDBA) and severe accident analysis (SAA) methods to identify protection measures and safety functional requirements.

42. The tier two documents supporting the PCSR (Ref. 4) include requirement and methodology documents, and analysis documents. The requirement and methodology documents describe how the external hazards safety demonstration is made via the development of safety evaluation methodologies based on reviews of international and national good practices. The analysis reports describe the application of the safety evaluation methodologies for the purpose of demonstrating that external hazards do not challenge the delivery of fundamental safety functions. The safety evaluation methodologies and analysis documents are on a hazard-by-hazard basis (e.g. earthquake) or grouping of hazards with similar effects (e.g. meteorological hazards).

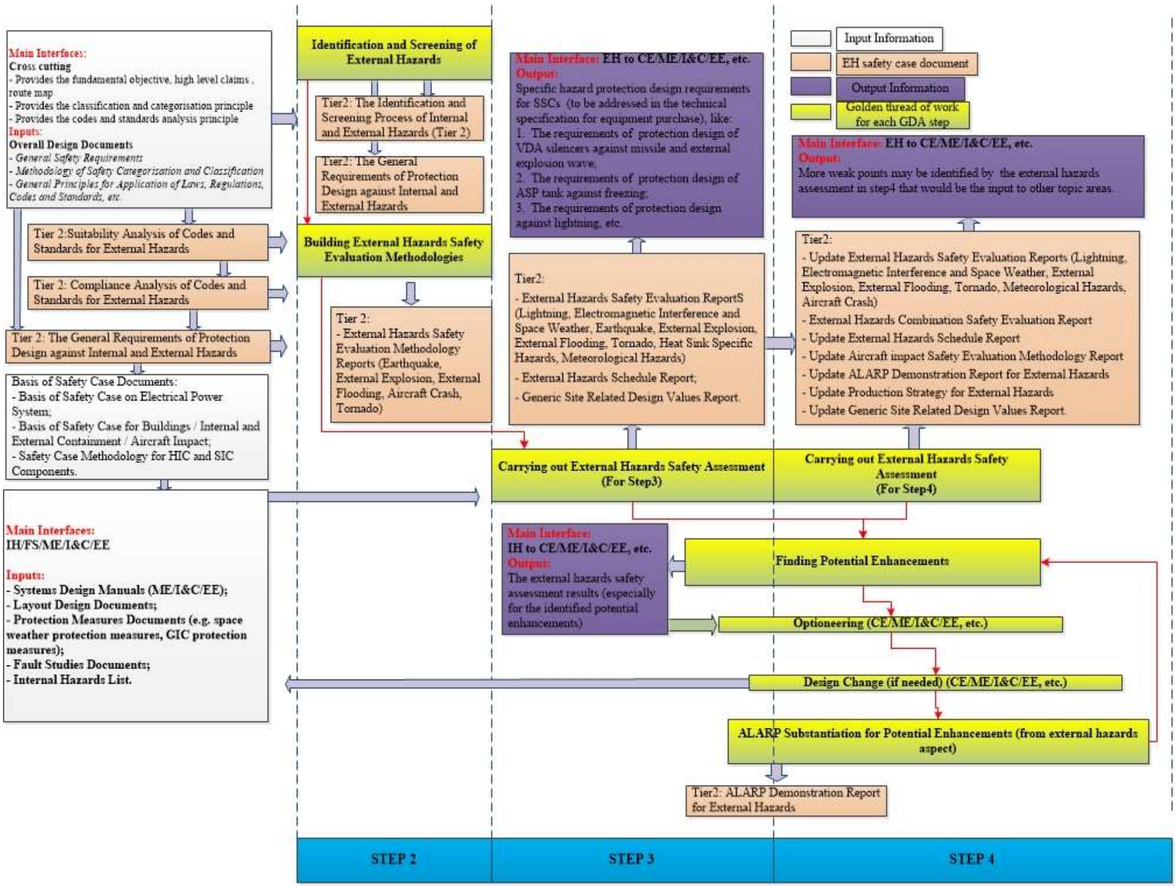

Figure 3: The external hazards safety case 'golden thread'. *(Ref. 48)*

43. The external hazards safety case submissions directly supporting PCSR Chapter 18 (Ref. 4) are described in Table 4, as well as their overall context in the safety case architecture.

44. The design philosophy for UK HPR1000 to deliver the fundamental safety claim is described in the PCSR (Ref. 47), and is based on the principles of defence-in-depth, and the independence, diversity, redundancy and segregation of safety systems. This is achieved by three segregated safety trains and their support systems, which deliver the fundamental safety functions of reactivity control, heat removal for the reactor and Spent Fuel Pool (SFP), and containment of any radiological release. The RP claims that the UK HPR1000 design and its layout have considered a range of external hazards relevant to the UK context. It is argued that the design has been substantiated to demonstrate that it is robust against these hazards and their effects. The principal means of protection from external hazards is provided by the civil structures and / or appropriate qualification of safety and safety-related systems. Items important to safety and their support systems are physically separated where possible, to avoid CCF and loss of multiple trains to a hazard.

45. The design incorporates learning from the 2011 Fukushima Dai-ichi NPP accident. This includes additional safety systems and measures as part of the design's defence-in-depth approach to prevent fault escalation, such as the Secondary Passive Heat Removal System (ASP [SPHRS]) that can provide a heat removal function for the reactor and SFP.

Table 4: External hazards safety case submissions for UK HPR1000 GDA

Title	Description	Context
The Identification and Screening Process of Internal and External Hazards (Ref. 51)	Describes the process for identification and screening of external hazards used in GDA.	These documents define the scope of the external hazards safety case for GDA by identifying hazards to be analysed and defining the requirements for protection. These documents are used by the RP to develop the safety evaluation methodologies (below).
The General Requirements of Protection Design against Internal and External Hazard (Ref. 52)	Describes the principles and requirements for protection of SSCs against hazards including external hazards.	
Suitability Analysis of Codes and Standards in External Hazards (Ref. 53)	Identifies RGP for external hazards and determines its suitability for application to the UK HPR1000 design.	
Compliance Analysis of Codes and Standards in External Hazards (Ref. 54)	Demonstrates compliance of the UK HPR1000 evaluation of external hazards against the identified RGP (Ref. 53).	

Title	Description	Context
Hazard safety evaluation methodologies	Describes the methods and processes used to evaluate the design against those external hazards and combinations screened-in to GDA. The methods are based on good practice. The analysis aims to demonstrate safe shutdown of the reactor can be achieved during normal operating modes and the delivery of fundamental safety functions is not compromised.	Methodologies produced for: ■ Seismic (Ref. 55) ■ External flooding (Ref. 56) ■ Aircraft impact (Ref. 57) ■ Tornado (Ref. 58) ■ External explosion (Ref. 59) ■ Combined hazards (Ref. 60)
Beyond Design Basis External Hazards Evaluation Methodology (Ref. 61)	Identifies different hazard categories and for each presents a methodology for analysing the UK HPR1000's beyond design basis margin.	Supplements the hazard safety evaluation methodologies.
Hazard safety evaluation reports	Presents the results of the safety analysis of the UK HPR1000 design for those external hazards, combinations and relevant design basis conditions screened-in to GDA. The analysis aims to demonstrate that safe shutdown of the reactor can be achieved during / following an external hazard event for any normal operation mode, and that a sufficient number of safety trains remain available to deliver fundamental safety functions. The reports also qualitatively analyse the design's robustness to cliff-edge effects and beyond design basis margins.	Safety evaluations produced for: ■ Seismic (Ref. 62, Ref. 63, Ref. 64, Ref. 65, Ref. 66, Ref. 67, Ref. 68) ■ External flooding (Ref. 69) ■ Aircraft impact (Ref. 70) ■ Meteorological hazards (Ref. 71) ■ Tornado (Ref. 72) ■ Lightning, space weather and electromagnetic interference (Ref. 73) ■ Space weather (Ref. 74) ■ External explosion (Ref. 75) ■ Heat sink specific hazards (Ref. 76) ■ External hazards combinations (Ref. 77)
ALARP Demonstration Report for External Hazards (Ref. 78)	Summarises the evaluation of external hazards. Argues that residual risks from external hazards are reduced ALARP.	

Title	Description	Context
External Hazards Schedule (Ref. 79)	Summarises the external hazards safety case and provides the links between hazards, plant effects, impacted SSCs, protection measures and safety functional requirements.	Establishes the links between the external hazards safety case and the engineering schedules via the hazard protection requirement code. Links to fault schedule established via identification of design basis conditions (e.g. LOOP) initiated by each hazard.

4 ONR ASSESSMENT

4.1 Structure of Assessment Undertaken

46. This sub-section describes the structure of my assessment of the external hazards safety case for the UK HPR1000. The scope of my assessment is described in section 2 and has been informed by ONR guidance in the SAPs, TAGs and other relevant documents.

47. The structure of my Step 4 assessment is presented in Table 5. The structure broadly follows the sequence of external and internal hazards SAPs to address the technical aspects identified in my assessment scope and associated samples (sub-section 2.2). This report also addresses matters from previous GDA steps, including ROs. Finally, my assessment concludes on the adequacy of the UK HPR1000 design in reducing risks to ALARP, and whether the RP's final safety case submissions have consolidated all relevant information and reflect the UK HPR1000 GDA Design Reference 3.0.

Table 5: Structure of Step 4 external hazards assessment

Title	Sub Section	Relevant SAPs
Outputs from previous GDA steps	4.2	-
Identification and screening of external hazards	4.3	EHA.1 & EHA.19
Identification and screening of hazard combinations	4.4	EHA.1 & EHA.19
Generic site envelope definition	4.5	EHA.2, EHA.3 & EHA.4
UK HPR1000 design input values	4.6	-
Analysis of external hazards	4.7	EHA.5 & EHA.6
Seismic hazards	4.8	EHA.9
Flooding hazards	4.9	EHA.12
Meteorological hazards	4.10	EHA.10 & EHA.11
Space weather hazards	4.11	EHA.10 & EHA.11
Man-made hazards	4.12	EHA.8 & EHA.14
Design basis conditions	4.13	FA.5
Analysis of hazard combinations	4.14	EHA.5 & EHA.6
Hazard schedule	4.15	FA.8
Cliff-edge and beyond design basis analysis	4.16	EHA.7 & EHA.18
External hazards safety case for the fuel building	4.17	-
Regulatory observations	4.18	-
Demonstration that relevant risks have been reduced ALARP	4.19	-
Consolidated safety case	4.20	SC.4

48. The RP's documentation uses terminology that is not aligned with ONR's guidance. I have defined the terminology used in this assessment report in Table 6, and clarified how this compares with both ONR's and the RP's terminology.

Table 6: Assessment report terminology for external hazard values

ONR term	RP's term	Term used in this Assessment Report
Design basis event (SAP EHA.3) For external hazards, the design basis event should be derived conservatively to take account of data and model uncertainties. The thresholds in FA.5 for design basis events are 1 in 10 000‡ years for external hazards and 1 in 100 000 years for man-made hazards (SAP EHA.4). For hazard analysis performed in line with modern RGP a good starting point is to consider the 84th percentile (NS-TAST-GD-013)	**Generic site envelope value** GSE values are derived for relevant hazards on a frequency basis consistent with SAP EHA.4. The RP has derived a bounding value for the three candidate sites that inform the GSE (Bradwell, Sizewell and Hinkley Point) or selected a value using best available relevant data or RGP.	**GSE value** The term GSE value is used in this report: ▪ ONR technical guidance for GDA states the RP should specify the 'site envelope' within which the plant is designed to operate safely. ▪ The GSE values have been derived on a basis consistent with the expectations of the SAPs for a design basis event (unless otherwise stated). ▪ The term GSE value is aligned with the RP's terminology and therefore avoids confusion.
None defined in the SAPs or other guidance	**Values of the reference design** Hazard value that the FCG3 reference design has been designed to withstand.	**FCG3 reference design value** Hazard value that the reference design of FCG3 has been designed against: ▪ ONR guidance does not define a term. ▪ The term FCG3 reference design value is aligned with the RP's terminology to avoid confusion. ▪ Explicit reference to FCG3 to be clear on the source of the hazard value.

‡ The term "1 in 10,000 years or "1 in 10 000 year return period" is shorthand for an event with an annual probability of exceedance of 1×10^{-4} or 1×10^{-4} / yr. In this report 1×10^{-4} / yr. is used.

ONR term	RP's term	Term used in this Assessment Report
None defined in the SAPs or other guidance	**Values for UK HPR1000 design** The selected value for UK HPR1000 design is the bounding value of either the value of the reference design or GSE value (unless otherwise stated). The UK HPR1000 and SSCs are designed to withstand the values for the UK HPR1000 design. The RP has performed DBA against the values for the UK HPR1000 design. The RP has performed BDBA, where required, against hazard values greater than the values for the UK HPR1000 design.	**UK HPR1000 design input value** The UK HPR1000 design input value is the hazard value that the UK HPR1000 and SSCs are designed to withstand. There may be margin between the UK HPR1000 design input value and the GSE value. DBA is performed against the UK HPR1000 design input value. BDBA is performed against a hazard severity greater than the UK HPR1000 design input value, where appropriate.

4.2 Outputs from Previous GDA Steps

49. My Step 4 assessment has considered the outputs from previous GDA steps including ROs, RQs and the findings of previous assessment reports. I have resolved any matters from previous steps during Step 4.

50. ROs have been raised during previous GDA steps to address potential regulatory shortfalls. ROs relevant to external hazards include: RO-UKHPR1000-0002 (Ref. 12), RO-UKHPR1000-0007 (Ref. 13) and RO-UKHPR1000-0009 (Ref. 14). These ROs were all closed during Step 4 and the assessments supporting closure are reported in sub-section 4.18. I have supported the resolution of a number of other ROs relevant to external hazards including: RO-UKHPR1000-0039 (Ref. 15), RO-UKHPR1000-055 (Ref. 16) and RO-UKHPR1000-0056 (Ref. 80). My contribution to these ROs is also reported in sub-section 4.18.

51. The Step 3 external hazards assessment raised 18 areas for improvement (AFIs) for resolution by the RP and 11 open points for follow-up during Step 4 (Ref. 11). These were captured in the Step 4 external hazards assessment plan (Ref. 9) and communicated to the RP via RQs (Ref. 81, Ref. 82, Ref. 83, Ref. 84). The AFIs and open points have informed my Step 4 sampling, and have been subject to further engagement with the RP during Step 4. All AFIs and open points were closed during Step 4. Resolution of the AFIs is presented throughout section 0 and summarised in Annex 3.

4.3 Identification and Screening of External Hazards

4.3.1 Assessment

52. ONR's GDA technical guidance (Ref. 10) expects the RP to identify and screen hazards as part of defining the GSE against which the plant is expected to operate safely. ONR's expectations for the identification of hazards are presented in SAP EHA.1. The resulting list of hazards should be screened to identify those that can impact nuclear safety, as described in SAP EHA.19. I have compared relevant safety case submissions against these expectations.

53. The RP has developed and applied systematic processes to identify and screen external hazards, which are presented in 'The Identification and Screening Process of Internal and External Hazards' report (Ref. 51). The approach has three elements:

- Identification
- Grouping
- Screening

54. In developing the processes, the RP has considered a range of RGP including:

- ONR guidance.
- International codes and standards (e.g. WENRA documentation).
- Published safety case documentation for previous GDA projects, including:
  - Hitachi-GE's UK Advanced Boiling Water Reactor (ABWR) design.
  - Westinghouse's AP1000 design.
  - EDF / AREVA's EPR design.

55. Application of the RP's identification and screening methodology for external hazards is presented in a number of safety case submissions (Ref. 50, Ref. 51). The RP has generated a comprehensive list of external hazards via literature review. The unfiltered list of external hazards has been rationalised by grouping hazards with similar characteristics. This resulted in a total of 94 external hazards split between eight hazard groups (Ref. 50). The rationalised hazards and hazard groups have then been screened. The purpose of screening is to determine whether a hazard has a significant consequential effect on the safety of the facility, and therefore needs to be evaluated in the safety case. Hazards have been either screened-in to GDA for consideration or screened-out and have not been evaluated in GDA. The RP has applied the following screening criteria (Figure 4), which are based on good practice (e.g. SAP EHA.19):

- Low frequency of occurrence – screening-out of hazards with a 1×10^{-7} annual probability of exceedance or lower.
- Low consequence – screening-out of hazards that are judged to have no consequential effect on safety of the plant and its ability to deliver fundamental safety functions.
- Bounded by another hazard – screening-out of hazards and their effects that are judged to be bounded by (in other words, less severe than) another hazard that has been screened-in for consideration.

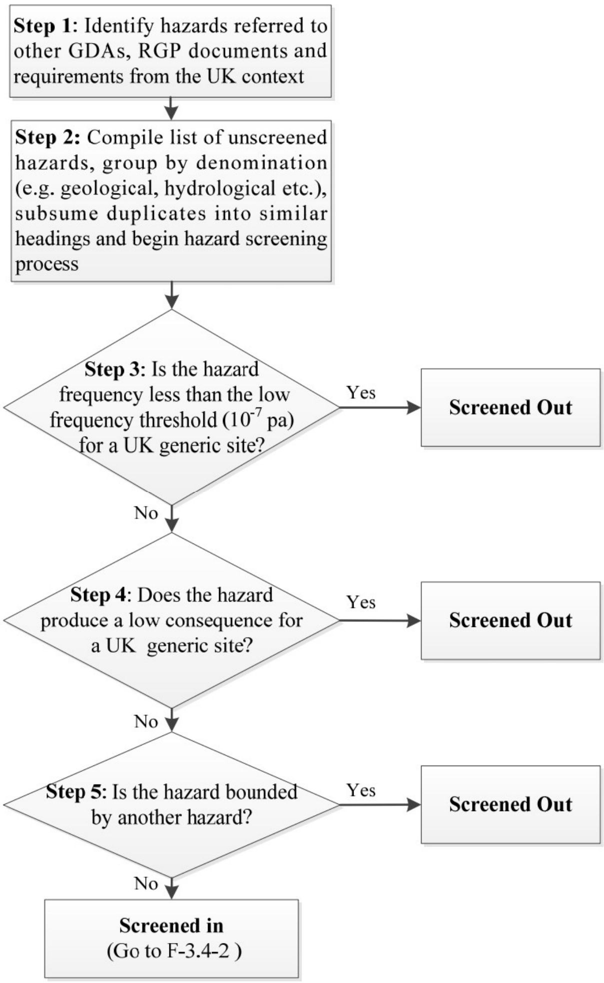

Figure 4: The RP's screening process. *(Ref. 3)*

56. A total of 16 hazards were screened-out, leaving 78 hazards for further consideration (Ref. 50). Whilst not explicitly stated in 'The Identification and Screening Process of Internal and External Hazards' (Ref. 51) the remaining 78 hazards were further screened on the basis of whether it is possible to characterise or analyse them in a meaningful way for GDA (Ref. 50). Hazards have been screened-in to GDA where it is feasible to characterise them on a generic basis or the effects on SSCs can be evaluated (e.g. solar energetic particles). Hazards have been screened-out of GDA where site-specific inputs are needed to inform the hazard characterisation and it is not considered possible to analyse the hazard's effects on a generic basis (e.g. long period ground motion).

57. I have assessed the RP's identification and screening processes and compared these with ONR's expectations (Ref. 2, Ref. 6) and other good practice (section 2.4.3). I judge the RP's approach to be consistent with the expectations of SAPs EHA.1 and EHA.19. The definition of internal and external hazards is in accordance with ONR's definition in the SAPs. Some site characteristics identified by the RP would be considered external hazards under ONR's definition (e.g. capable faulting / surface rupture). I am satisfied that this difference of terminology does not affect the results of the hazards identification and screening process.

58. The resultant list of external hazards screened-in for evaluation in GDA is presented in the PCSR (Ref. 3, Ref. 4), the 'UK HPR1000 Generic Site Report' (Ref. 50) and 'The Identification and Screening Process of Internal and External Hazards Report' (Ref. 51). The list of screened-in external hazards is reproduced in Table 7. My assessment has identified inconsistencies in the presentation of hazards and hazard groups

screened-in to GDA between the RP's documentation. For example, 'The Identification and Screening Process of Internal and External Hazards' (Ref. 51) identifies a space weather and electromagnetic interference group that is omitted from the generic site report (Ref. 50), although the individual hazards are still identified in other groups. I issued RQ-UKHPR1000-1764 (Ref. 85) requesting the RP to provide clarification on the apparent inconsistencies, and discussed this RQ during a technical engagement (Ref. 86). The RP's response (Ref. 87) clarifies that some differences relate to the RP's requirement to consider some hazards on a generic basis even if they are screened-out of GDA (Ref. 52). The response has not addressed all inconsistencies (e.g. the presentation of different hazard groups is not accounted for). This means the safety case has some inaccuracies and inconsistencies, and represents a shortfall against the expectations of SAP SC.4. I judge this to be a minor shortfall because I am satisfied that it has not impacted on the hazards analysed during GDA.

59. In forming a judgement on the adequacy of the hazards considered in GDA, I have applied ONR's Guidance to Requesting Parties (Ref. 10), which states: "The definition of the site envelope can be as broad or as narrow as the requesting party wishes. However, it should be unambiguous and specify any site-related characteristics which have been explicitly included within or excluded from that definition." It is the RP's decision which hazards are considered as part of the GSE. I judge the RP's screening processes meets the intent of this guidance. The hazards screened-in to GDA are logical and justifiable. I have compared the final list of external hazards screened-in for UK HPR1000 with previous GDA projects. This comparison shows the screened-in hazards are similar to previous GDA projects, albeit the UK HPR1000 GDA considers some additional hazards (e.g. space weather).

Table 7: Hazards screened-in to GDA for consideration

Hazard Group	Hazards
Seismic	Response spectra (earthquake) Shear wave velocity
Hydrological	Flooding (including pluvial flooding)
Man-made	Aircraft crash (accidental and malicious) External explosion* Missiles
Meteorological	Extreme air temperatures Humidity / enthalpy Wind Tornado Tornadic / wind-borne missiles Snow (including hail and sleet and icing) Extreme water temperature Precipitation Lightning Drought Space weather (solar energetic particles & geomagnetic induced current) Electromagnetic interference
Heat sink specific**	Hazards that can initiate a loss of ultimate heat sink (e.g. clogging, hydrocarbon pollution, ship collision and low-water level)

*Screened-out, but the RP has a requirement to consider the hazard on a generic basis during GDA (Ref. 52).
**Hazards in this group are screened-out from GDA, but the RP has a requirement to consider the hazards on a generic basis during GDA (Ref. 52). Heat sink specific hazards are assessed in sub-section 4.13.1.2.

60. Those hazards screened-out of GDA are presented in Annex 5. Hazards to be characterised during site-specific stages include:

- Individual hazards from screened-in hazard groups (e.g. fog from the meteorological hazard group).
- Three hazard groups:
  - Biological
  - Geological
  - Landscape change

61. The justification for screening of hazards is given in the RP's generic site report submission (Ref. 50), and includes the need for site-specific information to characterise the hazard in a meaningful way. I have considered the RP's screening approach and also compared with previous GDA projects. I judge that adequate justification has been provided for the hazards screened-out of GDA for consideration during site-specific stages.

62. Only two hazards have been screened-out from consideration entirely by the RP due to low frequency of occurrence: meteorites and volcanoes[§]. The RP argues that this approach is aligned with IAEA guidance. I judge the RP's justification logical and based on good practice including SAP EHA.19. It is also consistent with previous GDAs. The RP has also screened-out solar flares from further consideration and justified this as the effects are bounded by space weather (Ref. 50). The RP has clarified that space weather considers all hazardous effects related to solar phenomena including:

- Electromagnetic interference (EMI).
- Solar energetic particles and associated ground level effects.
- Geomagnetically induced currents.

63. I judge this approach for space weather hazards to be acceptable for GDA.

64. A licensee will need to revisit the identification and screening process during site-specific stages to ensure all relevant site-specific hazards are identified. I consider this normal business, and the GDA work provides a reasonable basis for development by a licensee.

4.3.2 Strengths

65. I have identified the following strengths with the RP's identification and screening process for external hazards:

- The identification and screening processes are consistent with RGP including the SAPs.
- The categorisation of internal and external hazards is consistent with the ONR SAPs.
- Screening criteria are consistent with SAP EHA.19.
- The resultant list of screened-in external hazards has been compared with other GDA projects and shows that similar hazards are being considered by the UK HPR1000 project.
- The RP's approach is consistent with ONR's technical guidance for GDA.

[§] *Volcanic ash and dust is a separate hazard and is screened-out for consideration at site-specific stages*

4.3.3 Outcomes

66. I have identified one minor shortfall based on my assessment of this topic as described in sub-section 4.3.1. A licensee will need to revisit the identification and screening process during site-specific phases. I judge this be normal business and no findings are raised by my assessment.

4.3.4 Conclusion

67. I have assessed the RP's identification and screening process for external hazards. I conclude that:

- The process is adequate for GDA.
- The process is aligned with RGP including the expectations of SAPs EHA.1 and EHA.19.
- I have identified one minor shortfall in the RP's application of the identification and screening process. I judge this minor shortfall does not detract from the RP's overall approach or challenges the hazards analysed in this GDA.

4.4 Identification and Screening of Hazard Combinations

4.4.1 Assessment

68. The ONR SAPs (Ref. 2) expect reasonably foreseeable combinations of independently occurring hazards, causally-related hazards and consequential events resulting from a common initiating event to be identified, and screened (e.g. SAP EHA.1 and paragraph 234, and EHA.19). Further guidance is provided in NS-TAST-GD-013 (Ref. 6). I have assessed relevant safety case submissions against these expectations from the SAPs and ONR's technical assessment guidance.

69. During GDA Step 3 I assessed the RP's methodology for the identification and screening of hazard combinations as presented in an earlier revision of 'The Identification and Screening Process of Internal and External Hazards' report (Ref. 88). Hazard combinations were identified only for those hazards screened-in to GDA and based on mechanisms of occurrence and engineering experience. I judged that the RP's approach did not meet the intent of SAP EHA.1, and some reasonably foreseeable hazard combinations were omitted from evaluation (Ref. 2, Ref. 6). I captured this as an area for improvement (AFI-1) in my Step 3 assessment report (Ref. 11). I raised RQ-UKHPR1000-0619 (Ref. 89) for the RP to explain their approach and to provide my expectations.

70. The RP committed to revisiting the identification and screening of external hazard combinations in response to RQ-UKHPR1000-0619 (Ref. 90). The revised process for the identification and screening of combined hazards is presented in an updated version of 'The Identification and Screening Process of Internal and External Hazards' (Ref. 51) and applied in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77) to produce the list of hazard combinations for consideration in GDA. The RP's process is similar to the processes for identification and screening of individual hazards, and has three steps:

- Identification
- Categorisation
- Screening

71. This process is applied to identify the following combination types:

- Combinations of external hazards[**].

[**] *Both correlated and independently occurring (coincidental)*

- Combinations of external and internal hazards.
- Combinations of external hazards with design basis conditions[††].

72. For identification of hazards, the RP has considered the following information:

- External hazards – an unscreened list of hazards (both external and internal) based on the Advanced Safety Assessment Methodologies: extended Probabilistic Safety Analysis (ASAMPSA_E) project (Ref. 91). This project is recognised as RGP in NS-TAST-GD-013 (Ref. 6).
- Internal hazards – based on the extant list of internal hazards presented in 'The Identification and Screening Process of Internal and External Hazards' (Ref. 51).
- Design base conditions – based on 'The Design Condition List and Acceptance Criteria' (Ref. 92).

73. The ASAMPSA_E project breaks hazards down to a detailed level, which does not align with the RP's approach for GDA. The RP has rationalised and grouped the ASAMPSA_E hazards based on the UK HPR1000 hazards. I judge this step reasonable for the purposes of GDA and note that this has provided a further check on the completeness of independently occurring hazards considered in GDA. The RP presents the rationalised hazards and design basis conditions as a number of 2-D matrices, enabling the identification of potential combinations and the categorisation of their relationship (Ref. 77). The RP's process has also considered possible combinations of three or more hazards based on expert judgement.

74. The use of an unscreened list of hazards for identification of potential combinations is good practice and consistent with the expectations of SAP EHA.1. I judge the use of 2-D matrices to also be good practice based on NS-TAST-GD-013 guidance (Ref. 6) and it provides clarity on how combinations have been identified and categorised. The RP's categorisation of hazard combinations is also aligned with ONR's guidance in NS-TAST-GD-013 (Ref. 6) and comprises:

- Correlated – hazards occurring simultaneously due to a common physical process (e.g. a storm giving rise to wind and rain hazards).
- Consequential – a second hazard resulting from the occurrence / effects of the primary hazard (e.g. fire as a result of a lightning strike).
- Independent – two separate, unrelated hazards occurring simultaneously with no causative link (e.g. earthquake and wind).

75. I have, on a sampling basis, compared the external hazard combinations and their categorisation presented in the appendices of 'The Identification and Screening Process of Internal and External Hazards' report (Ref. 51) and the matrices of the 'External Hazards Combination Safety Evaluation Report' (Ref. 77). I have found some inconsistencies between the documentation, mostly relating to categorisation of combinations, and discussed these with the RP at a technical engagement (Ref. 86). I judge this to be a minor shortfall against SAP SC.4**.** This minor shortfall does not detract from the overall approach developed by the RP and does not fundamentally affect the outcomes of the combinations considered in GDA.

76. All identified hazard combinations have been subject to screening. The screening criteria are based on those applied for screening of individual hazards (sub-section 4.3) supplemented with additional criteria specific to combinations. I judge the screening criteria to be logical and consistent with good practice. Screening criteria are applied in the following order (Figure 5):

[††] Design basis conditions are fault scenarios identified in 'The Design Condition List and Acceptance Criteria Report' (Ref. 92). Some design basis conditions (e.g. loss of off-site power and loss of ultimate heat sink) can be initiated by external hazards and these have been analysed in combination with relevant external hazards to demonstrate the UK HPR1000's resilience.

- One or more hazards in the combination require site-specific information for their characterisation.
- Hazards are mutually exclusive and are judged to not be capable of occurring together (e.g. low- and high-air temperature).
- Effects / consequences are bounded by another hazard or hazard combination already considered.
- Effects / consequences are inherent of a hazard or hazard combination already considered.
- Low consequences.
- The combination is judged to be slow progressing such that consequential effects can be prevented or mitigated.
- Low frequency of occurrence ($<1 \times 10^{-7}$ / yr.).

77. Following application of the screening criteria, a total of nine external to external hazard combinations were screened-in for consideration in GDA, eight external to internal hazard combinations and also external hazards with design base conditions (Table 8). All other potential hazard combinations are screened out for evaluation post-GDA when site-specific data is available to characterise hazards in a meaningful way and more detailed plant layout information will be available for consequential internal hazards. All combinations of three or more hazards were also screened-out. I judge the screened-in hazard combinations to be reasonable, with screened-out combinations adequately justified.

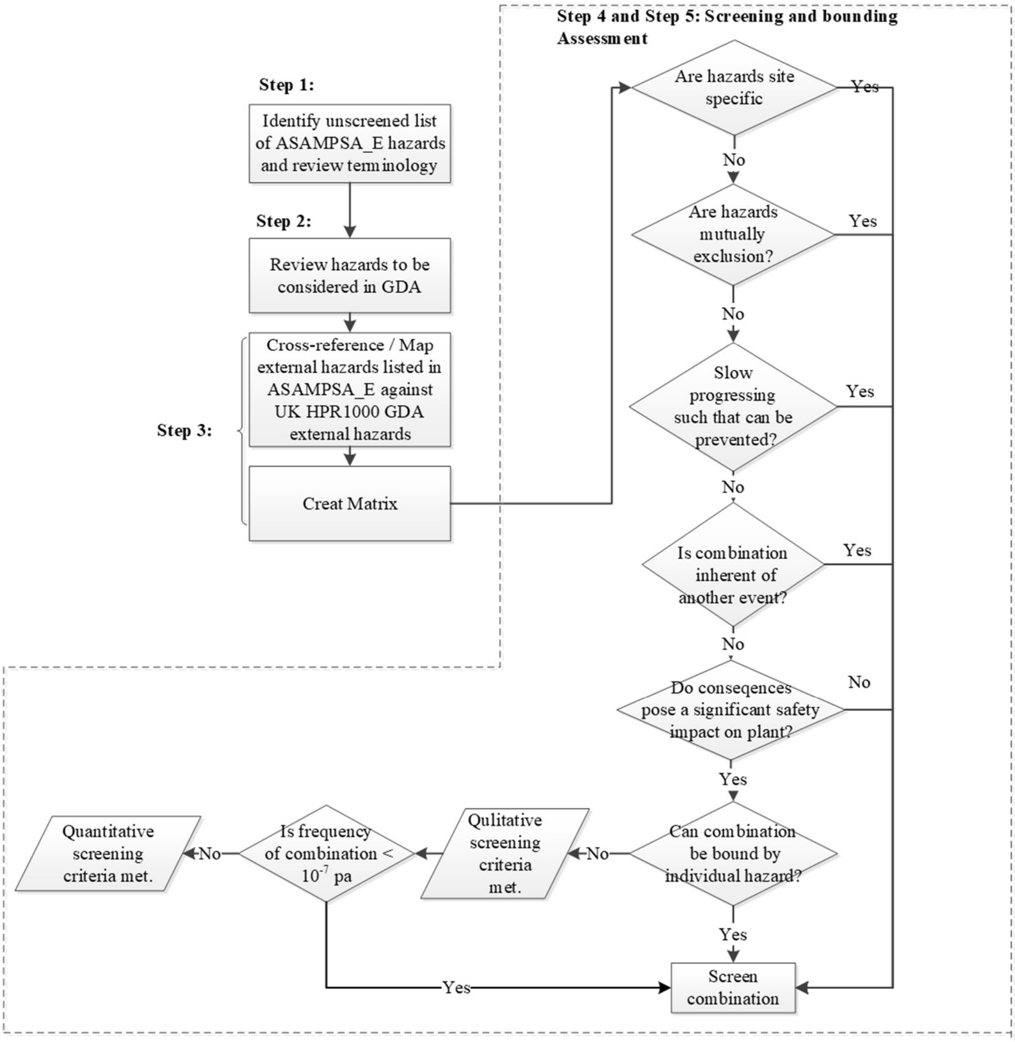

Figure 5: Hazard combinations identification and screening process. *(Ref. 77)*

78. The analysis of screened-in combinations is presented in the Safety Evaluation Reports (Table 4), where the combination was identified in previous revisions of the 'Identification and Screening of Internal and External Hazards' report (Ref. 88), or in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77) if they are a new hazard combination screened-in to GDA post-Step 3 based on the revised process.

Table 8: External hazard combinations screened-in to GDA

Combination type	Hazards
Correlated external hazard combinations	High-water temperature + High-air temperature High humidity / low humidity + High-air temperature Low-air temperature + Low-water temperature Low humidity + Low-air temperature High wind / tornado + Lightning
Independent external hazard combinations	Earthquake + High wind Earthquake + Low-air temperature Earthquake + Snow High wind + Low-air temperature
Consequential external – internal hazard combinations	Earthquake + Internal fire Earthquake + Internal explosion Earthquake + Internal flooding Earthquake + Dropped loads Earthquake + High energy pipe failures Earthquake + Internal missiles External Flooding + Internal flooding Extreme Hail, Sleet, Snow, Icing + Internal flooding
External hazard – design basis condition combinations	Individual external hazards with LOOP and / or LUHS

79. I have interfaced with the ONR Internal Hazards Inspector with respect to the external to internal hazard combinations. Whilst the Internal Hazards Inspector was content with the identified internal hazards and resulting combinations screened-in for GDA, they did not consider the RP's definition of external to internal flooding consistent with the SAPs as the flooding source is an external hazard. Further commentary on this is presented in the Step 4 internal hazards assessment report (Ref. 93). Of particular relevance is that the 'External Hazards Combination Safety Evaluation Report' (Ref. 77) screens in a combination of earthquake and consequential internal fire. This combination was the topic of RQ-UKHPR1000-832 (Ref. 94, Ref. 95), where the RP confirmed the combination was screened-out from evaluation in the Earthquake Safety Evaluation Reports on a frequency basis. This led to the ONR Internal Hazards Inspector raising RO-UKHPR1000-0055 (Ref. 96), which relates to potential regulatory shortfalls in the RP's approach to analysing consequential hazards resulting from earthquake. My interactions with the Internal Hazards Inspector in relation to this RO are discussed in sub-sections 4.8 and 4.18.1.5 of this report.

80. Overall, I judge the RP's approach to identify and screen hazard combinations to be systematic and to have met the expectations of SAP EHA.1 and EHA.19 (Ref. 2). ONR's guidance to RPs (Ref. 10) is clear that the definition of the GSE is the RP's decision to make. The RP's screening process for hazard combinations meets the intent of this guidance and has been applied to develop a list of reasonably foreseeable combinations for evaluation in GDA.

81. Further work on hazard combinations is necessary post-GDA for a target site, including consideration of those hazard combinations screened-out from GDA. The RP has recognised this themselves in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77), which states: "… the combinations identified (and considered in the GDA submission) represent the most comprehensive generic list available prior to including site-specific detailed information. External hazard combinations will need to be reviewed by a licensee according to RGP at that time." I consider this work to be normal business for a licensee during site-specific stages. I judge the RP's work during GDA provides a reasonable starting point for development of the site-specific identification and screening of hazard combinations.

4.4.2 Strengths

82. I have identified the following strengths with the RP's identification and screening process for hazards combinations:

- The RP has developed an identification and screening process for hazard combinations that meets the expectations of SAPs EHA.1 and EHA.19.
- The ASAMPSA_E methodology is recognised as RGP in NS-TAST-GD-013 for identification of hazard combinations.
- The categorisation of hazard combinations and terminology used aligns with ONR's guidance in NS-TAST-GD-013.
- The screening criteria appear logical and are based on those used for screening of individual hazards.
- The RP has applied the methodology to develop a list of reasonably foreseeable hazard combinations for evaluation in GDA.

4.4.3 Outcomes

83. My assessment of the identification and screening of hazard combinations has identified a minor shortfall as discussed in sub-section 4.4.1 above. I judge that this does not detract from the RP's overall approach or fundamentally challenges the hazard combinations that have been screened-in to GDA.

84. A licensee will need to revisit the hazard combination identification and screening process during site-specific stages to identify any site-specific hazard combinations and to also consider those combinations that have been screened-out from GDA. This is normal business, and no findings are raised by my assessment. I judge the RP's process provides a reasonable starting point for a licensee to develop.

4.4.4 Conclusion

85. I have assessed the RP's hazard combinations identification and screening process. I conclude that:

- The process is adequate for GDA.
- The process has been developed using RGP.
- The process is consistent with the expectations of SAPs EHA.1 and EHA.19.
- Although some inconsistencies exist in the categorisation of hazard combinations within different documents, I judge that this does not detract from the overall approach or fundamentally challenges those combinations screened-in to GDA.

4.5 Generic Site Envelope Definition

4.5.1 Assessment

86. The purpose of the GSE, and ONR's expectations related to its definition, are provided in the GDA technical guidance (Ref. 10): "Although many details of a NPP design will be independent of the location chosen for its construction, some assumptions about the characteristics of the plant's environment need to be considered in developing the design of certain safety-related features. To ensure that a design submitted for GDA will be suitable for construction on a variety of sites within GB, the RP should specify the 'site envelope' within which the plant is designed to operate safely. The definition of the site envelope can be as broad or narrow as the RP wishes. However, it should be unambiguous and specify any site-related characteristics which have been explicitly included within or excluded from that definition. If a subsequent site licence application is made for a site which has characteristics bounded by the generic site envelope, then the time taken for ONR's licensing assessment will be minimised." The GSE definition comprises both external hazards and other relevant aspects including:

- Geotechnical parameters
- Heat sink
- Grid connection
- Density and distribution of local population

87. My assessment has focused on determining the adequacy of the external hazard definitions. I have applied the guidance from the GDA technical guidance (Ref. 10) along with the expectations of SAPs EHA.2, EHA.3 and EHA.4 to determine the adequacy of the RP's approach for defining GSE values for external hazards. I have liaised with relevant ONR inspectors in relation to other aspects of the GSE definition, including:

- The ONR Electrical Engineering Inspector for the definition of LOOP.
- The ONR Civil Engineering Inspector for geotechnical parameters.

88. Previous GDA projects have defined their GSE based on the eight candidate sites identified for nuclear new build in EN-6 (Ref. 49, Ref. 97). The definition of the site envelope can, however, be as broad or narrow as the RP wishes (Ref. 10). For the UK HPR1000 GDA, the RP has based its GSE on three of the EN-6 sites, namely: Bradwell, Sizewell and Hinkley Point (the 'candidate sites'). The RP has access to site data for these sites, and Bradwell is being considered as the target site for deployment of the UK HPR1000 reactor technology. I am content with the RP's selection of sites, as the decision is for them to make.

89. The three candidate sites are underlain by soft sediments and rock types:

- Crag group and London Clay for Sizewell.
- London Clay for Bradwell.
- Sedimentary rocks (mudstone, shale and limestone) for Hinkley Point.

90. The ONR Civil Engineering Inspector and I agree that the RP has selected a range of geotechnical parameters for the GSE that adequately bounds the three sites based on assessment of documentation submitted in response to RO-UKHPR1000-0009 (Ref. 14) (sub-section 4.18.1.3). Further discussion is provided in the Step 4 civil engineering assessment report (Ref. 98).

91. The geotechnical parameters for the GSE defined by the RP explicitly excludes hard rock sites included in EN-6 (Ref. 49, Ref. 97). The reference design has been designed and is being constructed on a hard rock site at Fangchenggang, China. A licensee would need to undertake appropriate site-specific analysis post-GDA if they wished to

deploy the UK HPR1000 on a hard rock site in GB. This may require additional analysis and / or modification to demonstrate the design reduces risks ALARP. Such work would be normal business during the site-specific stages of design development.

92. The RP has defined a GSE value for each hazard screened-in to GDA, with some exceptions (e.g. for solar energetic particles, a consequence analysis has been provided). I judge this approach to be consistent with the expectations of SAP EHA.3. The RP's process for defining external hazard magnitude values and site characteristics is presented in the 'UK HPR1000 Generic Site Report' (Ref. 50). GSE values are defined in accordance with ONR's expectations of SAP EHA.4 where possible (in other words, conservatively derived 1 in 10 000 years for external hazards and 1 in 100 000 years for man-made external hazards). Values have been derived by a combination of:

- Selecting a value from available data from Bradwell, Hinkley Point and Sizewell sites.
- Calculating a value.
- Making a judgement.

93. When selecting a value from the candidate sites the RP has chosen the bounding value for the three sites. I judge this to be a conservative approach. Where site-specific data is unavailable, the RP has calculated a value using relevant codes and standards (e.g. Eurocodes) or selected a value based on best available relevant data, which includes consideration of previous GDA projects. Hazard values based on previous GDA projects are representative of the eight candidate sites from EN-6, and are likely to be conservative compared with a value defined only on the basis of the Bradwell, Sizewell and Hinkley Point candidate sites. I judge the RP's approach is consistent with the expectations of SAP EHA.2. I have also taken confidence on the validity of selected values, where they have been assessed by ONR during previous GDA projects and found to be adequate, so long as the assumptions and inputs made in deriving the value remain valid.

94. Overall, I consider the RP's approach to be aligned with ONR's expectations in SAPs EHA.2, EHA.3 and EHA.4. My formal judgement on the adequacy of the values selected for external hazards and relevant site characteristics is presented in sub-sections 4.8 to 4.14. A licensee will need to compare the site-specific hazard values (sometimes referred to as the 'site challenge') with the GSE (and UK HPR1000 design input) values derived in GDA. Further analysis is needed for those site-specific hazards that exceed the GSE (and UK HPR1000 design input) values. I consider this normal business for a licensee, and no findings are raised in relation to this work.

4.5.1.1 Climate Change

95. Climate change is a change in global and / or regional climatic patterns. The phrase is often used to describe the demonstrable climatic changes that have occurred since the late 20th century onwards, which have been primarily attributed to the increased levels of atmospheric greenhouse gases resulting from anthropogenic activities. Some natural hazards are affected by climate change (e.g. meteorological hazards) (Ref. 99). ONR's expectation is that the reasonably foreseeable effects of climate change over the lifetime of the facility are taken into account (e.g. SAP EHA.11 and paragraph 259). I have assessed the RP's approach to define climate change allowances against ONR's expectations.

96. During Step 3 the RP used UK Climate Projections 2009 (UKCP09) to define climate change allowances, as this was considered RGP when the RP entered GDA. UKCP09 was replaced in 2018 by UKCP2018. ONR now considers UKCP18 to be RGP (Ref. 100). ONR's position statement on use of UKCP18 expects "… dutyholders… [to] take account of UKCP18 when assessing the impacts of climate change. This includes

taking UKCP18 into account at all stages of the facility lifecycle, from design, planning, construction, operation, and through to decommissioning and eventual release from regulation." I judged it proportionate for the RP to consider the impact of UKCP18 during GDA and, where suitable data exists, to include climate change allowances based on UKCP18 projections.

97. The fundamental difference between UKCP09 and UKCP18 is the treatment of greenhouse gas emissions. UKCP09 used three scenarios drawn from the Special Report on Emission Scenarios (SRES). UKCP18 uses scenarios called representative concentration pathways (RCPs) that specify the radiative forcing at the top of the atmosphere by 2100, relative to pre-industrial levels. Four forcing levels have been defined: 2.6 W/m^2, 4.5 W/m^2, 6.0 W/m^2 and 8.5 W/m^2, which give the four RCPs used in UKCP18: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Each RCP results in a different range of global mean temperature increases to 2100.

98. ONR's guidance does not prescribe an RCP for use, this being for the RP to define (Ref. 100). However, there should not be a reduction in the level of conservatism with the use of UKCP18 compared with previous approaches that ONR has accepted. I engaged with the RP in relation to their proposed approach for using UKCP18 (Ref. 101, Ref. 102, Ref. 103). The RP first proposed using either the bounding value of RCP 4.5 at the 84th percentile or RCP 8.5 at the 50th percentile. I judged the use of RCP 4.5, which is equivalent to a low emissions scenario, to represent a reduction in conservatism compared with the UKCP09 medium emissions scenario (SRES A1B) that ONR has previously accepted. In my opinion the assumptions in RCP 4.5 are quite optimistic when compared with observed climate change trends.

99. The RP subsequently chose to use RCP 6.0 at the 84^{th} percentile for deriving climate change allowances, where suitable data is available (Ref. 50). Where UKCP18 does not currently provide data for particular hazards (e.g. sea water temperature) the RP has adopted a different approach, but this is discussed in more detail for relevant hazards in the following sections and sub-sections of this report. For hazard minima (e.g. low-air temperature, snow etc.) the RP's approach is to not include a climate change allowance. The RP considers this approach conservative as extreme minima are expected to become less frequent in future epochs in a warming climate.

100. I find that the RP's approach to climate change is consistent with ONR's expectations in the SAP EHA.11 and other guidance. In particular:

- The RP has used UKCP18 to define climate change allowances, which I judge to be RGP (Ref. 100).
- The approach for hazard minima is conservative, although I caution its application should be considered on a hazard-by-hazard basis, with appropriate consideration of scientific evidence.
- The RP has provided sufficient evidence to demonstrate that RCP 6.0 and SRES A1B (available in UKCP18 for comparison of some hazards) result in similar climate change impacts at a 2100 epoch based on calculations for air temperature and rainfall hazards.
- Use of RCP 6.0 aligns with ONR's guidance that there should be no reduction in conservatism compared with previously accepted approaches (Ref. 100).
- The RP's selection of RCP 6.0 over SRES A1B is consistent with the UK Met Office's guidance in sub-section 2.2 of the UKCP18 Science Overview report (Ref. 104).
- More onerous climate change scenarios (e.g. RCP 8.5) remain available for beyond design basis events and credible maximum scenario considerations.

4.5.2 Strengths

101. Based on my assessment of the RP's definition of the GSE I have identified the following strengths:

- The RP has clearly defined the scope of the GSE for use in GDA.
- The GSE definition is based on three sites identified for new nuclear build from EN-6 namely Bradwell, Sizewell and Hinkley Point. I am content with the RP's proposal as ONR's guidance allows the RP to define the GSE scope.
- The RP has defined a GSE value for all hazards screened-in to GDA, where appropriate. Each external hazard GSE value has been defined in accordance with ONR's expectations in SAPs EHA.3 and EHA.4.
- GSE values have been derived by a combination of: selecting a bounding value from the three candidate sites, calculating a value using codes and standards, or selecting a value from best available relevant data, including values derived by previous GDA projects. I consider the RP's approach to be aligned with ONR's expectations in SAP EHA.2.
- Climate change is included in the GSE value for relevant hazards. The RP has adopted UKCP18 for deriving climate change allowances, where suitable data is available. I consider the RP's approach to using UKCP18 to be aligned with ONR's expectations in SAP EHA.11 and the joint position statement (Ref. 100).

4.5.3 Outcomes

102. Based on my assessment of the RP's general approach to define the GSE I have not identified any Assessment Findings or minor shortfalls. I note the following:

- I consider the RP's approach for defining the GSE to be adequate and consistent with ONR's expectations. Post-GDA, a licensee will need to compare hazard values defined for the target (the 'site challenge') with the GSE (and UK HPR1000 design input) values. If a target site has characteristics bounded by the GSE, then the time taken for ONR's licensing assessment will be minimised. I consider this normal business for site-specific stages and no formal findings are raised in relation to this matter.
- I consider the RP's adoption and use of UKCP18 to be consistent with good practice and ONR's expectations. I expect a licensee to apply RGP to calculate climate change allowances for all hazards during site-specific stages. Should a licensee choose to apply UKCP18 as RGP, then it will need to demonstrate that the assumptions made during GDA remain valid. This is normal business, and no formal findings are raised in relation to this matter.
- The GSE definition for UK HPR1000 GDA explicitly excludes hard rock sites. The reference design has been developed and constructed on a hard rock site at FCG3. This gives confidence that with appropriate analysis post-GDA the UK HPR1000 could be deployed on such a site in the UK.

4.5.4 Conclusion

103. I have assessed the RP's approach for definition of the GSE. I conclude that:

- The RP has a clearly defined scope for the GSE, which is based on three EN-6 sites (Bradwell, Sizewell and Hinkley Point).
- The GSE includes both external hazards and other relevant site characteristics as per ONR's technical guidance for GDA.
- My assessment has found the RP's approach to deriving external hazard values for the GSE is aligned with SAP EHA.2 and comprises:
  - Selection of a bounding value for the three candidate sites that inform the GSE.

- Calculating a value using RGP.
- Select a value from best available relevant data.

- External hazards are defined on a basis consistent with SAPs EHA.3 and EHA.4.
- The reasonably foreseeable effects of climate change, over the lifetime of the facility, have been included for relevant hazards using RGP.
- I judge that the RP's approach to define the GSE is consistent with ONR's expectations for GDA and the SAPs.

4.6 UK HPR1000 Design Input Values

4.6.1 Assessment

104. I have assessed the adequacy of the RP's approach to selecting UK HPR1000 design input values. These are the external hazard loads that SSCs are designed to withstand (Table 6).

105. The RP's process for the selection of UK HPR1000 design input values is presented in the PCSR (Ref. 3) and reproduced in Figure 6. As a general principle, for each external hazard, the RP has selected as the UK HPR1000 design input value the bounding value of either:

- The FCG3 reference design value.
- The GSE value.

106. The UK HPR1000 design input value exceeds ONR's expectations in SAP EHA.4 where a bounding FCG3 reference design value is selected. This is because the annual probability of exceedance of the FCG3 reference design value will be lower than 1 x 10^{-4} (0.01%) given the GSE values are based on the expectations in SAP EHA.4. I judge this a conservative approach, and it provides confidence that the UK HPR1000 design will have demonstrable beyond design basis margin (compare with the expectations of SAPs EHA.7 and EHA.18).

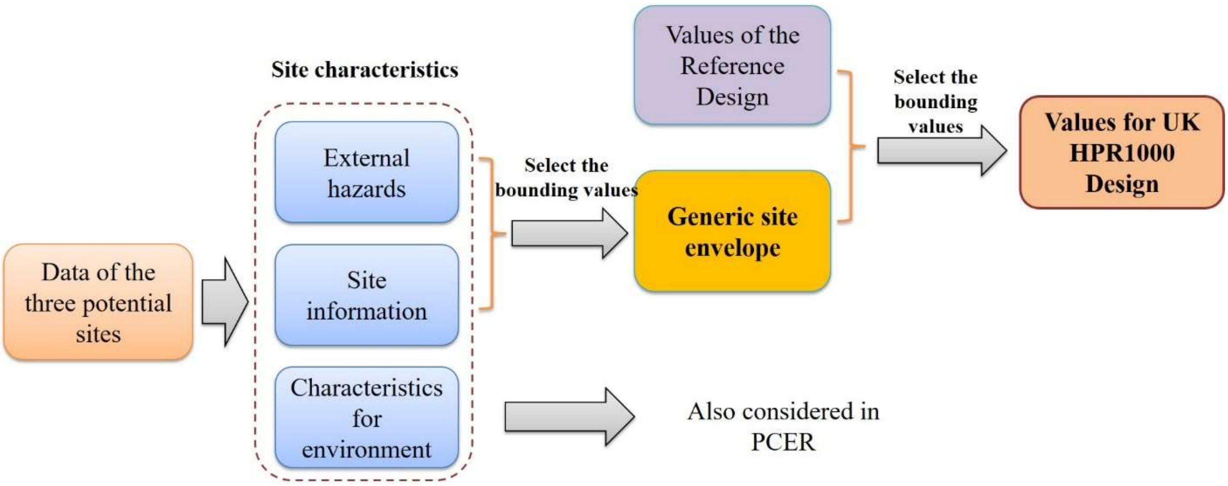

Figure 6: The RP's process for selection of UK HPR1000 design input values for external hazards. *(Ref. 3)*

107. Whilst the RP's selection of bounding values is commendable, it could lead to an overly conservative design with associated design, engineering and cost implications. There are several hazards where the RP has presented an adequate justification for the use of a GSE value as the UK HPR1000 design input value, even though the equivalent FCG3 reference design value is bounding. For example, the GSE value for 24 hours rainfall is significantly smaller than the FCG3 reference design value. In this

case the design of drainage systems would be conservative for the UK HPR1000 design if the FCG3 reference design value was adopted (sub-section 4.9.1.1).

108. During Step 2, the RP analysed the GSE values for external hazards against the FCG3 reference design values. This analysis identified a number of gaps where the GSE values exceeded the FCG3 reference design values. The RP has provided additional analysis in response to RO-UKHPR1000-0002 (Ref. 12) to demonstrate that the design could withstand the increased hazard loadings of the GSE. The gaps comprised:

- Air temperature
- Water temperature
- Snow and icing
- Space weather
- Shear wave velocity

109. My assessment of these gaps is presented in sub-sections 4.8 to 4.14. A number of associated ROs were raised based on potential regulatory shortfalls in the RP's submissions for RO-UKHPR1000-0002, and to seek address of specific matters including RO-UKHPR1000-0039 (Ref. 15) related to substantiation of HVAC systems against the GSE value for air temperature hazards. The ROs were closed during Step 4 as ONR has been satisfied that the RP has adequately addressed the concerns (sub-section 4.18).

110. Overall, I judge that the RP's approach for the selection of UK HPR1000 design input values is adequate. The RP's selection of a bounding value from either the GSE or FCG3 reference design is conservative. The selection of a bounding FCG3 reference design value exceeds the expectations in SAP EHA.4, and provides confidence the UK HPR1000 design will have credible beyond design basis withstand. The RP has identified instances where the GSE value is bounding as a gap and has provided additional analysis to demonstrate the generic UK HPR1000 design can withstand the increased hazard loadings, or modified the design to withstand the increased loading.

4.6.2 Strengths

111. Based on my assessment of the RP's selection of UK HPR1000 design input values, I have identified the following strengths:

- The RP has selected a UK HPR1000 design input value for all external hazards screened-in to GDA (where appropriate).
- The RP's typical approach to define a UK HPR1000 design input value is to select the bounding hazard value from either the FCG3 reference design value or GSE value.
- The RP has provided adequate justification for use of GSE values as the UK HPR1000 design input values, where the use of a bounding FCG3 reference design value would be overly conservative (e.g. rainfall).
- Where the FCG3 reference design value bounds the GSE and is selected, then it exceeds UK expectations in SAP EHA.4, and gives confidence that the design will have beyond design basis margin available.
- The RP has analysed the impacts on the UK HPR1000 design where the GSE hazard value exceeds the FCG3 reference design value.

4.6.3 Outcomes

112. I have identified no findings or minor shortfalls based on my assessment of the selection of UK HPR1000 design input values for external hazards. A licensee will need to demonstrate that the UK HPR1000 design input values bound the site-specific hazard values for a target site during site-specific stages. Any gaps identified in the UK

HPR1000 design input values against the target site hazard values will need to be evaluated during site-specific stages. This is normal business for site-specific stages.

4.6.4 Conclusion

113. I have assessed the RP's approach for selecting UK HPR1000 design input values. I conclude that:

- The RP's typical approach to select the bounding values from either FCG3 reference design or GSE as the UK HPR1000 design input value is conservative.
- Adequate justification has been provided for any exceptions to this approach.
- The RP's design philosophy provides confidence that the UK HPR1000 design input values should, in the future, bound any target site that is selected for deployment of the UK HPR1000 reactor technology.

4.7 Analysis of External Hazards

4.7.1 Assessment

114. This sub-section provides a high-level assessment of the RP's approach to analysing the UK HPR1000 design against external hazards including combinations. I have assessed the RP's approach against RGP, including ONR's SAPs EHA.5 & EHA.6, to determine its adequacy. Detailed analysis for individual hazards is provided in the sub-sections 4.8 to 4.14.

115. The RP has performed design basis analysis (DBA), beyond design basis analysis (BDBA) and PSA for hazards, and also considered hazards as potential initiating events (PIEs) for severe accident analysis (SAA). In my view, the RP's use of a range of different analysis approaches is consistent with the expectations of SAP paragraph 243 and guidance in NS-TAST-GD-013, which I judge to be RGP. The RP's DBA has considered all permitted, normal operating modes to identify the most onerous operating modes for risk from external hazards. I judge this consistent with the expectations of SAP EHA.5.

116. My external hazards assessment focuses on the RP's DBA and BDBA. The aim of the RP's analysis is to demonstrate that safe shutdown of the reactor can be achieved, and that external hazards do not impact the delivery of the fundamental safety functions of the UK HPR1000. I have interfaced with the ONR PSA and SAA Inspectors during GDA to ensure the RP's approach is consistent, where appropriate, between discipline areas. Relevant, joint interactions are discussed in sub-sections 4.8 to 4.14. On the basis of these engagements, I judge that the RP has met the intent of SAP paragraph 243. I recommend that the PSA (Ref. 105) and SAA (Ref. 106) assessment reports are read in conjunction with this assessment report to gain a broader understanding of the UK HPR1000 design's robustness against hazards and associated PIEs.

117. The ONR PSA Inspector and I raised and assessed RQ-UKHPR1000-1452 (Ref. 107) to gain an understanding of the integration of the safety case across deterministic and probabilistic aspects of the external hazards safety case. The PSA Inspector and I judged that the response was consistent with our expectations on the integration of deterministic and probabilistic approaches for external hazards (Ref. 108). We also engaged on consistency between the deterministic and probabilistic flooding safety cases, and found them to be consistent, where appropriate (Ref. 109, Ref. 110).

4.7.1.1 Design Basis Analysis of Individual Hazards

118. The RP's general approach to deterministic evaluation of external hazards is presented in the PCSR chapter 18 (Ref. 4). Six steps are identified:

- Identification and screening of external hazards – sources of external hazards are identified and captured for a generic site.
- Quantification of hazard loads – the external hazard UK HPR1000 design input value is selected.
- Consequence analysis – the effects of external hazards are identified.
- Identification of protection measures – protection measures are identified based on the consequence analysis.
- Substantiation of protection measures – the effects of an external hazard on the protection measures (e.g. hazard barriers) are assessed to ensure that the protection measures do not fail, and the fundamental safety functions are fulfilled.
- Development of external hazards schedule – provides the links between hazards, protection measures, and safety functional requirements delivered to relevant engineering disciplines.

119. The RP's methods for identification and screening of external hazards and derivation of UK HPR1000 design input values (in other words, quantification of loads) are presented in sub-sections 4.3 - 4.6. The development of the external hazards schedule is discussed in sub-section 4.15. This sub-section focuses on the consequence analysis, and the identification and substantiation of protection measures.

120. External hazards have various interactions with, and effects on, a NPP. The RP has identified plant effects in the 'External Hazards Schedule Report' (Ref. 79) and mapped these to screened-in hazards in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77). This enables the SSCs impacted by a particular hazard to be identified, and provides a clear link between hazards, plant effects and impacted SSCs. Hazard-related plant effects are based on the Swedish Nuclear Inspectorate guidance for analysis of external events (Ref. 111). I judge that this represents RGP, and highlight that the same guidance was used in the UK ABWR GDA project for similar purposes. A total of nine plant effects are identified comprising:

- Pressure (loads) on SSCs.
- Missiles impacting on SSCs.
- Flooding and inundation of SSCs.
- Fire and associated damage to SSCs.
- Challenges to the plant cooling provided by ventilation systems.
- Challenges to the plant cooling provided by the ultimate heat sink.
- Challenges to the off-site power supply.
- Challenges to electrical systems caused by hazards producing electrical or magnetic fields.
- Other.

121. The RP has developed a suite of safety evaluation methodologies for the purpose of analysing the design and protection measures against external hazards. The safety evaluation methodologies have been developed based on information from a number of the RP's submissions as shown in Figure 3 (Ref. 52, Ref. 53, Ref. 54). The general protection requirements against hazards are described in sub-section 5.1 of 'The General Requirements of Protection Design against Internal and External Hazards' (Ref. 52). These requirements are to ensure that the challenges from external hazards do not impact the delivery of the fundamental safety functions of the UK HPR1000. The general requirements are aligned with the SAPs and other RGP, and include:

- Defence-in-depth should be applied in the design.

- Hazards should not result in failure of SSCs providing fundamental safety functions.
- Priority should be given to barriers protection, and the integrity of the barrier against individual and combined hazards should be substantiated.
- Habitability of the Main Control Room (MCR) should be maintained, and the availability and accessibility of the remote shutdown station ensured.
- Conservative assumptions are used in the deterministic assessment and single failure criterion is applied.
- Protection should not experience cliff-edge effects.

122. General and specific protection requirements against external hazards are presented in sub-sections 5.1 and 5.3 of ‘The General Requirements of Protection Design against Internal and External Hazards’ (Ref. 52) respectively. These are also aligned with the SAPs and other RGP. In particular:

- External hazards loadings should be determined for the UK HPR1000. I judge the RP has satisfied this requirement with the selection of UK HPR1000 design input values that are consistent with, or exceed, the expectations of SAP EHA.4.
- The potential influence of climate change on the future operation of the plant should be considered, including margins to respond to more onerous changes, and the feasibility to implement design improvements to respond to such changes. This is consistent with the expectations of SAP EHA.11 (Ref. 2) and the ‘managed adaptive approach’[‡‡] (Ref. 112).
- Many external hazards are protected against by the UK HPR1000 civil structures. As external hazards originate off-site, the RP’s analysis focuses on the effects on external boundaries and other SSCs located external to the buildings unless design shortfalls are identified that enable a hazard to penetrate into the structure or the hazards effects cannot be protected by the buildings (e.g. solar energetic particles).
- The generic design adopts the principles of segregation / separation, redundancy, and diversity of safety systems and their support systems. This is consistent with the expectations of SAP paragraph 244 (b) (Ref. 2).
- Protection against earthquake comprises seismic qualification of SSCs and analysis of non-seismically qualified equipment to ensure its failure does not impair the delivery of safety functions. I judge this approach to be consistent with the expectations of SAP EHA.9 paragraph 255 (Ref. 2).
- The report includes the requirement to consider some hazards on a generic basis in GDA, even if the hazard has been screened-out on a frequency basis or site-specific inputs are needed to characterise the hazard (e.g. accidental aircraft impact and external explosion respectively). I judge this a conservative approach that will demonstrate the adequacy of the protection strategy against these hazards.

123. The RP has undertaken a review of RGP to identify protection measures against external hazards and to inform the development of the safety evaluation methodologies (Ref. 53, Ref. 54). The purpose of the ‘Suitability Analysis of Codes and Standards in External Hazards’ report (Ref. 53) is to demonstrate the applicability, adequacy and sufficiency of identified codes and standards for use in the design of protection against external hazards. The RP has considered IAEA standards and WENRA reference levels that are recognised RGP (sub-section 2.4.3). The RP has used WENRA Issue T for natural hazards (Ref. 113), which has been superseded by the publication of Issue TU for external hazards (Ref. 36). I judge this a minor shortfall

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‡‡ *The managed adaptive approach is described in ONR’s ‘Principles for Flood and Coastal Erosion Risk Management’ paper (Ref. 112). The aim of the managed adaptive approach is to build flexibility into decisions today so that they can be ‘adjusted’ depending on what happens in the future. This includes: building in the ability to adjust an option should it be required - flexible options, and building flexibility into the decision process itself through waiting and learning - flexible plans.*

only, as the RP has considered a range of RGP relevant to both natural and man-made hazards. The RP has compared its approach against RGP in the 'Compliance Analysis of Codes and Standards in External Hazards' report (Ref. 54) to confirm the design rules from selected codes and standards have been applied and met.

124. I assessed the RP's safety evaluation methodology reports (Table 4) during Step 2. Methodologies were not available for all hazards / hazard groups. Furthermore, the methodologies were not sufficiently detailed to form a judgement on the adequacy of the analysis that would be performed. No additions or updates have been made to the safety evaluation methodology reports since Step 2 and they remain insufficiently detailed by themselves to be considered adequate. I consider this a minor shortfall, as I have assessed the analysis provided in Steps 3 and 4 via the safety evaluation reports to make a judgement on the adequacy of the RP's approach.

125. The RP's analysis of the design against external hazards is provided in the various safety evaluation reports (Table 4). The purpose of this analysis is to demonstrate that the UK HPR1000 protection measures do not fail, and fundamental safety functions are fulfilled. The analysis considers all normal operation modes, which is consistent with the expectations of SAP EHA.5 (Ref. 2). Where shortfalls have been identified in the protection, the RP has considered the consequences for items important to safety. If necessary, the design shortfalls have been subject to optioneering to identify additional protection measures or modifications that can be implemented. This optioneering has considered the RP's requirements for protection against external hazards (Ref. 52) and other RGP (section 2.4.3). The chosen options have been implemented in the design via the RP's modifications process to ensure the design can withstand hazard effects and associated risks are reduced ALARP. The modifications process was assessed by ONR Management for Safety and Quality Assurance (MSQA) during GDA and found to be fit-for-purpose (Ref. 114).

126. My Step 3 assessment identified a number of areas for improvement (Annex 3) as the RP's analysis was not supported by an adequate evidential basis to determine its completeness and to support the conclusions. During Step 4 I have clarified my expectations as to what comprises an adequate evidential basis in relation to certain hazards that I have sampled. The RP has provided more detailed analysis in some safety evaluation reports in response to my assessment. My sampling comprises the following hazards, which are described in the following sections:

- Analysis of earthquake on UK HPR1000 (sub-section 4.8).
- Analysis of external flooding on UK HPR1000 (sub-section 4.9).
- Air temperature and enthalpy on HVAC systems (sub-sections 4.10.1.4 and 4.10.1.5).
- Analysis of wind-borne missiles on UK HPR1000 (sub-section 4.10.1.3).
- Analysis of lightning and EMI on UK HPR1000 (sub-section 4.10.1.12 and 4.10.1.13).
- Analysis of space weather effects on C&I, electrical and mechanical systems (sub-section 4.11).
- Analysis of aircraft impact on UK HPR1000 (sub-section 4.12.1.3).

127. Overall, I judge the RP has provided an adequate evidential basis to support the conclusions of the safety evaluation for each hazard.

128. Substantiation of protection measures is provided by relevant engineering disciplines. Where appropriate, I have engaged with ONR engineering inspectors during GDA to ensure protection measures have been substantiated against the relevant UK HPR1000 design input values. The ONR engineering reports should be consulted for an understanding of the design's substantiation against load cases (including external hazards) and that the design can deliver the required safety functions.

129. Overall, I judge the RP's DBA approach for external hazards to be consistent with the expectations of SAP EHA.5 and EHA.6 (Ref. 2):

- The RP has applied a combination of engineering, deterministic and probabilistic methods for analysis of the design consistent with SAP paragraph 243.
- The RP has determined the effects of screened-in external hazards on the UK HPR1000 design and identified impacted SSCs (e.g. SAP paragraph 244 clause (a)).
- The UK HPR1000 design comprises three segregated and redundant safety trains that deliver the fundamental safety functions (e.g. SAP paragraph 244 clause (b)).
- Protection measures have been identified based on RGP.
- The RP has determined the safety functional requirements to be provided by protection measures (e.g. SAP paragraph 244 clause (c)).
- The UK HPR1000 design and protection measures have been deterministically analysed against screened-in external hazards and all permitted operating modes have been considered, consistent with SAP EHA.5.
- The consequences of any design shortfalls have been evaluated and, if necessary, the design subject to optioneering to identify additional measures for implementation to ensure risks are reduced ALARP.

4.7.1.2 Analysis of Hazard Combinations

130. SAP EHA.6 (Ref. 2) states: "the analysis should take into account hazard combinations, simultaneous effects, common cause failures, defence in depth and consequential effects". Further guidance is provided in NS-TAST-GD-013 (Ref. 6). I have assessed relevant safety case submissions against these expectations to ensure the RP has provided an adequate analysis for hazard combinations screened-in to GDA. I have also sampled a number of hazard combinations to ensure that combination effects are adequately addressed. NS-TAST-GD-013 (Ref. 6) states that these effects can be summarised as:

- Adding an additional, similar load to a SSC, potentially causing it to fail (e.g. seismic and wind both applying a structural load to a civil structure).
- Challenging the plant's defence-in-depth / diversity (e.g. the Fukushima Dai-ichi NPP accident whereby the plant survived the earthquake, but the LOOP and subsequent flooding of emergency power systems led to meltdown of three reactors).

131. During Step 3 I assessed hazard combinations. I raised an area for improvement (AFI-1, Annex 3) as I judged the RP had not provided an adequate analysis and that some credible combinations had been omitted. The RP has provided a more detailed methodology for the identification, screening and analysis of hazard combinations during Step 4 (Ref. 77). Application of this methodology for identification and screening of hazard combinations is discussed in sub-section 4.4. This section focuses on the analysis approach adopted by the RP for hazard combinations. My assessment of specific hazard combinations is provided in sub-section 4.14.

132. The 'External Hazards Combination Safety Evaluation Report' (Ref. 77) categorises hazard combinations on a basis consistent with NS-TAST-GD-013 (Ref. 6). The categorisation informs the RP's evaluation approach. Hazard combination categories comprise:

- Correlated
- Consequential
- Independent (coincident)

133. For independent hazard combinations (coincidental relationship) the RP has not considered the UK HPR1000 design input values for both hazards, as this would produce a combination with a very low frequency of occurrence (in other words, below the 1 x 10^{-7} annual probability of exceedance screening criterion). The RP has considered the bounding hazard using the UK HPR1000 design input value, and the secondary hazard at the upper or lower bound of the range of routinely experienced operational level, depending on whether it is a maxima or minima hazard respectively. This is usually taken as a 1 x 10^{-2} / yr. event. I judge this approach consistent with the guidance provided in NS-TAST-GD-013, paragraph 157 (Ref. 6).

134. For correlated hazards, the RP considers each hazard at the UK HPR1000 design input level. In these situations, the RP has considered whether the combined loading is bounded by the UK HPR1000 design input value for each individual hazard that the plant is engineered to withstand. In my opinion the RP is applying clause a) within sub-section 5.2.2.1 of IAEA Safety Reports Series No. 92 (Ref. 115), which states: "A correlated hazard can be screened out if (a) the plant has a design basis [in other words, UK HPR1000 design input value] for both hazards." I consider this reasonable screening criteria. However, the plant effects associated with each hazard should be considered prior to screening-out from analysis to ensure the effects of one hazard do not undermine the claims made in relation to the other hazard in the combination (in other words, one hazard attacks the plant's defence-in-depth leaving it more vulnerable to the second hazard). NS-TAST-GD-013 paragraph 150 (Ref. 6) provides some examples of combination effects that should be considered including:

- One or more hazards may exacerbate other hazards.
- One or more hazards that affect the plant during the same timeframe due to persistence or similar causative factors.
- One or more sequential hazards that affect the plant.

135. For consequential hazards, the RP has considered the primary hazard at the UK HPR1000 design input value level and provided a consequence analysis for the secondary hazard. I judge this approach acceptable for GDA.

136. I have sampled the hazard combinations screened-in to GDA and the RP has considered combination effects in accordance with ONR guidance, albeit this is not explicitly stated in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77). This includes:

- Consideration of the effects of one hazard to make plant more vulnerable to the second hazard (e.g. potential for wind to damage the lightning protection system and make the plant more vulnerable to a lightning strike even though UK HPR1000 design input values are defined for both hazards).
- Consideration of the whole fault sequence (e.g. earthquake initiating a consequential internal hazard, which in turn initiates other hazards).
- Consideration of all normally permitted operating states.
- Evaluation of hazards in combination with design basis conditions including LOOP and LUHS.

137. The RP's process for determining if detailed analysis of the combination is needed is presented in Figure 7. Detailed analysis is undertaken if the effect of the combined hazards is not enveloped by effect of individual hazards and has not been considered in the design.

138. Analysis of hazard combinations is provided in the individual safety evaluation reports (Table 4). Additional combinations screened-in to GDA following Step 3 and to address AFI-1 (Annex 3) are evaluated in section 5 of the 'External Hazards Combination Safety Evaluation Report' (Ref. 77) in Tables:

- T-5.4-1 for correlated external hazards.
- T-5.4-2 for coincidental external hazards.
- T.5-4-3 for consequential internal hazard resulting from external hazard initiators.

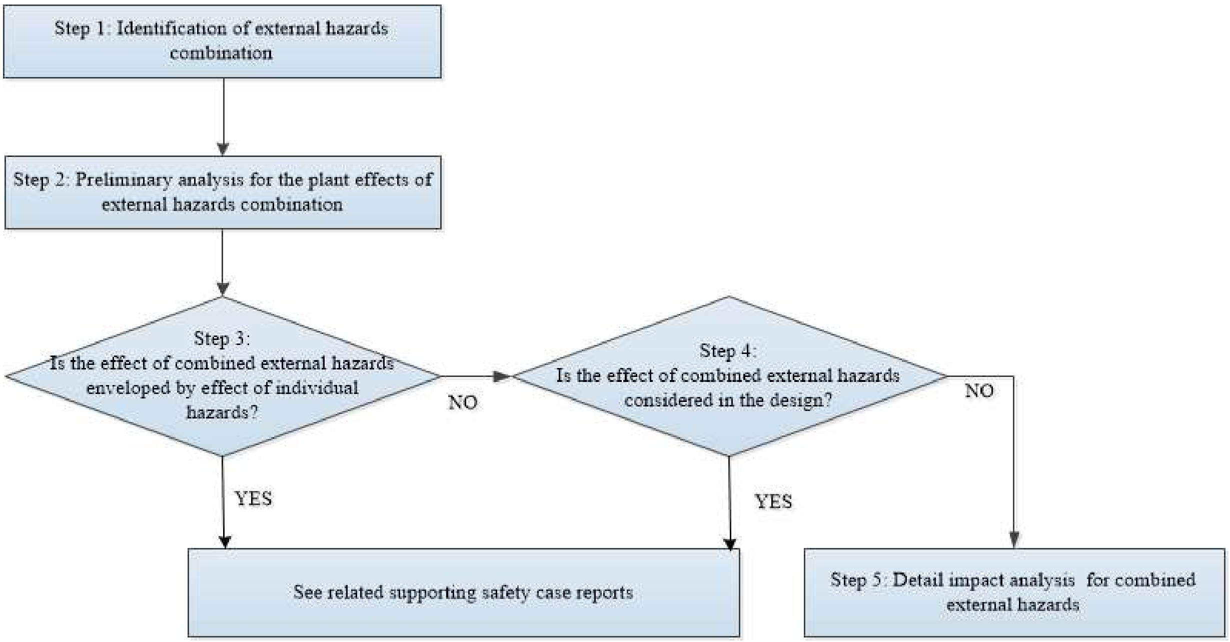

Figure 7: Evaluation methodology for hazard combinations. *(Ref. 77)*

139. To determine the adequacy of the RP's analysis for hazard combinations I have sampled the following combinations:

- Earthquake and snow – combination applies similar loadings (sub-section 4.14).
- High wind and lightning – combination challenges the plant's defence-in-depth (sub-section 4.14).
- Earthquake and internal fire – combination challenges the plant's defence-in-depth (sub-section 4.8.1.2).
- Earthquake and dropped loads – combination challenges the plant's defence-in-depth (sub-section 4.8.1.2).

140. I have engaged with the ONR Internal Hazards Inspector during Step 4 in relation to the aforementioned external to internal hazard combinations that were also identified as a potential regulatory shortfall in RO-UKHPR1000-0055 (Ref. 16). This RO was closed by the ONR Internal Hazards Inspector during Step 4, as the RP addressed ONR's concerns and provided an adequate analysis of these hazard combinations. The ONR Internal Hazards Inspector has identified that further work is needed on external to internal hazard combinations by a licensee during site-specific phases. The Step 4 internal hazards assessment report should be consulted for further details (Ref. 93). The ONR External Hazards Inspector will need to interface with the ONR Internal Hazards Inspector during detailed design of the UK HPR1000 for a target site to ensure this work adequately analyses all relevant hazard combinations that are initiated by an external hazard.

141. Hazard combination loadings are often protected against by the civil structures and divisional barriers. The RP has considered the following combination types in the GDA civil structure design:

- External–external combination load cases.
- Internal–internal combination load cases.

- One external–internal combination load case of earthquake and high-energy pipe failure.

142. The RP claims that the civil design is substantiated against bounding hazard combination load cases. The RP considers earthquake and high-energy pipe failure to be the bounding load case for external–internal combinations. This claim has been assessed in Section 4.2.2. of the ONR civil engineering assessment report (Ref. 98). The ONR Civil Engineering Inspector has identified further work is required as part of the site-specific design, and this is captured in AF-UKHPR1000-0215. I support this finding.

143. Overall, I judge the RP's approach to analysing hazard combinations to be aligned with SAP EHA.6 and ONR's guidance in NS-TAST-GD-013. The RP has provided a more detailed methodology for identification, screening, and evaluation of hazard combinations during Step 4 (Ref. 77). I am satisfied that AFI-1 raised during Step 3 has been addressed by the RP. There are some detailed matters that have been identified in relation to the hazard combinations and loads cases considered in the design, and an Assessment Finding has been raised for this by the ONR Civil Engineering Inspector. I judge that this matter can be resolved post-GDA and do not undermine the hazard combinations safety case for the generic UK HPR1000 design.

4.7.1.3 Beyond Design Basis Analysis

144. I have assessed the RP's analysis of cliff-edge effects and beyond design basis events against the guidance provided in SAPs EHA.7 and EHA.18 respectively, and ONR NS-TAST-GD-013 (Ref. 6). During Step 3 I raised an area for improvement in relation to the RP's BDBA, as I considered it to be simplistic and lacking a defined methodology (AFI-12, Annex 3). I raised RQ-UKHPR1000-0619 (Ref. 84) for the RP to provide clarity on their approach and to provide my expectations. In response to this RQ (Ref. 116) the RP has developed a beyond design basis methodology in Step 4 (Ref. 61). Three different analysis approaches are recognised for GDA:

- Category 1: Consider the adequacy of margin in the UK HPR1000 design input value compared with the GSE value (e.g. tornado).
- Category 2: Compare the UK HPR1000 design input value with the 1×10^{-5} / yr. mean hazard value, where hazard curves are available and extend to this return period (e.g. extreme air temperatures).
- Category 3: Consequence analysis for a nominal beyond design basis event(s), where the hazard has not been characterised by a hazard curve in GDA (e.g. seismic and flooding).

145. In my view the RP's approaches for cliff-edge effects and BDBA are reasonable and suitable for the purposes of GDA. I note the following with respect to each approach:

- Where the UK HPR1000 design input value is adequately larger than the GSE value (in other words, the frequency of occurrence is lower than that expected by SAP EHA.4), then this provides confidence that the design will be robust against hazard occurrences in the UK and that there will be an absence of cliff-edge effects. This occurs where the FCG3 reference design value bounds the GSE value, and is selected as the UK HPR1000 design input value.
- NS-TAST-GD-013 (Ref. 6) provides the following guidance for non-discrete hazards with respect to BDBA: "if a single BDB [beyond design basis] event is selected for the BDBA, a reasonable starting position is to consider the 1×10^{-5} / yr. event". The RP's approach aligns with NS-TAST-GD-013 (Ref. 6), which I consider to be RGP, and I judge to be reasonable for the purposes of GDA.
- Consequence analysis has been used in previous GDAs for hazards such as flooding and seismic (Ref. 117). Consequently, I judge this a reasonable approach for the purposes of GDA.

146. The RP has categorised each screened-in hazard against the above three approaches. The relevant analysis approach has then been applied, and the analysis is provided in relevant safety evaluation reports (Table 4). A cliff-edge analysis report has also been developed for civil engineering structures (Ref. 118). This report analyses the civil structures against beyond design basis events for relevant hazards to demonstrate the absence of cliff-edge effects. I judge that this report addresses the expectations of SAP EHA.7 (Ref. 2).

147. The RP's BDBA has not identified the hazard level at which safety functions are lost for beyond design basis events. I consider this to be a minor shortfall against the expectations of SAP EHA.18. This is because the margins to failure are best determined post-GDA, when site data is available to characterise the site-specific hazards ('site challenge') and compare this with the UK HPR1000 design input value to calculate the available margin and actual risk. I judge that this work will be undertaken as normal business during site-specific phases, and as the design detail increases.

148. I have, on a sampling basis, assessed the application of the RP's BDBA methodology for individual hazards including:

- Seismic – sub-section 4.8.1.2
- Flooding – sub-section 4.9.1.2
- Tornado – sub-section 4.10.1.1
- Snow – sub-section 4.10.1.10

149. Overall, I judge the RP's approach for cliff-edge effects to be consistent with the expectations of SAP EHA.7. I have identified a minor shortfall against SAP EHA.18 as the RP has not identified the hazard level at which safety functions could be lost for beyond design basis events. In my opinion this is best addressed post-GDA, when actual margins can be determined by comparison of the site-specific hazard values with the UK HPR1000 design input values.

4.7.2 Strengths

150. I have assessed the RP's approaches to DBA for both independently occurring hazards and hazard combinations, and BDBA. I have also liaised with the ONR PSA and SAA Inspectors to understand the RP's approaches for external hazards. I note the following strengths:

- The RP has used a combination of engineering, deterministic and probabilistic methods for analysis of the UK HPR1000 design against external hazards consistent with SAP paragraph 243.
- The RP has analysed the design against all independently occurring hazards screened-in to GDA.
- Plant effects associated with each hazard have been identified based on RGP.
- Protection measures against the hazard effects have been identified based on RGP.
- DBA has been undertaken to demonstrate that the design can achieve and maintain safe shutdown of the reactor, and there is no impact on the delivery of fundamental safety functions.
- The RP has considered all normally permitted operating states in the analysis of external hazards, which I judge consistent with SAP EHA.5.
- The RP has analysed the effects of hazard combinations on the UK HPR1000, which I judge consistent with the expectations of SAP EHA.6.
- The RP's approach for independently occurring hazards is consistent with ONR's guidance in NS-TAST-GD-013.
- The RP's approach for correlated hazards is to consider both hazards at the UK HPR1000 design input value level. I judge this a conservative approach.

- The RP's approach for consequential hazards is to provide a consequence analysis for the secondary hazard.
- The RP's analysis of hazard combinations has considered combination effects identified in NS-TAST-GD-013 paragraph 150.
- The RP has identified and analysed additional hazard combinations that were omitted from Step 3 of the UK HPR1000 GDA. On this basis I am content that AFI-1 has been addressed.
- The RP's BDBA approach is consistent with the expectations of SAP EHA.7.
- The RP's analysis approaches provide an adequate starting point for use by a licensee.

4.7.3 Outcomes

151. My assessment of the RP's analysis of external hazards has not identified any Assessment Findings. I note that the ONR Internal Hazards and Civil Engineering Inspectors have raised Assessment Findings relevant to hazard combinations and the substantiation of SSCs protecting against hazard combination effects. My assessment has identified several minor shortfalls as discussed in sub-section 4.7.1 above.

152. A licensee will need to revisit the analysis that has been provided to demonstrate that it remains fit-for-purpose for a target site (e.g. the UK HPR1000 design input values are bounding of the site-specific hazard values), and to also analyse those hazards and combinations that were screened-out of GDA. This work is judged to be normal business during site-specific stages.

4.7.4 Conclusion

153. I have assessed the RP's general approach for evaluating external hazards. I conclude that:

- The RP's approach uses a combination of engineering, deterministic and probabilistic methods for analysis including DBA and BDBA.
- I judge the RP's approaches for DBA and BDBA are aligned with RGP including the expectations of the SAPs.
- The various analysis demonstrates the design is robust against external hazards, safety functional requirements can be delivered and there are no cliff-edge effects.
- I have identified several minor shortfalls. I am satisfied that these do not challenge the fundamental approach adopted by the RP or the findings of my assessment.

4.8 Seismic Hazards

4.8.1 Assessment

154. I have assessed the RP's safety case for seismic hazards in relation to ONR's expectations, which include:

- SAP EHA.9 (Ref. 2)
- NS-TAST-GD-013 (Ref. 6) and the associated Annex 1 (Ref. 119)

155. In the seismic hazards group the RP has considered earthquake as well as parameters that are inputs to the earthquake analysis comprising:

- Response spectra
- Spectral acceleration
- Shear wave velocity (Ref. 51)

156. Other seismic hazards, such as capable faulting and liquefaction, are screened-out for consideration post-GDA (Ref. 50). I judge it appropriate to screen seismic hazards such as capable faulting and liquefaction out of consideration from GDA as it would be unreasonable to develop a generic UK HPR1000 design capable of withstanding these hazards. Furthermore, capable faulting is an exclusionary criterion for siting. I conclude that such hazards are appropriately addressed during site justification by a licensee.

157. The following sub-sections focus on the RP's DBA and BDBA analysis for earthquake including derivation of the earthquake hazard response spectra, spectral acceleration and shear wave velocity.

4.8.1.1 Earthquake

Table 9: Earthquake hazard parameters for the GSE and UK HPR1000 design input

Hazard		GSE values	UK HPR1000 Design Input values
Earthquake	Peak ground acceleration – horizontal	0.3g	0.3g
	Peak ground acceleration – vertical	0.2g	0.2g
	Response spectra	EUR soft and medium	EUR soft and medium
	Shear wave velocity	150 m/s – 300 m/s	150 m/s – 1,100 m/s

158. The RP presented the FCG3 reference design values for earthquake in the Preliminary Safety Report (PSR) (Ref. 120). ONR assessed this submission during Step 2 and was concerned that the shear wave velocities used in the FCG3 reference design were not bounding of the three candidate sites that inform the GSE. ONR found the RP had provided insufficient information to form a judgement on the UK HPR1000's suitability for deployment in the UK. The RP committed to addressing this gap in the resolution plan to RO-UKHPR1000-0002 (Ref. 121).

159. The RP has defined shear wave velocities in response to RO-UKHPR1000-0002 (sub-section 4.18.1.1) for use in the UK HPR1000 design, along with corresponding soil and bedrock profiles, and geotechnical parameters as part of RO-UKHPR1000-0009 (sub-section 4.18.1.3).

160. The shear wave velocity for the GSE is based on data for the Heathrow Terminal 5 that the RP considers bounding of the Bradwell site. Both Heathrow Terminal 5 and Bradwell are underlain by London Clay.

- GSE shear wave velocity: 150 m/s to 300 m/s

161. I have compared the RP's GSE definition with information held by ONR for the candidate sites. Available site-specific test data for the Bradwell site corresponds to a velocity range consistent with the proposed GSE (Ref. 122). The RP's GSE values are not bounding of the three sites that inform the GSE. Hinkley Point is underlain by sedimentary rocks with shear wave velocities up to approximately 1,100 m/s. I judge this to be a minor shortfall as the values for the GSE are not bounding of the candidate sites, and this is inconsistent with the RP's stated approach for defining the GSE (compare with sub-section 4.5). This is a minor shortfall because the RP has selected shear wave velocities for the UK HPR1000 design input values that are bounding of the three candidate sites. Consequently, there is no material impact on the overall

analysis provided for the earthquake hazard. The RP's approach, however, leads to ambiguity in the safety case, which I judge to be a shortfall against SAP SC.4.

162. The shear wave velocities selected for the UK HPR1000 design input values comprise:

- Very Soft: 150 m/s
- Soft: 500 m/s
- Medium: 1100 m/s
- Total range: 150 m/s to 1,100 m/s

163. The shear wave velocities for the UK HPR1000 design input are based on the EUR (Ref. 42). The EUR definition for a soft site is 250-500 m/s and 600-1,100 m/s for a medium site. I note the following points:

- The RP has expanded the lower bound shear wave velocity using data for Heathrow Terminal 5 (150 m/s – 350 m/s).
- At 1,100 m/s, the adopted medium velocity is greater than the BS EN 1998 stiffest site class (Ref. 123), but is below the EUR definition of 1200-2500 m/s for a hard site (Ref. 42). A hard site as defined in EUR is not considered by the RP.

164. The RP has not defined a hard rock site as part of the GSE or UK HPR1000 design input. It is noteworthy that the FCG3 reference design is built on a rock site with shear wave velocity >1,100 m/s. This provides confidence that the UK HPR1000 design could also be deployed on such a site following appropriate substantiation of SSCs, and where needed, modification (sub-section 4.5.1). Overall, I am satisfied that the stated range of shear wave velocity is adequate for the purposes of GDA.

165. The RP has selected the corresponding EUR response spectra for soft and medium sites. The proposed response spectra differ from the reference design, which uses US Regulatory Guide 1.60 design spectra (Ref. 124). The RP justified this approach in response to RQ-UKHPR1000-0462 (Ref. 125) and in subsequent submissions. I am content with the RP's approach for the purposes of GDA, and consider the EUR code to be RGP, noting its use by other GDA and new nuclear build projects in the UK.

166. The GSE values for earthquake ground motion are defined as follows:

- Horizontal spectral acceleration: 0.3g.
- Vertical spectral acceleration: 0.2g (assumed vertical to horizontal ratio of 2/3).

167. I have compared the RP's proposed GSE value for spectral acceleration with available information including previous seismic hazard studies for the UK (Ref. 126), EU Stress Test results (Ref. 127, Ref. 128) and previous GDAs (Ref. 129). Bradwell has the highest peak ground acceleration (PGA) of all UK sites at 0.261g (Ref. 130). I judge a PGA of 0.3g to be adequately bounding for UK sites and a 1×10^{-4} annual probability of exceedance. The use of a bounding PGA provides confidence that the design will be robust against the site-specific earthquake hazard for a target site, and there will be an absence of cliff-edge effects immediately beyond design basis as required by EHA.7. The RP's response to RQ-UKHPR1000-0336 (Ref. 131) justifies the use of a vertical to horizontal ratio of 2/3 for GDA and cites RGP including IAEA SSG-9 and the EUR code. I judge the proposed spectral acceleration to be adequately conservative for the three candidate sites and appropriate for GDA. I expect a licensee to evaluate the vertical to horizontal ground motions in the future as part of a probabilistic seismic hazard analysis (PSHA) for a target site. This is normal business for site-specific stages.

168. The PCSR (Ref. 3) compares the GSE values with the FCG3 reference design values. The GSE values for earthquake are selected as the UK HPR1000 design input values.

The UK HPR1000 design input values for earthquake and associated parameters are defined as follows:

- Spectral acceleration: 0.3g horizontal and 0.2g vertical (assumed vertical to horizontal ratio of 2/3).
- Response spectra: Soft and medium EUR spectra.
- Shear wave velocity: 150 m/s – 1,100 m/s.

169. I am content with the RP's approach given it is based on European good practice that has been applied for other GDA and new build projects in the UK. I consider the definition of the earthquake hazard to be adequately conservative and meets the expectations of SAP EHA.4.

170. SAP EHA.9 and paragraph 253 expect the seismic evaluation to "enable buildings, structures and plant in the facility to be designed to withstand safely the ground motions involved". The RP's approach for GDA is to identify those SSCs requiring seismic qualification as described in 'The General Requirements of Protection Design against Internal and External Hazards' (Ref. 52). The RP has developed and applied a methodology to determine the SSCs that need to withstand seismic motions (Ref. 132). Those SSCs meeting relevant criteria require seismic qualification, and this requirement is recorded in the relevant schedules (sub-section 4.15). All SSCs in GDA scope have been classified using this process:

- SSE-1 – all class 1 and 2 safety systems are classified as SSE-1. Class 3 systems are not generally SSE-1 unless they meet relevant criteria defined in the 'Methodology of Safety Categorisation and Classification' (Ref. 132). All SSE-1 SSCs are designed to withstand the UK HPR1000 design input values for earthquake.
- SSE-2 – SSCs are given this classification if their failure during an earthquake event can cause an internal hazard and / or impact those SSE-1 systems delivering safety functions. SSE-2 SSCs are designed to withstand the UK HPR1000 design input values for earthquake.
- Non-classified – a SSC that does not deliver fundamental safety functions, and whose failure does not impact on safety systems delivering fundamental safety functions.

171. During GDA only the seismically classified civil structures have been substantiated against the UK HPR1000 design input values for earthquake. The Step 4 civil engineering assessment report should be read for further details (Ref. 98). Other SSCs that need to withstand the earthquake hazard will be substantiated post-GDA, including mechanical, electrical and C&I systems. This approach is consistent with previous GDAs, and proportionate given the level of detail available at GDA. A licensee will need to substantiate all relevant SSCs against the UK HPR1000 design input values for earthquake at the detailed design stage. This is normal business.

172. The RP has analysed non-seismically qualified SSCs to ensure their failure during an earthquake does not impact on the delivery of fundamental safety functions. I have collaborated with the ONR Internal Hazards Inspector to assess the adequacy of the RP's approach. This joint assessment is described in the following sub-section 4.8.1.2.

173. Overall, I judge the RP's definition of the UK HPR1000 design input values for earthquake to be consistent with ONR's expectations in SAPs EHA.3 and EHA.4 and other RGP. The selected UK HPR1000 design input values are appropriate for use as the parameters are aligned with the three candidate sites that inform the GSE. The RP's approach to identifying those SSCs requiring seismic qualification is consistent with the expectations of SAP EHA.9. The substantiation of the civil structures against the UK HPR1000 design input values for earthquake is proportionate given the level of

design detail available at GDA. A licensee will need to substantiate other SSCs during detailed design.

4.8.1.2 Consequential Internal Hazards resulting from Earthquake

174. SAP EHA.9 paragraph 255 expects: "The effects of failure of non-nuclear safety related structures, systems and components (SSCs) should be taken into account if this could affect access for the control and/or repair of plant." I have assessed relevant submissions with the ONR Internal Hazards Inspector against these expectations to ensure the UKHPR1000 generic safety case provides an adequate demonstration that the design is robust against consequential hazards resulting from earthquake.

175. During Step 3 the RP submitted a series of Earthquake Safety Evaluation Reports (Table 4) that consider consequential internal hazards on a building-by-building basis (Ref. 62, Ref. 63, Ref. 64, Ref. 65, Ref. 66, Ref. 67, Ref. 68). The analysis is based on the RP's earthquake safety evaluation methodology (Ref. 55). The reports analyse failure of non-seismically qualified SSCs to determine the potential impact on SSE-1 and SSE-2 classified SSCs and ensure that there is no impact on the delivery of fundamental safety functions required to achieve and maintain a safe shutdown of the reactor. The reports assume seismically classified SSCs can withstand the ground motions defined by the UK HPR1000 design input values for earthquake, and their failure is not considered. I judge this is reasonable for GDA (sub-section 4.8.1.1), but note that a licensee will need to substantiate this during detailed design, post-GDA.

176. I assessed the earthquake safety evaluation reports during Step 3. I raised RQ-UKHPR1000-0619 (Ref. 84) in relation to AFI-7 (Annex 3), as I did not consider the safety evaluation reports provided an adequate evidential basis to support the conclusions of the reports. I discussed my findings with the ONR Internal Hazards Inspector during GDA Step 4. We raised additional RQs (Ref. 133, Ref. 134) for the RP to clarify their approach, and attended joint meetings with the RP to discuss our expectations (Ref. 135). The ONR Internal Hazards Inspector raised RO-UKHPR1000-0055 (Ref. 16) as they were of the opinion the RP had not provided an adequate safety evaluation of consequential internal hazards initiated by earthquake given the nuclear safety significance of the gaps identified, including:

- The RP had not analysed all credible combinations, and had not provided an adequate justification for those consequential hazards that had been screened-out. This included internal fire that was identified as a credible combination in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77), but screened-out of the earthquake safety evaluation reports on a frequency basis. This meant that the RP's approach was inconsistent with their own methodology for evaluation of consequential hazards.
- The scope of the RP's analysis did not meet ONR's expectations for GDA, and the dropped load safety evaluation did not consider some large SSCs that could potentially challenge nuclear safety including monorail maintenance cranes, walkways and gantries.
- Time-at-risk was the only claim presented for some credible hazard sources (in other words, non-seismically classified SSCs). This approach is inconsistent with the expectations of SAP NT.2 and paragraph 759 ff. (Ref. 2), and also NS-TAST-GD-013 paragraph 162 (Ref. 6).
- The RP had not provided an adequate evidential basis to support the findings of the evaluation reports (e.g. only screenshots from the 3D model were provided without any explanation or illustration of their context relevant to the analysis), and the evidence was not related to the design reference information.

177. I have supported the ONR Internal Hazards Inspector with assessment of submissions made in response to RO-UKHPR1000-0055 (sub-section 4.18.1.5). The RO was subsequently closed during Step 4 by the ONR Internal Hazards Inspector based on

assessment of submissions made in response to this RO. From an external hazards perspective the RP has:

- Analysed consequential fire initiated by earthquake and seismically qualified some additional SSCs that were credible fire sources and could challenge the habitability of the MCR and Remote Shutdown System (RSS).
- Analysed swing loads in the BFX and BSB / BSC, the findings of which show that the main targets impacted by the crane swing loads are pipes related to the lifted items with no impact on delivery of fundamental safety functions.
- Considered periods of elevated risk, such as undertaking certain maintenance activities as per the expectations of SAP NT.2.
- Confirmed the seismic qualification of some large components that ONR expects the RP to consider during GDA, including monorail maintenance cranes, walkways and gantries.

178. Overall, I judge the RP's analysis of external to internal consequential hazards initiated by earthquake to be acceptable for GDA. The RP has provided additional analysis specifically for internal fire and dropped loads in response to RO-UKHPR1000-0055, which I consider addresses my concerns raised during GDA Step 3 and on this basis AFI-7 is closed. The ONR Internal Hazards Inspector expects a further in-depth assessment to be undertaken during site licencing to ensure all potential external to internal hazard combinations are fully analysed and controlled to reduce risks in line with the ALARP principle. This is considered normal business. I agree with this approach and consider it proportionate given the design detail at GDA.

4.8.1.3 Beyond Design Basis Earthquake

179. My Step 3 assessment identified shortfalls in the RP's general approach to BDBA (AFI-12, Annex 3). The RP has developed a methodology for BDBA (Ref. 61). This methodology identifies earthquake as a Category 3 hazard, which means the RP has analysed the design against an event more severe than the UK HPR1000 design input value to demonstrate the absence of cliff-edge effects. The RP has analysed seismically classified structures against the UK HPR1000 design input value for earthquake multiplied by a factor of 1.5 (in other words 150%). The RP has adopted the EPRI Conservative Deterministic Failure Margin (CDFM) approach to confirm the margin of the civil structures (Ref. 136). I note the same approach was applied for the UK ABWR GDA. I consider the proposed approach reasonable for the purposes of GDA in the absence of site-specific data to define the hazard at lower frequencies.

180. The results of the BDBA for BFX, inner containment and BEX are presented in the civil engineering report 'Cliff-edge Effect of Extreme Environmental Hazard for Civil Engineering Structure' (Ref. 118). The RP considers earthquake to be the bounding natural hazard for beyond design basis strength design and lateral stability, and evidence is provided to support this, including comparison with projected 1 x 10^{-5} / yr. loads for snow and wind. The analysis shows there are no cliff-edge effects for the sampled structures, including BEX, which is SSC-2 classified. The ONR Civil Engineering Inspector has confirmed the adequacy of the RP's approach (Ref. 98). I agree with this position and that the RP has provided a proportionate analysis for the purposes of GDA, which meets the expectations of SAP EHA.7. On this basis I consider the RP has addressed my concerns in AFI-11 and AFI-12 (Annex 3).

181. The RP's BDBA for earthquake has not identified the margins to failure as expected by SAP EHA.18. I judge this a minor shortfall. This work is best undertaken for a target site when the site-specific earthquake hazard ('site challenge') has been defined and can be compared with the UK HPR1000 design input to demonstrate the actual margins to failure. I am content for this work to be undertaken as normal business during the detailed design of civil structures.

182. In response to post-Fukushima Dai-ichi NPP accident lessons learnt, the RP has included a range of defence-in-depth measures in the design of the UK HPR1000, including mobile diesel generators (Ref. 137). The ONR SAA Inspector and I raised RQs in relation to these measures and for the RP to explain their proposed approach for storage and connection of these measures when needed (Ref. 138, Ref. 139). The responses (Ref. 140, Ref. 141) indicate that mobile equipment is planned to be stored in an independent mobile equipment storage building. The RP has identified requirements for the independent mobile equipment storage building as being SSE-2 seismically qualified and elevated above the level of the diesel generator buildings (BD_X) (see sub-section 4.9.1.2 for further discussion in relation to flooding). I consider this appropriate as failure of the independent mobile equipment storage building should not impact on the availability of the mobile equipment that may be required to deliver safety functions post-event.

183. The RP has argued that the mobile diesel generators will be qualified against a reduced 1×10^{-2} / yr. event, rather than the UK HPR1000 design input values for earthquake. I have discussed this with the ONR Electrical Engineering Inspector (Ref. 142). We consider this a reasonable qualitative argument recognising:

- The conservative design of the primary and diverse lines of protection against the design basis earthquake.
- Difficulty obtaining mobile equipment qualified to a 1×10^{-4} requirement.
- The resilience included through the vehicle mounting.
- The equipment not being required to operate during any initial event.

184. Overall, I consider the RP has provided a suitable and sufficient analysis of the UK HPR1000's beyond design basis resilience to earthquake. The conservative derivation of the GSE value for earthquake, and its selection as the UK HPR1000 design input value provides confidence that there will be inherent margin against the site-specific earthquake hazard, and an absence of cliff-edge effects immediately beyond design basis as required by EHA.7. This is because the PGA of 0.3g bounds all sites included in EN-6 for new nuclear build. The RP's BDBA has confirmed there is an absence of cliff-edge effects compared with the UK HPR1000 design input values used for GDA. The design also implements lessons learned from the Fukushima Dai-ichi NPP accident, including the provision of mobile diesel generators.

4.8.2 Strengths

185. My assessment of the RP's safety case for seismic hazards has identified the following strengths:

- The RP has defined a GSE value for earthquake that adequately bounds the candidate sites for the GSE and meets the expectations of SAPs EHA.3 and EHA.4.
- The RP has used RGP in defining the earthquake PGA and inputs including the EUR code.
- The RP's selection of the GSE value as the UK HPR1000 design input value for the earthquake hazard is adequately justified.
- The conservatively defined UK HPR1000 design input value for the earthquake hazard provides confidence that there is an absence of cliff-edge effects for a target site.
- The RP has developed and applied a methodology for seismic classification of SSCs.
- The RP has substantiated the civil structures against the UK HPR1000 design input value for earthquake.
- The RP has identified credible internal hazard combinations with earthquake.

- The RP has provided additional analysis of consequential internal hazards initiated by earthquake in response to RO-UKHPR1000-0055, which has addressed AFI-7 from the ONR Step 3 external hazards assessment.
- The RP has developed a methodology for BDBA in GDA that is aligned with ONR's guidance in NS-TAST-GD-013, and which addresses AFI-12 from the ONR Step 3 external hazards assessment.
- The RP has applied the BDBA approach for a sample of civil structures and demonstrated an absence of cliff-edge effects.

4.8.3 Outcomes

186. My assessment of the RP's safety case for seismic hazards has identified several minor shortfalls as discussed in sub-section 4.8.1. I am satisfied that these minor shortfalls do not undermine any of the RP's claims made in relation to the earthquake hazard at GDA. Concerns relevant to the earthquake hazard in previous GDA steps have been addressed by the RP including the closure of RO-UKHPR1000-0002 (sub-section 4.18.1.1).

187. I expect a licensee to characterise all relevant seismic hazards for a target site during site-specific stages, and to provide an adequate safety justification for the site-specific design that is commensurate with the level of design detail at that time. This should include undertaking of a PSHA and capable faulting study that is consistent with ONR's expectations in NS-TAST-GD-013 Annex 1 (Ref. 119). The licensee will need to substantiate all seismically qualified SSCs against the earthquake hazard and demonstrate the design beyond design basis margins to failure as per the expectations of SAP EHA.18. I am content for this work to be undertaken as normal business.

188. I have collaborated with the ONR Internal Hazards Inspector to assess submissions made in response to RO-UKHPR1000-0055 for consequential internal hazards initiated by earthquake. The ONR Internal Hazards Inspector has closed this RO during Step 4 based on these submissions and the findings are discussed in the Step 4 internal hazards assessment report (Ref. 93). The ONR External Hazards Inspector should continue to liaise with the ONR Internal Hazards Inspector post-GDA to ensure the risks associated with earthquake and consequential hazards are reduced ALARP, as part of normal business.

4.8.4 Conclusions

189. I have assessed the RP's safety evaluation for seismic hazards. I conclude that:

- The screening-in of the earthquake hazard for GDA is appropriate. Other seismic hazards are screened-out with appropriate justification.
- The definition of the earthquake hazard uses best available data and RGP. Sufficient evidence has been provided to demonstrate that the GSE value for PGA bounds the three candidate sites. I judge the GSE values to meet the expectations of SAPs EHA.2, EHA.3 and EHA.4.
- The UK HPR1000 design input values used for shear wave velocity are bounding of the three candidate sites.
- The GSE values are selected as the UK HPR1000 design input values. I judge this acceptable for GDA given the conservative definition of the GSE values and use of RGP.
- The RP's DBA has:
    - Identified those SSCs that need to be seismically qualified and classified them accordingly.
    - Substantiated the civil structure design against the UK HPR1000 design input values for earthquake.

  - Other SSCs (e.g. mechanical systems) will be substantiated during detailed design and I judge this acceptable.
  - Provided sufficient evidence to demonstrate that the failure of non-seismically classified SSCs does not impact on the delivery of fundamental safety functions.

- The RP's BDBA has:

  - Demonstrated an absence of cliff-edge effects for the civil structures by analysing their withstand against 150% the UK HPR1000 design input PGA.
  - Implemented lessons learnt from the Fukushima Dai-ichi NPP accident, including additional cooling and electrical supply systems.

- The RP has not met the expectations of SAP EHA.18. I judge that this work is best addressed during site-specific stages when the site-specific earthquake hazard is known and can be compared with the UK HPR1000 design input values.
- The RP's evaluation has demonstrated that the design is robust against the earthquake hazard effects. Further work is needed post-GDA to ensure the risks are reduced ALARP including:

  - Evaluating other seismic hazards screened-out of GDA.
  - Substantiation of SSCs not evaluated in GDA.
  - Detailed of evaluation of other consequential internal hazards initiated by earthquake.

4.9 Flooding

4.9.1 Assessment

190. ONR expectations for flooding include:

- SAP EHA.12 (Ref. 2).
- Technical guidance in NS-TAST-GD-013 (Ref. 6) and Annex 3 (Ref. 143).
- Relevant parts of ONR-GDA-GD-007 (Ref. 10) including sub-section 3.7 relating to External Hazards.

191. I have considered the RP's flooding safety case for both DBA and BDBA against these expectations.

4.9.1.1 Design Basis Flooding

Table 10: Rainfall hazard values for the GSE and UK HPR1000 design input used in the pluvial flooding safety case

Hazard		GSE value	UK HPR1000 Design Input value
Pluvial flooding	1 hour – Present day	163 mm	216 mm
	1 hour – 2100 epoch	216 mm	216 mm
	24 hours – Present day	228 mm	302 mm
	24 hours – 2100 epoch	302 mm	302 mm

192. The RP has identified a range of possible flooding sources (Ref. 51). Most flooding sources are screened-out for evaluation in GDA as site-specific information is needed to characterise the flooding sources in a meaningful manner. Rainfall, and associated pluvial flooding, is screened-in for consideration in GDA. I judge this reasonable for DBA of flooding and the RP's justification to be adequate that site-specific data are needed to characterise other flooding sources (e.g. coastal flooding).

193. The RP has defined the maximum rainfall for the GSE by comparison of available rainfall data for the three candidate sites (Ref. 144, Ref. 145, Ref. 146), the EUR code and previous GDA projects (Ref. 129). These studies show significant spatial variation in rainfall across the UK, particularly between the west and east coasts. The RP has conservatively taken the bounding rainfall values for Hinkley Point, which are higher than those for both Bradwell and Sizewell based on the literature the RP has reviewed. Previous GDA projects have also found rainfall totals for Hinkley Point to be greater than those for Sizewell and Bradwell. The Hinkley Point 1×10^{-4} / yr. rainfall values for one hour and 24 hours are 163 mm and 228 mm respectively (Ref. 144). The Hinkley Point rainfall values have been derived using the Flood Estimation Handbook (FEH) (Ref. 147) which, through a comparison study, have been shown to give similar results to an extreme value analysis using local rainfall data for the Hinkley Point site. The FEH provides rainfall data on a best estimate basis only. However, I judge the RP's approach to be adequately conservative given the selection of bounding values from the three candidate sites.

194. Climate change allowances for the rainfall hazard have been calculated using UKCP18 RCP 6.0 taken at the 84th percentile (sub-section 4.5.1.1). The RP has selected a climate change allowance based on Bradwell, which bounds Sizewell and Hinkley Point. Whilst comparison with SRES A1B data provided in UKCP18 demonstrates the allowances would be larger using SRES A1B, the RP's selection of RCP 6.0 is consistent with Met Office advice and RGP. My TSC has provided an independent check on the RP's climate change allowance using available UKCP18 data. The results of this independent check give the same values as obtained by the RP (Ref. 44, Ref. 148). I am confident that the RP has correctly calculated the climate change allowance using UKCP18 data. I judge the RP's approach to deriving climate change allowances using RCP 6.0 at the 84th percentile to be consistent with ONR's expectations in both the SAPs (Ref. 2) and the 'Use of UK Climate Projections 2018' position statement (Ref. 100).

195. Using the approach described above the RP has defined extreme rainfall totals for the GSE for one hour and 24 hours and an annual exceedance of 1×10^{-4} / yr. as follows.

- GSE values for 1 hour rainfall:
  - Present day: 163 mm
  - 2100 epoch: 216 mm (+53 mm)
- GSE values for 24 hours rainfall:
  - Present day: 228 mm
  - 2100 epoch: 302 mm (+74 mm)

196. I have compared the proposed GSE values with previous GDAs, and other new nuclear build projects. I find that the GSE values for rainfall are similar to those defined for the UK ABWR GDA project (Ref. 117). Overall, I am content with the RP's definition of the GSE values for rainfall, and consider it meets the expectations of SAPs EHA.3, EHA.4 and EHA.11. The FEH guidance is in widespread use in the UK for the estimation of rainfall in the planning and assessment of flood defences. I judge the FEH guidance to represent best available data for the calculation of extreme values for

rainfall in the UK in the absence of site-specific data for a target site, and to meet the expectations of SAP EHA.2. The RP's selection of a bounding hazard value and climate change allowances for the three candidate sites using UKCP18, RCP 6.0 at the 84th percentile is also consistent with ONR's expectations (Ref. 100).

197. To select the UK HPR1000 design input values for rainfall the RP has compared the GSE values with the FCG3 reference design values as per the approach described in sub-section 4.6. The FCG3 reference design values for rainfall are given as 326 mm for one hour and 1320 mm for 24 hours in the response to RQ-UKHPR1000-0335 (Ref. 149). These were subsequently revised down using new information to 226.6 mm for one hour and 871.1 mm for 24 hours in the response to RQ-UKHPR1000-0625 (Ref. 150). The RP has selected the GSE values as the UK HPR1000 design input values for rainfall. This is because the RP considers the FCG3 reference design values to be overly conservative for the UK HPR1000 compared with the likely site challenge that will be presented for a target site. I accept this argument given the conservative derivation of the GSE values and that the FCG3 reference design values at 24 hours are significantly larger than the GSE values. It would likely be grossly disproportionate to design SSCs against the FCG3 values. Consequently, the rainfall UK HPR1000 design input value is the same as the GSE values at the 2100 epoch.

198. The RP has evaluated the design against UK HPR1000 design input values for rainfall using the methodology described in the 'External Flooding Safety Evaluation Methodology Report' (Ref. 56). The methodology identifies protection measures against flooding to include:

- Door threshold of 300 mm
- Civil structures
- Watertight materials
- Watertight, external doors

199. The analysis of the design against the rainfall UK HPR1000 design input values is presented in the 'External Flooding Safety Evaluation Report' (Ref. 69). The analysis shows that the door threshold of 300 mm is sufficient to protect against the one hour rainfall total of 216 mm. The RP concludes in sub-section 6.4 of the 'External Flooding Safety Evaluation Report' (Ref. 69) that the volumetric protection ensures no water can get into the buildings important to safety. I judge this adequate, based on the evidence provided by the RP. I note there is a small exceedance of the door threshold for the 24 hours rainfall total, but this is acceptable given:

- The exceedance would only be realised if there is ponding of water without any losses (e.g. due to infiltration).
- The site platform will be designed with gradients and falls so that water flows away from the nuclear island.
- There will also be a drainage system that will take rainfall away from structures important to safety.
- Additional defence-in-depth measures are identified including weather forecasting and monitoring, mobile protection and administrative arrangements to ensure watertightness of the nuclear island structures during an extreme event (Ref. 79). This is consistent with the expectations of SAP paragraph 266 (Ref. 2). I expect such arrangements will be developed post-GDA by a licensee as part of normal business.

200. The RP has demonstrated the design's resilience against the UK HPR1000 design input values for rainfall, and the approach to pluvial flooding is consistent with the expectations of SAP EHA.12 (Ref. 2). External flooding levels and occurrence frequencies are highly dependent on site-specific conditions. Therefore, the potential for external flooding to affect a nuclear installation can only be fully evaluated at the site-specific phase. I expect a licensee to demonstrate the adequacy of the UK

HPR1000's protection against all external flooding sources, including pluvial flooding during site-specific stages and once the plot plan and conceptual platform elevation and design are known.

4.9.1.2 Beyond Design Basis Flooding

201. As discussed in sub-section 4.9.1.1, the RP has screened-out from GDA many possible flood sources as requiring site-specific information to characterise the hazard including coastal flooding. SAP EHA.12 expects that flooding of the nuclear island (and associated platform) will be protected against for events up to and including the design basis event (as defined in SAP EHA.3). Given this, flood water on the platform (other than rainfall) is assumed to represent a beyond design basis event. The GDA technical guidance (Ref. 10) states: "… it is important that the RP is able to present the plant's robustness against water on the platform, including any assumptions and operator actions. This is independent of the assumption of a "dry site" or flood defences." The expectation is for a RP to consider beyond design basis flooding at GDA, regardless of the source, and demonstrate that the plant is resilient against such events (Ref. 10). I have assessed the RP's submissions against these expectations.

202. During Step 3 I assessed the 'External Flooding Safety Evaluation Report' (Ref. 151). I judged that the RP had not provided an adequate demonstration of the plant's robustness against beyond design basis flooding. Two vulnerable penetrations at elevations below the proposed volumetric protection were also identified; one on the BEJ building at 0.8m and a second on the BFX building at 1.15m above platform level (0.5m and 0.85m above the ground floor level respectively with a 0.3m threshold to the platform) (Ref. 152, Ref. 153, Ref. 154). These gaps were discussed with the RP (Ref. 155) and an area for improvement raised in my Step 3 assessment (AFI-8, Annex 3). I raised RQ-UKHPR1000-0626 (Ref. 156) for the RP to explain their approach and to provide my expectations for the RP to provide a consequence analysis for beyond design basis flooding.

203. The RP's response to RQ-UKHPR1000-0626 committed to providing the consequence analysis (Ref. 157), and this was provided in an updated version of the 'External Flooding Safety Evaluation Report' (Ref. 69). The RP's approach is based on the 'Beyond Design Basis External Hazards Evaluation Methodology' report (Ref. 61), which categorises flooding as a category 3 hazard, meaning the consequences have been analysed for flood levels beyond the UK HPR1000 design input values. The analysis scope includes all buildings within GDA that are important to safety, with the aim of demonstrating a safe shut down of the reactor can be achieved and fundamental safety functions maintained. Various flood levels above the nuclear island platform have been analysed to identify the potential consequences. For consistency with the PSA flooding work, the RP has assumed for GDA that the: "site ground elevation is assumed as 7.40m and crest elevation of external embankment is assumed as 9.60m, which is assumed based on the information of Bradwell B site" (Ref. 158).

204. The RP presented the detailed flooding analysis using a 3D model in a technical meeting (Ref. 159). This meeting was also attended by the ONR Internal Hazards Inspector to ensure consistency of approach once external flooding enters buildings. The analysis considers relevant protection measures, including watertight external doors and watertight materials. The analysis assumes the watertight external doors are breached when the flood level is higher than the doors' watertight capacity. External doors are specified to be watertight against 2.0m hydraulic pressure at platform level and doors below ground are required to withstand up to 10.0m hydraulic pressure. This means there could be up to 2.3m of standing water on the platform before the external doors are assumed to fail (0.3m threshold and 2.0m hydraulic pressure withstand). The RP's analysis is consistent with the internal flooding methodology (Ref. 160); once external flood waters enter the nuclear island buildings water is assumed to flow along

designated flood routes to stairwells, where it would flow down to the basement levels, filling them up by spreading through unsealed holes and non-watertight doors before flooding higher levels. The RP's analysis assumes plant arranged within the flow path of the floodwater inside the buildings fails, except for the passive SSCs / cables, which are generally assumed to be unaffected by submergence. The approach is aligned with good practice.

205. I have engaged with the ONR SAA, Fault Studies and Electrical Engineering Inspectors in relation to the potential CCF of the emergency diesel generators and the station black-out generators (SBO) during a 'more severe' beyond design basis flooding event. The RP's analysis indicates that such an event would occur when water on the platform exceeds 2.30m, causing the external doors to fail on the nuclear island buildings including the BD_X buildings (BDA, BDB, BDC, BDU and BDV). This would result in the simultaneous loss of both the emergency diesel generators and SBO generators, which with a LOOP, would result in a total loss of alternating current (AC) power (TLACP). The RP classifies this as a design extension condition – A event (Ref. 19). Based on the RP's assumed site properties in the PSA flooding analysis, such an event could occur if the still water level exceed 9.70m Above Ordnance Datum (AOD) (7.40m AOD platform height + 2.30m flood level), which is above the assumed defence height of 9.60m AOD, thus consistent with a beyond design basis event.

206. The mitigation offered for a TLACP event, and to prevent escalation to a severe accident, is that the RPV could continue to be passively cooled by the ASP [SPHRS] for a period of 72 hours. SFP cooling via the Fuel Pool Cooling Treatment System (PTR [FPCTS]) would also be lost in such an event (Ref. 161), including the air-cooled Extra Cooling System[§§] (ECS [ECS]) as this is powered by the SBO diesel generators. There is a period of grace time before boiling would begin in the SFP, which has been calculated using conservative assumptions (Ref. 162), and a few days would be available before spent fuel would become uncovered even in a bounding scenario (Ref. 106).

207. The generic UK HPR1000 design includes two mobile diesel generators to provide temporary emergency power supply during certain scenarios such as a TLACP event. The use of the mobile diesel generators would vary depending on the plant state at the time of the flooding event:

- If the TLACP event occurred when the reactor was at power (or hot shutdown state) then the ASP [SPHRS] would actuate automatically and be used to cool the RPV via the SGs. Power for this switch to ASP [SPHRS] cooling would be provided by the Nuclear Island 220V Direct Current (DC) Power Supply and Distribution System (24 hour) (LAP/LAQ [DCPS (NI-220V-24h)]). The batteries in this system are located within the BSA and BSB buildings at the +4.90m level (Ref. 163). To meet the 72 hours of ASP [SPHRS] operability, the mobile diesel generators must be connected within 24 hours to provide power and recharge the LAP/LAQ [DCPS (NI-220V-24h)] batteries for monitoring purposes, and the batteries of the Nuclear Island 220V DC Power Supply and Distribution System (2 hour) (LAA/LAB/LAC/LAD [DCPS (NI-220V-2h)]). The mobile diesel generators could also provide power to the PTR [FPCTS] enabling the heat exchange function to be maintained (Ref. 164).
- If the TLACP event occurred when the plant is shutdown and not intact (in other words, the Reactor Coolant System (RCP [RCS]) is open either for maintenance or refuelling activities) then the mobile diesel generators would support the Containment Heat Removal System (EHR [CHRS]) and ECS [ECS] for decay heat removal from the core. The ASP [SPHRS] is then available as a water source to replace water lost from the SFP via boiling.

§§ ECS [ECS] provides a cooling function for the heat exchangers of the EHR [CHRS] and PTR [FPCTS]

208. I judge the RP's claims relating to the mobile diesel generators to be adequate given they are assumed to be located on the site in an independent mobile equipment storage building that would be elevated above the main platform level (Ref. 164). The elevation of this building will be determined for a target site, giving due to consideration to the site-specific flooding safety case. I judge this to be normal business.

209. From the beyond design basis external flooding evaluation provided by the RP, it is apparent that there is a minimum potential of +2.60m (+4.90m – 2.30m) differential between the height of the LAP/Q [DCPS (NI-220V-24h)] 24h batteries and the external flood level that would cause the external doors to fail and result in a TLACP event, thus requiring the LAP/Q [DCPS (NI-220V-24h)] batteries to initiate ASP [SPHRS] cooling. This demonstrates there exists credible beyond design basis margin against the flooding hazard for the UK HPR1000 design, and there are no immediate cliff-edge effects as expected by SAP EHA.7 (Ref. 2). The ONR Fault Studies Inspector has also assessed claims on the ASP [SPHRS] in relation to design extension condition – A events (Ref. 162).

210. External flooding levels and occurrence frequencies are highly dependent on site-specific conditions. The potential for external flooding to affect a nuclear installation can only be fully evaluated at the site-specific phase when the platform height is known and the external flooding hazard to the site has been evaluated. For the purposes of GDA, I consider that the RP has supplied sufficient evidence to demonstrate the design can mitigate the effects of a beyond design basis flooding event, principally due to the design incorporating learning from the Fukushima Dai-ichi NPP accident. However, there are some matters that I judge need further consideration post-GDA as the detailed design is further developed, taking into consideration the characteristics of the target site and site layout:

- Unprotected penetrations are identified in BEJ and BFX that could allow beyond design basis flooding to enter these structures at flood depths lower than the watertightness of the external doors (in other words flooding of these structures could occur at depths <2.30m above platform). The RP's analysis assumes that flood water entering these buildings will not flow into other structures as all penetrations between structures have been specified to be watertight. For example, the analysis assumes flood waters entering the BFX building do not spread into BRX. This has not been substantiated at GDA as these penetrations are out of scope. Leakage has also not been considered in the RP's analysis. I expect a licensee to provide an adequate safety justification during site-specific stages that these unprotected penetrations do not undermine claims made in relation to external flooding safety case or to undertake optioneering to find reasonably practicable solutions to address any identified design shortfalls.
- Whilst there is credible margin in the proposed location of the LAP/Q [DCPS (NI-220V-24h)] batteries for the purposes of GDA, their elevation needs to be justified post-GDA in relation to the site-specific flooding hazard. A licensee will need to demonstrate that there is an adequate beyond design basis margin to the LAP/Q [NI-DCPS] batteries, and that they remain available to deliver the required safety functions.
- The ventilation shafts for the underground technical galleries are currently assumed to be located at 1.0m above the nuclear island platform. Whilst the technical galleries are not in GDA scope, I expect the elevation of the ventilation shafts to be justified with respect to the site-specific flood hazard during site-specific stages and that flooding of these galleries would not undermine the delivery of any fundamental safety functions.

211. I expect a more detailed evaluation of the flooding hazard to be undertaken during site-specific stages, including derivation of the design basis event (SAP EHA.3 definition) for the flooding hazard in accordance with SAPs EHA.3 and EHA.4 (Ref. 2), and

justification of the protection strategy against both the design basis event (SAP EHA.3) and beyond design basis flooding (SAP EHA.18). The RP has captured the need to determine the 1 x 10^{-5} / yr. site-specific flooding value for the purposes of cliff-edge analysis as a post-GDA commitment. I consider that the specific matters highlighted in paragraph 209 to be shortfalls in the current safety justification that need to be tracked post-GDA to ensure they are adequately addressed in-light of site-specific information. These shortfalls are captured in Assessment Finding AF-UKHPR1000-0087 below.

212. I have considered lessons learnt from the Fukushima Dai-ichi NPP accident relevant to flooding with the ONR SAA Inspector. The RP presents the implementation of lessons learnt from the Fukushima Dai-ichi NPP accident in the UK HPR1000 design in the 'Lessons Learnt from Fukushima' report (Ref. 137). The level of detail in this report is often insufficient for claims to be verified. Consequently, the ONR SAA Inspector and I raised RQ-UKHPR1000-1267 (Ref. 138) and RQ-UKHPR1000-1497 (Ref. 139) seeking further information on:

- How the lessons and observations from 'The Fukushima Daiichi Accident' (Ref. 165) and the recommendations from the 'Japanese Earthquake and Tsunami: Implications for the UK Nuclear Industry - Final Report' (Ref. 166) relating to provision of mobile equipment have been implemented in the generic UK HPR1000 design.
- The justification for the quantity of mobile equipment assumed in the design.
- Requirements for the design of the independent mobile equipment storage building.
- Assumptions for accessibility of mobile equipment connection points following an external hazard event.

213. I have assessed the RP's responses to these queries (Ref. 140, Ref. 141). I find that:

- The requirements for the independent mobile equipment storage building are SSE-2 seismically qualified and elevated above the level of BD_X (Ref. 141). I judge these requirements reasonable for ensuring the building and associated mobile equipment remain available following an external hazard event. Site-specific inputs are needed to determine the final elevation of the independent mobile equipment storage building for a target site.
- With respect to accessibility of the site and mobile connection points, the RP argues that a combination of a beyond design basis external hazard and severe accident cannot occur together on a frequency basis. This does not consider that a beyond design basis external hazards event could be the PIE for the severe accident, as at the Fukushima Dai-ichi NPP accident. This means there are no specific assumptions relating to possible disruption of access to both the site and / or connection points for mobile equipment following an external hazard. The RP simply assumes the connection points will be available. This assumption has not been adequately justified.
- The 380V connection boxes for the mobile diesel generator are installed within the BSA and BNX buildings at a height of 1.2m above ground level. This is below the depth of an external flood that would necessitate use of the mobile diesel generators (compare with a flood height of 2.3m when the external doors are assumed to fail). Whilst the LAA/LAB/LAC/LAD [DCPS (NI-220V-2h)] and LAP/Q [DCPS (NI-220V-24h)] batteries are assumed to provide power to essential systems for the prescribed durations, it has not been demonstrated that the connection points will be available or accessible following a flood event for connection of the mobile diesel generators.

214. I consider there to be a shortfall in the justification of the elevation of the connection points for mobile equipment, and further evaluation is needed during site-specific stages. This shortfall and the concerns discussed in paragraph 209 are captured in Assessment Finding AF-UKHPR1000-0087 below:

AF-UKHPR1000-0087 – The licensee shall justify that risks from external flooding sources have been reduced as low as reasonably practicable for the site-specific design. This safety justification should give due consideration to:

- Unprotected openings identified in the external walls of the fuel building and the extra cooling system and fire-fighting water production system building.
- The elevation of the mobile equipment connection points, the independent mobile equipment storage building, batteries of the nuclear island 220V DC power supply and distribution system, and technical gallery ventilation shafts.
- Potential for disruption both on and off-site.
- Minimising the potential for common cause failure of the emergency diesel generators and station black out diesel generators.

4.9.2 Strengths

215. My assessment of the external flooding safety case has identified the following strengths:

- A bounding value for the present day rainfall hazard has been selected based on best available data, consistent with expectations of SAP EHA.2.
- The reasonably foreseeable effects of climate change are included in the derivation of the GSE rainfall value using UKCP18 RCP 6.0 at the 84th percentile.
- The definition of the GSE value for rainfall meets the expectations of SAPs EHA.3 and EHA.4.
- The GSE value for rainfall is selected as the UK HPR1000 design input value with appropriate justification.
- Defence-in-depth is provided against flooding hazards with an emphasis on passive measures including building thresholds and the ASP [SPHRS].
- DBA of the design against the UK HPR1000 design input value for rainfall demonstrates the design is robust against the 1 hour rainfall hazard.
- The RP has provided BDBA of flooding via a consequence analysis.
- The BDBA demonstrates that fundamental safety functions can be maintained and the reactor and SFP can be cooled for 72 hours so long as the LAP/Q [NI-DCPS] batteries are available to open the valves to ASP [SPHRS].
- The LAP/Q [NI-DCPS] batteries are elevated above the flood level that would cause flooding of nuclear island structures, thus demonstrating credible beyond design basis margins to failure.
- The design implements engineering measures in response to the lessons learned from the Fukushima Dai-ichi NPP accident, including provision of mobile plant.

4.9.3 Outcomes

216. My assessment of the external flooding safety case has identified one Assessment Finding (AF-UKHPR1000-0087). This relates to the need for a licensee to justify that risks from the site-specific flooding hazard have given due consideration to unprotected openings in two nuclear island structures (BEJ and BFX), and the elevation of other SSCs once site-specific inputs are known, and the potential for CCF of generators is minimised. The licensee's safety justification will need to demonstrate that the identified concerns have been adequately addressed and that the risks from external flooding (including beyond design basis events) have been reduced to ALARP.

4.9.4 Conclusion

217. I have assessed the RP's safety evaluation for external flooding. I conclude that:

- The screening-in of the pluvial (rainfall) hazard for GDA is appropriate. Other flooding hazards are screened-out with appropriate justification as site-specific information is required to characterise the flooding sources in a meaningful way.
- The definition of the pluvial (rainfall) hazard uses best available data and RGP. Sufficient evidence has been provided to demonstrate that the GSE values are bounding of the three candidate sites. I judge the GSE values to meet the expectations of SAPs EHA.2, EHA.3 and EHA.4.
- The GSE values are selected as the UK HPR1000 design input values. I judge this acceptable for GDA and that the RP has provided sufficient evidence to demonstrate the selection of the FCG3 reference design value are suitably conservative.
- The RP's DBA has:
  - Identified those measures that protect against the pluvial flooding hazard and demonstrated defence-in-depth.
  - Provided sufficient evidence to demonstrate that the design is robust against the pluvial flooding hazard.
- The RP's BDBA has:
  - Demonstrated the design has credible beyond design basis margin against flooding from a variety of sources.
  - Fundamental safety functions can be maintained as long as the LAP/Q [NI-DCPS] batteries remain available to switch to provide passive cooling from the ASP [SPHRS].
  - Implemented lessons learnt from the Fukushima Dai-ichi NPP accident, including additional cooling and electrical supply systems.
- I have raised an Assessment Finding for a licensee to evaluate unprotected openings in two nuclear island structures (BEJ and BFX), and the elevation of other SSCs against the site-specific flooding hazards.
- The RP's evaluation has demonstrated that the design is robust against flooding hazard effects. External flooding levels and occurrence frequencies are highly dependent on site-specific conditions. Further work is needed post-GDA to demonstrate risks are reduced ALARP once the platform height (and flood defences for a non-dry site) is known.

4.10 Meteorological Hazards

4.10.1 Assessment

218. Meteorological hazards can impact nuclear safety through a variety of means including loadings on structures, missiles and challenging plant cooling (Ref. 79). ONR's expectations for meteorological hazards include:

- SAPs EHA.10 and EHA.11 (Ref. 2).
- Technical guidance in NS-TAST-GD-013 (Ref. 6) and Annex 2 (Ref. 99).

219. I have assessed the RP's safety case submissions for meteorological hazards against these expectations.

220. The RP has identified and screened-in a range of meteorological hazards for evaluation during GDA. I am satisfied with the meteorological hazards that the RP has screened-in for evaluation during GDA, and the justification provided for those hazards screened-out to site-specific stages. I have assessed these hazards to determine the adequacy of the derivation of GSE and UK HPR1000 design input values with respect to SAP EHA.4. On a sampling basis, I have also assessed the RP's analysis of the design against meteorological hazards to ensure the analysis is consistent with RGP, including SAPs EHA.5 and EHA.6, and adequate protection measures are identified to protect against and / or mitigate the hazards' effects. My assessment is provided on a hazard-by-hazard basis in the following sub-sections.

4.10.1.1 Tornado

Table 11: Tornado hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Tornado	Wind Speed	65 m/s	89 m/s
	Pressure Drop	2.6 kPa	6.3 kPa
	Pressure Drop Rate	0.75 kPa/s	2.5 kPa/s

221. The RP has defined its GSE tornado hazard based on the Hinkley Point design input value for tornado (Ref. 144). The GSE values are as follows:

- Tornadic wind speed: 65 m/s
- Pressure drop rate: 7.5 mbar/s (0.75 kPa/s)
- Maximum pressure drop: 26 mbar (2.6 kPa)

222. I have considered the GSE value for tornado by comparing with RGP, previous GDAs and other new build projects. The Hinkley Point tornado hazard is categorised in accordance with the Tornado and Storm Research Organisation (TORRO) scale (Ref. 167, Ref. 168), which is based on a study of tornadoes in GB (Ref. 167). The Hinkley Point tornado is a T5 event (Ref. 169) or Intense Tornado, and bounds the site-specific hazard at Hinkley Point that has been estimated as a T3 event (Strong Tornado). Other studies of tornadoes in GB have characterised a 1 x 10^{-4} / yr. tornado as being equivalent to a T3 event or smaller (Ref. 72). This means there is likely to be inherent margin in the proposed GSE value compared with the actual hazard that would arise at any specific site in GB. It should be noted that the TORRO classification (Ref. 167, Ref. 168) provides a range of wind speeds for all tornado categories. The proposed GSE value of 65 m/s is close to the minimum wind speed for the T5 (Intense Tornado) category, which TORRO defines as having wind speed from 62 – 72 m/s. The RP's approach is conservative given the Hinkley Point design input value for tornado is likely to be bounding of the actual tornadoes occurring in GB. I judge that the GSE values for tornado meet the expectations of SAP EHA.3 and EHA.4.

223. Climate change values have not been considered in application to tornadoes, due to uncertainty in future storminess (Ref. 50). This is consistent with the latest understanding of climate change for the UK (Ref. 170). I judge this reasonable for the purposes of GDA based on the evidence presented by the RP. I expect a licensee to reconsider this position during site-specific stages and in accordance with RGP at that time. This is normal business.

224. The PCSR (Ref. 3) has compared the GSE value with the FCG3 reference design value for tornado hazard. The FCG3 reference design values are bounding of the GSE values, and are selected as the UK HPR1000 design input values for tornado in the

PCSR (Ref. 3). The following UK HPR1000 design input values for tornado are used for GDA:

- Tornadic wind speed: 89 m/s
- Pressure drop rate: 25 mbar/s (2.5 kPa/s)
- Maximum pressure drop: 63 mbar (6.3 kPa)

225. I have compared the RP's proposed tornado for the UK HPR1000 design input with the TORRO scale. The proposed UK HPR1000 design input values equate to a T7 or Strongly-Devastating Tornado event, which has a wind speed range of 84 – 95 m/s. This is a conservative position to adopt given the information I have assessed for the frequency and magnitude of tornadoes occurring in GB (Ref. 167). It also provides confidence that the UK HPR1000 will be robust against tornado loads and will have beyond design basis margins to withstand the hazard. The RP recognises this by categorising the hazard as Category 1 in accordance with the 'Beyond Design Basis External Hazards Evaluation Methodology' (Ref. 61).

226. The plant effects arising from tornado include pressure, missiles on structures, and LOOP (Ref. 79). Missiles and LOOP are dealt with below in sub-sections 4.10.1.3 and 4.13.1.1 respectively. This section focuses on the substantiation of the civil structures against tornado pressure. I have sampled relevant engineering documents to ensure the definition of the UK HPR1000 design input values for tornado are consistent with the external hazards safety case including the 'Generic Site Related Design Values' (Ref. 171) and the 'Generic Design Parameters for Civil Engineering' (Ref. 172) reports. The definition of the tornado UK HPR1000 design input used in the civil engineering design is consistent with the external hazards safety case. I have engaged with the ONR Civil Engineering Inspector with regards to pressure on structures from tornado. They have confirmed the design methodologies include external hazard loads. The structures that the Civil Engineering Inspector has sampled as part of the civil engineering assessment have demonstrated the adequacy of the RP's approach in defining bounding load cases. The substantiation of the civil engineering design is presented in the relevant design substantiation reports. The ONR Step 4 civil engineering assessment report should be consulted for further details (Ref. 98).

227. Overall, I judge the RP's evaluation of the tornado hazard to be consistent with RGP including ONR SAPs. The UK HPR1000 design input values for tornado are conservative, with the FCG3 reference design values being selected as they bound the GSE values that were derived in accordance with SAP EHA.4. This provides confidence that the design will be robust against the site-specific tornado hazard for a target site and there will be an absence of cliff-edge effects. The Civil Engineering Inspector has confirmed the civil structure design has adequately considered external hazards loadings and is substantiated against bounding load cases.

4.10.1.2 Wind

Table 12: Wind hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Wind	3-second gust, 10m above ground level – present day	41.66 m/s	80 m/s
	3-second gust, 10m above ground level – 2100 epoch	43.66 m/s	80 m/s

228. The RP has defined wind speed for its GSE using Eurocode 1 part 1-4 (Ref. 173) and the associated UK National Annex (Ref. 174). A basic, 10 minute average wind-speed

of 23 m/s for Sizewell has been selected as bounding of the three candidate sites. Eurocode enables calculation of the hazard on a best estimate basis only. However, the use of a bounding wind value for the three sites is conservative. I judge the use of Eurocode and the national annex to represent best available relevant data in the absence of site-specific data and consistent with the expectations of SAP EHA.2.

229. The methodologies of Eurocode (Ref. 173, Ref. 174) and American Society of Civil Engineers (ASCE) 7-10 (Ref. 175) have been used by the RP to derive a 3-second gust wind speed at 10m above ground level for 1 x 10^{-2} (1%) and 1 x 10^{-4} (0.01%) annual probability of exceedances. The effective basic wind speed value for a 1 x 10^{-4} annual probability of exceedance is 41.66 m/s and for a 1 x 10^{-2} annual probability of exceedance is 35.85 m/s. Comparison with previous GDA projects and other new build projects shows similar wind speeds were calculated for the three candidate sites of Bradwell, Sizewell and Hinkley Point.

230. The RP claims ASCE 7-10 to be RGP, although I note that ASCE 7-10 (Ref. 175) was replaced by ASCE 7-16 (Ref. 176) in 2017 and a guide for wind loads was published in 2020 (Ref. 177). My TSC undertook a review of ASCE 7-16 (Ref. 176) to determine whether any changes are made in the derivation of the wind velocity pressure that would affect the results derived by the RP (Ref. 178). There is one fundamental change for the calculation of wind velocity pressure, presented as Clause 26.10-1-si of ASCE 7-16 (Ref. 176), which is the addition of a ground elevation factor. However, this inclusion does not affect the results presented by the RP as ASCE recommends a value of 1 is applied for this factor. On this basis, I judge this to be a minor shortfall as there is no material impact on the hazard derivation. A licensee will be expected to use modern standards during site-specific stages.

231. My TSC has independently calculated the 1 x 10^{-4} / yr. wind speed value through application of the Eurocode and ASCE codes, and the same wind speed was obtained as by the RP. I am content that the RP has applied the codes correctly. I note that for a 1 x 10^{-2} / yr. wind speed the RP's probability factor of 1.078 was greater than that calculated by my TSC (1.038). The RP's approach is more conservative given the basic wind speed is multiplied by the probability factor and results in a more onerous wind speed.

232. The RP has considered climate change allowances for wind using UKCP18, RCP 6.0 at the 84th percentile (sub-section 4.5.1.1). The mean wind speeds baseline suggest that the central estimates of change are very small and that a reduction in wind speeds is possible in future epochs. The RP has adopted a small increase in wind speed for the GSE of +2 m/s based on expert judgement. I judge this a conservative approach for the purposes of GDA, noting that there is considerable uncertainty on the effects of climate change for wind speeds in general.

233. Overall, I judge the RP's approach to deriving the wind hazard for the GSE to be consistent with the expectations of SAPs EHA.3 and EHA.4. The 1 x 10^{-4} annual probability of exceedance wind hazard (3-second gust wind speed at 10m above ground level) for the GSE is:

- Present day: 41.66 m/s
- 2100 epoch: 43.66 m/s

234. The PCSR (Ref. 3) compares the GSE value for wind with the FCG3 reference design value. The FCG3 reference design wind speed value is selected as the UK HPR1000 design input value as it is bounding of the GSE value. This is a conservative approach, as the UK HPR1000 design input value for wind exceeds the expectations of SAP EHA.4 (in other words a less frequent and therefore more onerous event). The UK HPR1000 design input value for the wind hazard (3-second gust wind speed at 10m above ground level) is used for both present day and future epochs:

- Wind hazard: 80 m/s

235. The plant effects for wind include pressure on buildings and missiles (Ref. 79). Wind-borne missiles are addressed in the following sub-section 4.10.1.3. The remainder of this section focuses on pressure effects on civil structures.

236. The UK HPR1000 design input value cannot be directly applied as a loading, and must first be converted to local pressures using relevant codes. I agreed with the ONR Civil Engineering Inspector to independently check the pressures obtained by the RP for the BFX building, as this aligned with the Civil Engineering Inspector's sampling. My TSC has calculated wind pressures using the coefficients from ASCE 7-10 (Ref. 175) used by the RP for the BFX building at UK HPR1000 GDA Design Reference 2.1. The results are presented in my TSC's report (Ref. 44) and have verified the RP's values. I am content the RP has correctly applied the guidance in the ASCE 7-10 standard (Ref. 175).

237. My TSC also provided a comparative study using Eurocode 1991-1-4 (Ref. 173) to calculate pressures. The calculations using the approach from Eurocode (Ref. 173) give larger loadings than those obtained from ASCE 7-10 (Ref. 175). Wind pressures are liable to increase should the Eurocode approach be adopted by a licensee for the site-specific design. The significant conservatisms in the UK HPR1000 design input value for wind provides confidence that the design will be robust against the wind hazard for most UK sites regardless of which approach is adopted:

- There is conservatism in the selected wind speed for the UK HPR1000 design input value of 80 m/s, which exceeds the GSE 1 x 10^{-4} / yr. event of 43.66 m/s.
- The BFX building is a reinforced concrete shear wall and slab structure and designed to resist a seismic event and an aircraft impact. It is unlikely that the wind loading will be the bounding load case for the overall design.

238. I have discussed my TSC's calculations with the ONR Civil Engineering Inspector. The Civil Engineering Inspector has confirmed that the BFX building has been analysed by the RP using appropriate methods and assumptions, and the design substantiated against bounding load cases. The ONR Step 4 civil engineering assessment report should be read for further information (Ref. 98). The UK HPR1000 GDA Design Reference 3.0 includes some modifications to the geometry and footprint of BFX relating to RO-UKHPR1000-0014 (Ref. 179) and RO-UKHPR1000-0056 (Ref. 180) (sub-section 4.18.1.6). The RP has provided qualitative analysis to demonstrate that the modified design is not challenged by load combinations considered during GDA (Ref. 181). Further work will be needed post-GDA to substantiate this. However, for the purposes of GDA, I am content that the RP has appropriately evaluated the wind hazard for the UK HPR1000 design.

239. Overall, I judge the RP's evaluation of the wind hazard to be consistent with RGP, including ONR SAPs. The UK HPR1000 design input value for wind is conservative, with the FCG3 reference design value being selected as it bounds the GSE value that was derived in accordance with SAP EHA.4 (compare 80 m/s and 43.66 m/s). This provides confidence that the design will be robust against the site-specific wind hazard for a target site and there will be an absence of cliff-edge effects. The RP has correctly applied international RGP to translate the UK HPR1000 design input value into local pressures, albeit there is a more modern version of the ASCE 7 standard, and Eurocode gives greater wind pressures. The Civil Engineering Inspector has confirmed the design has adequately considered external hazards loadings and is substantiated against bounding load cases.

4.10.1.3 Tornadic and Wind-Borne Missiles

Table 13: Tornado and wind-borne missile hazard parameters for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Tornado / wind-borne missiles	Schedule 40 pipe (0.168 m dia. x 4.58 m long, 130kg)	24 m/s	34 m/s
	Automobile	1,178 kg 24 m/s	1,810 kg 34 m/s
	Solid steel sphere (2.54 cm dia., 0.0669kg)	6 m/s	7 m/s

240. The RP has defined wind-borne missiles for the GSE using US NRC Regulatory Guide 1.76 (Ref. 40). This guide is in widespread use and relevant to nuclear facilities. I judge this to be RGP, and its use by the RP appropriate for the purposes of GDA.

241. The RP has selected the wind-borne missiles hazard based on the GSE tornado hazard, as the tornado hazard wind speeds bound the 3-second gust wind speed (65 m/s and 43.66 m/s respectively). The missiles are based on Region III parameters from US NRC Regulatory Guide 1.76 (Ref. 40), which the RP considers to be consistent with the GSE tornado wind speeds. I have assessed (Ref. 40) and Region III provides parameters for a maximum wind speed of 72 m/s, which is greater than the GSE tornado wind speed. I judge the RP's approach for defining the GSE wind-borne missiles to be adequately conservative and meet the expectations of SAPs EHA.3 and EHA.4.

242. The GSE wind-borne missiles are defined as follows:

- Schedule 40 pipe (0.168 m dia. x 4.58 m long, 130kg) at 24 m/s
- Automobile (1,178 kg) at 24 m/s
- Solid steel sphere (2.54 cm dia., 0.0669kg) at 6 m/s

243. The PCSR (Ref. 3) compares the GSE wind-borne missiles with those defined for the FCG3 reference design. The FCG3 reference design values for wind-borne missile are selected as the UK HPR1000 design input values, as the FCG3 reference design values bound the GSE values. The following wind-borne missile parameters are used for the UK HPR1000 design input values:

- Schedule 40 pipe (0.168 m dia. x 4.58 m long, 130kg) at 34 m/s
- Automobile (1,810 kg) at 34 m/s
- Solid steel sphere (2.54 cm dia., 0.0669kg) at 7 m/s

244. I judge the RP's UK HPR1000 design input values to be conservative and that:

- The FCG3 reference design values for wind-borne missiles bound the GSE values.
- The FCG3 reference design wind-borne missile values are based on Region II parameters from US NRC Regulatory Guide 1.76 (Ref. 40), which correspond to a maximum wind speed of 89 m/s; the same as the FCG3 reference design value for tornado hazard.
- The FCG3 reference design values for tornadic wind speed bound the 3-second gust wind speed (89 m/s and 80 m/s respectively – see sub-sections 4.10.1.1 and 4.10.1.2).

- The selection of the FCG3 reference design values as the UK HPR1000 design input values means that the missiles are defined on a consistent basis with the UK HPR1000 design input values for tornado, which is 89 m/s (based on the FCG3 reference design value see sub-section 4.10.1.1).

245. The plant effects of both wind and tornado hazards include wind-borne missiles (Ref. 79). For each building in GDA scope, the boundary of the building, including penetrations, has been evaluated against the wind-borne missiles hazard based on the methodology described in the ‘Tornado Safety Evaluation Methodology Report’ (Ref. 58). The evaluation is presented in the ‘Tornado Safety Evaluation Report’ (Ref. 72).

246. I have assessed the RP’s analysis for wind-borne missiles during Steps 3 and 4. This includes raising RQs for the RP to clarify certain points (Ref. 84, Ref. 182, Ref. 183, Ref. 184), discussing the RP’s approach during technical meetings (Ref. 185, Ref. 186, Ref. 187, Ref. 188) and interrogating the 3D model used for analysis of the design against wind-borne missiles (Ref. 186). AFI-7 and AFI-10 from my Step 3 external hazards assessment are also relevant to wind-borne missiles, relating to an inadequate evidential basis to support the conclusions of the analysis and identifying design shortfalls. My Step 4 assessment has focused on:

- Confirming the RP’s analysis is consistent with RGP.
- Confirming the RP’s findings are evidence based.
- Ensuring identified shortfalls are adequately addressed via optioneering, and SSCs are protected.
- Clarifying the design reference information used in the analysis.

247. I address each of these points in the following paragraphs.

248. The RP’s response to RQ-UKHPR1000-1110 (Ref. 189) states that the analysis has considered missiles striking in all directions. Further evidence supporting this has been provided in Revision C of the ‘Tornado Safety Evaluation Report’ (Ref. 72). I judge this approach consistent with Table 2 of RG1.76, which states missiles are capable of striking in all directions and at all levels with the exception of the automobile, which is limited to below 30 ft (~9.1m). I have confirmed the applicable missile loads are considered for relevant SSCs in the ‘External Hazards Schedule Report’ (Ref. 79).

249. The RP has provided additional evidence to support the conclusions of the analysis in Revision C of the ‘Tornado Safety Evaluation Report’ (Ref. 72). This includes sections illustrating the angles considered for missiles striking different openings on nuclear island structures (Figure 8). I judge the RP has provided sufficient evidence to support the conclusions of the analysis.

250. The RP’s analysis has identified the following shortfalls in the protection design:

- Main feedwater flow control system (ARE [MFFCS]) and main steam system (VVP [MSS]) over-pressure relief openings in the BSA and BSB.
- Rooms adjacent to some inverse-L structures where the steel pipe missile can penetrate beneath the protection and enter the buildings.

251. The RP conservatively assumes all SSCs in a room penetrated by a missile are damaged, with loss of associated safety functions. This includes rooms containing safety classification 2 (F-SC2) equipment of the electrical division safeguard buildings ventilation system (DVL [EDSBVS]), meaning the safety function of the system is lost. The RP has undertaken ALARP optioneering for these shortfalls and the following modifications have been proposed:

- The addition of ‘inverse-L’ structures to protect the ARE [MFFCS] and VVP [MSS] over-pressure relief openings in the BSA and BSB. The ‘inverse-L’

structures that are part of the civil structure and designed to withstand bounding load cases. This has been implemented during GDA as a category 3 modification.
- The preferred option for the vulnerable inverse-L structures is a steel grille installed at the base of the inverse-L structures to prevent missile penetration. This modification has been deferred to site-specific stages as it is dependent on the detailed design of the inverse-L structures.

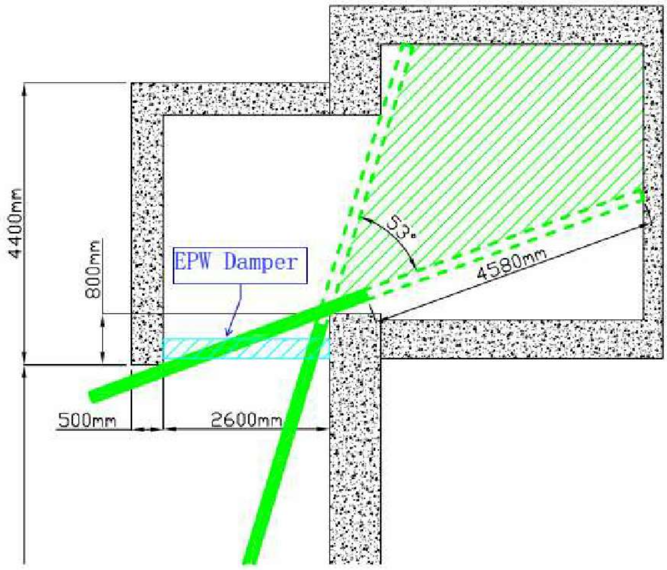

Figure 8: An example section illustrated to show the angles for wind-borne missiles that might penetrate rooms adjacent to the building boundary. *(Ref. 72)*

252. I have considered the nuclear safety consequences of the shortfalls associated with inverse-L structures, and I judge it is reasonable for this modification to be implemented during site-specific stages for the following reasons:

- The RP's analysis is conservative and assumes all SSCs in rooms penetrated by missiles are lost.
- The RP has conservatively assumed all three trains of DVL [EDSBVS] can be lost during a tornado / extreme wind event, despite being spatially separated.
- The detailed design of the inverse-L structures is out of GDA scope.
- There are other potential mitigating options that could be implemented at the site-specific phase, including shadowing of the vulnerable openings using other structures, which is dependent on the site-specific plot plan.

253. The RP has placed a requirement on a licensee to consider the modification to inverse-L structures in the GDA commitment log as CM-SUPP-1751. To ensure the modification is adequately implemented during site-licensing and associated risks are reduced to ALARP, I raise Assessment Finding AF-UKHPR1000-0088:

AF-UKHPR1000-0088: The licensee shall demonstrate that the site-specific design provides protection against the wind-borne missiles hazard and that risks are reduced to be as low as reasonably practicable, including the implementation of modification options identified during GDA, where necessary.

254. The RP has, in response to RQ-UKHPR1000-1453 (Ref. 190), provided sufficient information for the purposes of GDA to demonstrate that the steel sphere missile cannot penetrate the explosion, pressure wave (EPW) dampers. The openings between cells of the FCG3 reference design dampers are 1.55 cm, which is smaller

than the 2.54 cm diameter of the steel sphere missile. The missile also has insufficient mass to penetrate the steel dampers and then damage SSCs in the adjacent rooms.

255. The RP has provided analysis for SSCs located external to the civil structures:

- The calculation in Appendix A of the 'Tornado Safety Evaluation Report' (Ref. 72) provides confidence that the Atmospheric Steam Dump System (VDA [ASDS]) can withstand wind-borne missiles.
- The requirement for external doors to withstand external hazards including missiles has been captured in the external hazards schedule (Ref. 79). I judge this proportionate for GDA as the design of these features is out of scope.
- Other openings / penetrations in the external walls of civil structures (Ref. 191), such as for cables and pipes, are plugged with a material that is required to withstand external hazard loads (Ref. 182, Ref. 192). This requirement is captured in relevant documentation (Ref. 72).

256. I expect a licensee to substantiate these other SSCs against external hazards as normal business during site-specific phases.

257. The RP has demonstrated the links between the 3D model used for analysis of the design against wind-borne missiles, the conclusions of the safety evaluation report and SDMs:

- During a technical meeting (Ref. 188), the RP demonstrated a clear link between the 3D model used in the analysis and relevant SDM Chapter 9 flow diagrams for DVL [EDSBVS] (Ref. 193).
- The response to RQ-UKHPR1000-1453 (Ref. 190) links the figures and tables in the 'Tornado Safety Evaluation Report' (Ref. 72) with design reference information, including general arrangement drawings.

258. I have assessed information extracted from the 3D model for room BSA3701ZRX in BSA to verify the data presented in T-3.5-6 of the 'Tornado Safety Evaluation Report' (Ref. 72). My assessment has identified some inconsistencies:

- T-3.5-6 of (Ref. 72) identifies Nuclear Island Fire Protection System (JPI [NIFPS]) pipe JPI1152TY. The correct code should be the JPI1490TY.
- Some JPI components are not explicitly identified in T-3.5-6 of the 'Tornado Safety Evaluation Report' (Ref. 72) namely: valve JPI1477TY, several small pipes and other pieces of equipment. These components may be relevant from a consequential (internal) hazards perspective, and should be included for completeness.

259. I judge these inconsistencies to be a minor shortfall. The inconsistencies do not affect the overall results of the analysis as the RP's conservative approach to the deterministic analysis assumes the safety functions with the JPI [NIFPS] system are lost.

260. I note that the hazards analysis information is presented differently between the external hazards and internal hazards generic UK HPR1000 safety case documentation. Most external hazards are protected against by the external shells (walls and roof) of the civil structures, but the wind-borne missiles can penetrate into the buildings. This means the different approaches for presenting information between external and internal hazards analysis became more obvious and potentially important from a consequential hazard perspective. For internal hazards the RP uses room data sheets that identify all SSCs in discrete rooms and are linked with relevant SDMs. A similar approach would be acceptable for external hazards and would:

- Make inconsistencies between the 3D model and safety evaluation reports / SDMs easier to identify and resolve (e.g. paragraph 258).
- Provide a consistent approach between the hazards topic areas.
- Support the evaluation of consequential hazards initiated by external hazards.

261. I highlight the inconsistent approaches as a minor shortfall. The RP has provided an adequate justification for the approach used in GDA, given the conservative nature of the analysis and by demonstrating the analysis is based on the latest design reference information. However, the approach used by internal hazards is applicable to the external hazards safety case and would aid multi-disciplinary working in relation to hazard combinations.

262. Overall, I judge that the RP has analysed the effects of wind-borne missiles on the UK HPR1000 design in accordance with RGP. The UK HPR1000 design input values for wind-borne missiles are conservative, being based on the bounding FCG3 reference design values. The wind-borne missiles definition for the UK HPR1000 is consistent with the tornado hazard wind speeds of 89 m/s. The RP's analysis has identified design shortfalls to the hazard and ALARP optioneering has been undertaken to identify additional protective measures. I have raised Assessment Finding AF-UKHPR1000-0088 to ensure the selected modification for inverse-L structures is adequately implemented post-GDA, during detailed design of the civil structures and once the plot plan is known. A licensee will need to undertake work to substantiate other SSCs against the wind-borne missiles hazard that are out of GDA scope, including doors and plugging materials. I judge that this evaluation can be performed as normal business, and no additional findings are raised.

4.10.1.4 High-Air Temperature

Table 14: High-air temperature hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
High-air temperature	Instantaneous high-air temperature (dry bulb) – Present day	41.5 °C	48.5 °C
	Instantaneous high-air temperature (dry bulb) – 2100 epoch	48.5 °C	48.5 °C

263. The RP has defined the high-air temperature hazard for the GSE using Eurocode 1991-1-5 (Ref. 194) and the UK National Annex (Ref. 195). The RP has used the bounding 1 x 10^{-2} annual probability of exceedance value for the three candidate sites from the UK National Annex. A value for Hinkley Point was selected as the site is located within the 32 °C isotherm, compared with Bradwell and Sizewell that are located within the 31 °C isotherm. The RP has calculated the maximum shade air temperature values for a 1 x 10^{-4} annual probability of exceedance using Equation A.1 and the suggested coefficients from BS EN 1991-1-5 (Ref. 194). This approach provides a best estimate value only. The RP's approach is conservative as a bounding value for the three candidate sites is used, along with the specified coefficients, which are likely to be conservative compared with site-specific data. The RP has provided evidence to demonstrate this latter point in T-5-5 of the 'UK HPR1000 Generic Site Report' (Ref. 50), which shows air temperatures for Hinkley Point derived using Eurocode coefficients bounded those based on site-specific data. Eurocode represents RGP, and in the absence of site-specific temperature data, I judge the use of this code to meet the expectations of SAP EHA.2 for use of best available relevant data.

264. Using the methodology described above the RP has defined a present day 1 x 10^{-4} annual probability of exceedance high-air temperature hazard value. The hazard is affected by climate change. The RP has included the reasonably foreseeable effects of climate change over the lifetime of the facility based on UKCP18 RCP 6.0 at the 84th percentile. An allowance of +7 °C has been defined for a 2100 epoch (sub-section 4.5.1.1). The epoch of 2100 approximately aligns with the lifetime of the generic UK HPR1000 design, and the latest epoch for which UKCP18 provides climate change projections. I judge this approach consistent with ONR's expectations in SAP EHA.11 and the position statement on use of UKCP18 (Ref. 100).

265. The GSE high-air temperature values are defined as follows:

- Present day: 41.5 °C
- 2100 epoch: 48.5 °C

266. I have compared the GSE value for the high-air temperature hazard with other new nuclear build and previous GDA projects. This exercise demonstrates that the climate change allowance and hazard value for 2100 epoch is the most onerous defined by a RP compared with other projects. The high-air temperature hazard for the GSE has been calculated using RGP and meets the expectations of SAPs EHA.2, EHA.3, EHA.4 and EHA.11. Overall, I judge the GSE value to be adequate for the purposes of GDA.

267. The PCSR (Ref. 3) compares the GSE value for the high-air temperature hazard with the FCG3 reference design value of 38 °C. The GSE value is selected as the UK HPR1000 design input value. This approach is consistent with the RP's stated methodology for selection of UK HPR1000 design input values. I judge the selected value to be conservative and consistent with ONR's expectations for GDA (Ref. 10).

268. The high-air temperature hazard has been identified as a gap as the UK HPR1000 design input value is more onerous than that which the FCG3 reference design has been designed against. This potential regulatory shortfall was captured in RO-UKHPR1000-0002 (Ref. 12) (sub-section 4.18.1.1). The RP has analysed the impact of these gaps for relevant SSCs and, if needed, modified the design to withstand the UK HPR1000 design input value (Ref. 196). The SSCs affected by the high-air temperature hazard are presented in the 'External Hazards Gap Identification and Evaluation Report' (Ref. 197) and comprise:

- HVAC systems including DVD [DBVS]
- Safety Chilled Water System (DEL [SCWS])
- C&I systems supported by HVAC
- Electrical systems supported by HVAC
- Mechanical systems supported by HVAC

269. The ONR Mechanical Engineering Inspector and I judged that there were potential regulatory shortfalls in the RP's analysis performed for the design of the HVAC systems against extreme meteorological conditions, based on submissions made by the RP, including those submitted in response to RO-UKHPR1000-0002. I also considered the RP had not provided an adequate evidential basis to support claims made in relation to HVAC systems. The ONR Mechanical Engineering Inspector raised RO-UKHPR1000-0039 to address these potential regulatory shortfalls (Ref. 15).

270. I have supported the ONR Mechanical Engineering Inspector in the development of RO-UKHPR1000-0039, subsequent engagement with the RP (Ref. 198), assessment of relevant submissions and raising of RQs (Ref. 199, Ref. 200). From an external hazards perspective, my aim for RO-UKHPR1000-0039 (Ref. 15) was to ensure:

- The analysis was based on the UK HPR1000 design input values for extreme air temperatures (see sub-sections 4.10.1.5 for low-air temperature).
- The adequacy of the enthalpy UK HPR1000 design input value (see sub-section 4.10.1.6).
- The analysis meets the expectations of SAP EHA.6 and also demonstrates beyond design basis withstand (SAP EHA.18) including the absence of cliff-edge effects (SAP EHA.7) via appropriate use of sensitivity analyses (SAP AV.6).
- The adequacy of requirements management via sampling of relevant SDMs.
- Adequacy of the RP’s approach for consideration of fabric heat gain.
- Review of site adaptability modifications in relation to the HVAC.

271. The UK HPR1000 design uses two types of ventilation systems (Figure 9):

- Type A ventilation systems – these are once through systems without air conditioning. Volume of air is used to remove heat and provide cooling to equipment. The efficacy of type A systems is principally dependent on the external air temperature. The diesel building ventilation system (DVD [DBVS]) is a type A system.
- Type B ventilation systems – these are ventilation systems equipped with air conditioning equipment. The system is sized based on the specified enthalpy difference between the internal and external air, rather than temperature. Within type B systems, rooms with high heat load are supplemented with Local Cooling Units (LCUs) to maintain desired operating temperatures during normal operation fault conditions. The type B ventilation systems can be further sub-divided into those with or without an air return for recirculation of internal air. The blending of exterior and recirculated air to maintain the space supply air temperature is an important consideration as the exterior temperature increases. The DCL [MCRACS] and DVL [EDSBVS] are type B systems with air return. The Nuclear Auxiliary Building Ventilation System (DWN [NABVS]) is a type B system without air return.

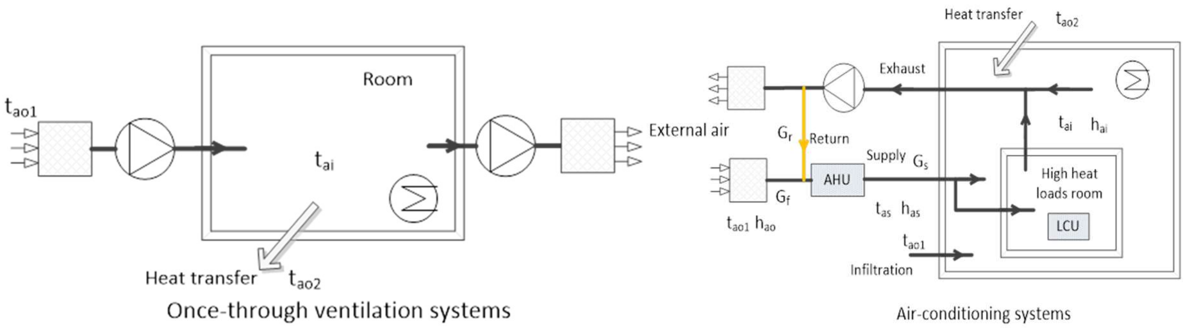

Figure 9: Ventilation system types used on UK HPR1000. Left, type A once-through system without air conditioning. Right, type B air conditioned system (with air return). *(Ref. 201)*

272. The RP’s strategy for RO-UKHPR1000-0039 (Ref. 202) applied the following screening criteria to identify those the cooling systems for detailed analysis:

- Systems in GDA scope.
- Safety classified systems.
- System types.
- PSA risk contribution.
- Representativeness of the systems for the design.

273. The systems selected for analysis comprise:

- Type A – DVD1 [DBVS] system.

- Type B – DCL [MCRACS] and DVL [EDSBVS] systems.
- The safety chilled water system (DEL [SCWS]), as the only chilled water system in GDA scope, and which one train uses the air as its heat sink.

274. The analysis for these systems is reported in the 'Analysis Report of the HVAC Sample Systems' (Ref. 203). The RP has provided:

- Steady-state thermal analysis using a lumped parameter modelling code.
- Transient analysis of the spaces ventilated by these systems during a range of transient fault and non-fault scenarios.

275. I have confirmed that the external hazard inputs to the analysis are consistent with the UK HPR1000 design input values for air temperature (both high and low) and enthalpy / humidity. The combined UK HPR1000 design input values for high-air temperature and enthalpy when plotted on a psychrometric chart results in a low relative humidity value. I sought clarity on this matter via RQ-UKHPR1000-0736 (Ref. 204). The RP's response (Ref. 205) clarifies that:

- Extreme temperature and enthalpy provide a bounding, psychrometric envelope.
- The extreme temperature and enthalpy should not be considered coincident (in other words they do not necessarily occur at the same time but represent separate limits for the two variables).
- Type B ventilation systems are sized on enthalpy only, as air temperature has little impact on the design of these systems (discussed below).

276. I accept this approach for GDA given the conservative definition of the UK HPR1000 design input values for temperature and enthalpy (discussed above and in sub-section 4.10.1.6 respectively).

277. Fabric heat gain is an important input to the HVAC analysis and is caused by buildings absorbing heat to achieve equilibrium between the exterior and interior surfaces. A greater extreme exterior temperature increases the building fabric heat gain, which in turn slightly raises the enthalpy of the recirculated air to LCUs of Type B systems. Temperature increase only has a small, indirect effect on the chiller sizing. The blending of exterior and recirculated air to maintain the space supply air temperature is also an important consideration as the exterior temperature increases. The proportion of air recirculated is determined by the fresh air requirements and blending will be considered further at site-specific stages as normal business. The RP has applied the Chartered Institution of Building Services Engineers (CIBSE) admittance method to evaluate fabric heat gain effects (Ref. 206, Ref. 207). The RP has applied three cases:

- A steady state approach with constant 38 °C (average 24 hours profile temperature).
- A 24 hours temperature varying profile.
- A constant 48.5 °C temperature based on the UK HPR1000 design input value for high-air temperature.

278. The RP has defined a 24 hours temperature varying, sinusoidal profile (Figure 10):

- Duration: 24 hours
- Average temperature: 38 °C
- Maximum temperature: 48.5 °C
- Minimum temperature: 27.5 °C

279. I judge the RP's approach adequate for determining fabric heat gain in GDA given the absence of site-specific data. I expect a licensee to revisit the sinusoidal profile in light of site-specific information as normal business during site-specific stages.

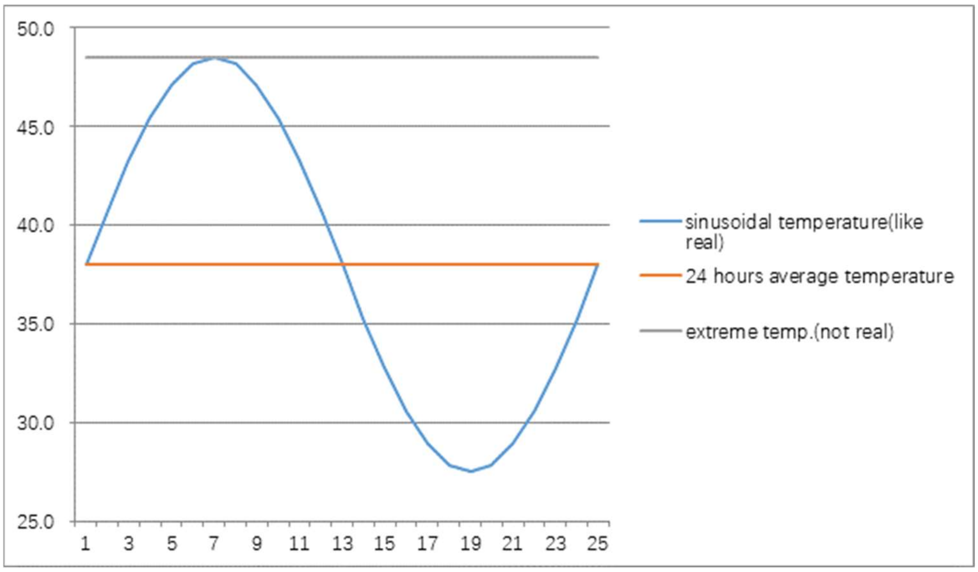

Figure 10: Sinusoidal temperature profile used for calculating the solar gain input to HVAC analysis. *(Ref. 202)*

280. The RP's HVAC analysis shows that for a diurnally varying temperature profile, the extant chiller sizes of Type B systems are sufficient to manage external hazards loadings. The RP estimated that, based on the FCG3 reference design, the cooling loads will increase by 3%, but has demonstrated the chiller capacities can accommodate this increased loading for DCL [MCRACS], DVL [EDSBVS] and DEL [SCWS] systems. The ONR Mechanical Engineering Inspector has raised AF-UKHPR1000-0128 for a licensee to demonstrate the chillers can satisfy the 48.5 °C extreme ambient temperature during detailed design.

281. The analysis has identified the following gaps:

- Insufficient flowrate for some HVAC systems in extreme summer conditions (in other words against the UK HPR1000 design input values for high-air temperature and enthalpy) and with a constant exterior temperature of 48.5 °C applied in the fabric heat gain calculations.
- Insufficient heating in some rooms in extreme winter conditions (in other words UK HPR1000 design input values for low-air temperature), such as staircases and anterooms.

282. The RP determined that:

- The current flow rate satisfies the cooling requirement but there is insufficient safety margin (less than 10%). Ventilation systems may need to be enlarged during site-specific stages to provide the increased flowrate and sufficient space exists in the building to accommodate this.
- Additional local heaters are required to resolve the heating gaps. Heater sizing will be determined at site-specific stages (once the site-specific environmental data is known). This is discussed further in sub-section 4.10.1.5.

283. The RP has identified measures that can be implemented to address these gaps, and proposes to implement these once site-specific environmental conditions are known. The ONR Mechanical Engineering Inspector considers the above to be normal business during site-specific phases. I agree with this position given the level of detail available during GDA.

284. The analysis of cooling systems has included sensitivity analysis to identify any cliff-edge effects:

- For the DVD [DBVS] air temperatures up to 52.5 °C have been analysed.
- For DCL [MCRACS] and DVL [EDSBVS] enthalpy of 103 kJ/kg has been evaluated, which is consistent with the FCG3 reference design value of enthalpy and associated capacity of LCU cooling coils.

285. The RP's sensitivity analysis demonstrates that:

- DCL [MCRACS] and DVL [EDSBVS] can withstand enthalpy up to 103 kJ/kg.
- DVD [DBVS] can maintain the diesel hall temperature below the 60 °C specified qualification temperature of the emergency diesel generators and SBO diesel generators when the external air temperature is at 50.2 °C or lower (in other words 1.7 °C above the UK HPR1000 design input value of 48.5 °C) (Ref. 208).

286. I queried whether the DVD1 [DBVS] system has sufficient resilience against cliff-edge effects in RQ-UKHPR1000-1699 (Ref. 200). The RP's response (Ref. 209) argues that there is not a disproportionate increase in risk for the emergency diesel generators or SBO diesel generators when temperatures exceed 50.2 °C as they can be de-rated to provide a lower electrical output. The RP has also identified additional measures that could be implemented to further enhance the capacity of the DVD [DBVS] system and has confirmed there is sufficient space in the layout to accommodate these measures, if needed. The need for these measures will be evaluated during site-specific stages. I judge this acceptable for GDA because:

- The RP has demonstrated there is a small margin beyond the UK HPR1000 design input value.
- The RP has demonstrated that there is not a disproportionate increase in risk for the emergency diesel generators or SBO diesel generators.
- The need for the modification to DVD1 [DBVS] is best evaluated during site-specific stages where the site-specific air temperature hazard can be compared with the UK HPR1000 design input value.
- The ONR Mechanical Engineering Inspector has raised AF-UKHPR1000-0128 for a licensee to demonstrate that equipment important to safety remain within their qualified range against local temperatures.

287. I judge the RP's use of sensitivity analysis for enthalpy and high-air temperature hazards, along with the additional information provide in response to RQ-UKHPR1000-1699 (Ref. 209), demonstrates an absence of cliff-edge effects as per the expectations of SAP EHA.7. The RP has not fully satisfied the expectations of SAP EHA.18, as the margins to failure for these systems has not been determined. I judge this to be a minor shortfall. Determination of margins to failure is most effectively addressed during detailed design of relevant SSCs, and once the site-specific hazards have been characterised. I judge this work to be normal business during site-specific phases of design development.

288. A summary of the RP's analysis of HVAC systems against extreme temperature and enthalpy is provided in the 'HVAC Systems Analysis Report—Site Adaptability Modification in UK HPR1000' (Ref. 210), which is a submission in response to RO-UKHPR1000-0002 (Ref. 12). This report is consistent with the findings and modifications in relevant submissions from RO-UKHPR1000-0039 (Ref. 203, Ref. 211).

289. The 'HVAC Systems Analysis Report—Site Adaptability Modification in UK HPR1000' (Ref. 210) states that relevant SDMs have been updated during GDA to reflect changes to meet the UK HPR1000 design input values. I assessed a sample of SDMs for the HVAC systems analysed under RO-UKHPR1000-0039 to ensure the external hazard inputs presented therein are consistent with the UK HPR1000 design input values. I issued RQ-UKHPR1000-1764 (Ref. 85) to request the RP explain the

apparent inconsistencies in the safety case, and to provide my expectations for the resolution of these matters. The RP's response (Ref. 87) has only addressed some of these inconsistences in GDA. This does not meet the expectations of SAP SC.4 for an accurate safety case. I judge this is a minor shortfall because it has not impacted on the analysis performed by the RP.

290. Overall, I consider the RP's analysis has demonstrated that the sampled HVAC systems can provide required safety functions and withstand relevant external hazard loadings. Further work is needed post-GDA, once site-specific hazards are defined to demonstrate the resilience of HVAC systems and the margins to failure.

291. Overall, I judge the RP's evaluation of the high-air temperature hazard to be consistent with RGP including ONR SAPs. The UK HPR1000 design input value for high-air temperature is conservative, with the bounding GSE value selected that was derived in accordance with SAP EHA.4. The RP has provided analysis for a sample of HVAC systems in response to RO-UKHPR1000-0002 and RO-UKHPR1000-0039. I have assessed the adequacy of the RP's analysis in collaboration with the ONR Mechanical Engineering Inspector. The RP has demonstrated an absence of cliff-edge effects for SSCs impacted by the high-air temperature, although a number of modifications to the design are needed and the ONR Mechanical Engineering Inspector has raised AF-UKHPR1000-0128 for further work during the detailed design of HVAC systems. The modifications will be implemented post-GDA when site-specific information is available.

4.10.1.5 Low-Air Temperature

Table 15: Low-air temperature hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Impact value
Low-air temperature	Instantaneous low-air temperature (dry bulb) – Present day	-22 °C	-22 °C
	Instantaneous low-air temperature (dry bulb) – 2100 epoch	-22 °C	-22 °C

292. The RP has defined the low-air temperature hazard for the GSE using Eurocode part 1-5 (Ref. 194) and the UK National Annex (Ref. 195), which was also used for the high-air temperature hazard (sub-section 4.10.1.4). Temperature data for Hinkley Point was selected as it bounds the three candidate sites (Ref. 195). A minimum shade air temperature value was calculated for a 1 x 10^{-4} annual probability of exceedance using Equation A.2 and the suggested coefficients from BS EN 1991-1-5 (Ref. 194). The use of a bounding value for the three candidate sites is conservative. Eurocodes are considered RGP, and in the absence of site-specific temperature data, I judge the use of this code to meet the expectations of SAP EHA.2 for use of best available relevant data.

293. The RP has chosen to not apply a climate change allowance to the low-air temperature hazard. This is because air temperatures are expected to increase in future epochs due to climate change, thus reducing the hazard severity over the lifetime of the plant. The RP considers it conservative to not include this allowance. This approach is consistent with the RP's treatment of hazard minima affected by climate change (sub-section 4.5.1.1). I concur with the RP's position based on existing RGP and current climate projections, and I judge this approach to be conservative for the low-air temperature hazard.

294. The low-air temperature hazard for the GSE is defined as follows:

- Present day: -22 °C
- 2100 epoch: -22 °C (no climate change allowance)

295. I have compared the RP's GSE value for the low-air temperature hazard with other new nuclear build and previous GDA projects. This benchmarking exercise shows the value to be similar with these other projects. Overall, I judge that the low-air temperature hazard defined for the GSE meets the expectations of SAPs EHA.3 and EHA.4, and is suitable for the purposes of GDA.

296. The PCSR (Ref. 3) compares the GSE value for low-air temperature with the FCG3 reference design value of 6 °C. The PCSR selects the GSE as the UK HPR1000 design input value because it bounds the FCG3 reference design value. This is consistent with the RP's stated approach for the selection of UK HPR1000 design input values.

297. The low-air temperature hazard was identified as a gap because the UK HPR1000 design input value is more onerous than what the FCG3 reference design has been designed to withstand. This potential regulatory shortfall was captured in RO-UKHPR-1000-0002 (Ref. 12) (sub-section 4.18.1.1). The RP has analysed the impact of this gap for relevant SSCs and, if needed, modified the generic UK HPR1000 design to withstand the UK HPR1000 design input values (Ref. 196). The SSCs affected by the low-air temperature hazard are presented in the 'External Hazards Gap Identification and Evaluation Report' (Ref. 197) and comprise:

- HVAC systems including DVD [DVBS], DVL [EDSBVS] and DCL [MCRACS].
- ASP [SPHRS].
- ECS [ECS].

298. My assessment of the RP's analysis of HVAC systems against the air temperature hazards has been discussed in the high-air temperature hazard sub-section (sub-section 4.10.1.4). With respect to the low-air temperature hazard, I highlight that:

- The RP's HVAC analysis identified insufficient heating in some rooms in extreme winter conditions (in other words UK HPR1000 design input values for low-air temperature), such as staircases and anterooms.
- The RP determined that additional local heaters are required to resolve the heating gaps. Heater sizing will be determined at site-specific stages, once the site-specific temperature data is known, and as normal business.
- The RP has not provided any sensitivity analysis for the low-air temperature hazard and has not demonstrated the absence of cliff-edge effects for relevant HVAC systems or the margins to failure as per the expectations of SAPs EHA.7 and EHA.18.

299. I judge the latter point to be a shortfall. The ONR Mechanical Engineering Inspector has raised Assessment Finding AF-UKHPR1000-0128 for the RP to demonstrate the absence of cliff-edge effects for HVAC systems, in addition to other matters, during site-specific phases. On this basis, I do not raise an additional finding here, but I expect the External Hazards Inspector to collaborate with the ONR Mechanical Engineering Inspector in relation to this matter during assessment of the site-specific safety case. I also expect a licensee to consider the expectations of SAPs EHA.7 and EHA.18 when undertaking this work post-GDA.

300. Both ASP [SPHRS] and ECS [ECS] can freeze during a low-air temperature hazard event and be unavailable to deliver required safety functions. Detailed evaluation for these systems is presented in the reports:

- 'Optioneering on Resisting of the Extremely Low Air Temperature on ASP [SPHRS]' (Ref. 212).
- 'Optioneering on Anti-freezing of Mechanical Draught Cooling Tower on ECS [ECS]' (Ref. 213).

301. The RP determined that both systems required modification to withstand the low-air temperature hazard. The RP presented these modifications at technical meetings (Ref. 214, Ref. 215), but they have not formed part of my detailed sampling. I note that:

- The ASP [SPHRS] was a category 3 modification.
- The modification to ECS [ECS] was category 2, and required formal acceptance by ONR into GDA. I discussed this with relevant engineering disciplines including mechanical engineering and C&I. The modification was formally accepted into GDA (Ref. 216).

302. I am satisfied that the RP has provided sufficient information to enable the modifications to be implemented in GDA.

303. Overall, I judge the RP's evaluation of the low-air temperature hazard to be consistent with RGP including ONR SAPs. The UK HPR1000 design input value for low-air temperature is conservative, with the bounding GSE value selected that was derived in accordance with SAP EHA.4. The RP has identified SSCs impacted by the low-air temperature hazard in response to RO-UKHPR1000-0002:

- HVAC systems have been analysed against the low-air temperature hazard as part of RO-UKHPR1000-0039. The RP has demonstrated modifications are needed to the design of various HVAC systems to withstand the hazard that will be implemented post-GDA when site-specific information is available. A licensee will need to demonstrate an absence of cliff-edge effects for these systems to address AF-UKHPR1000-0128 raised by the ONR Mechanical Engineering Inspector.
- The ASP [SPHRS] and ECS [ECS] have been modified during GDA to withstand the low-air temperature hazard.

4.10.1.6 Relative Humidity and Enthalpy

Table 16: Relative humidity and enthalpy hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Enthalpy	Maximum hourly enthalpy – Present day	78.4 kJ/kg	90.5 kJ/kg
	Maximum hourly enthalpy – 2080 epoch	90.5 kJ/kg	90.5 kJ/kg
	Maximum six hours enthalpy – Present day	78.4 kJ/kg	90.5 kJ/kg
	Maximum six hours enthalpy – 2080 epoch	90.5 kJ/kg	90.5 kJ/kg
	Maximum 12 hours enthalpy – Present day	78.1 kJ/kg	90.5 kJ/kg
	Maximum 12 hours enthalpy – 2080 epoch	90.2 kJ/kg	90.5 kJ/kg
Relative Humidity	Maximum relative humidity	100%	100%
	Minimum relative humidity	12%	12%

304. Humidity is a measure of the moisture content contained in the air. Humidity and high-air temperature are combined in calculating enthalpy values, which are used in the design of the heating and ventilation (HVAC) systems.

305. The RP has adopted the same enthalpy values as those defined by Hitachi-GE for the UK ABWR GDA (Ref. 129) as the GSE values. The RP has also argued for use of the climate change allowance defined by Hitachi-GE of 12.1 kJ/kg, which is based on UKCP09 climate projections. The UK ABWR project selected a bounding enthalpy value for the eight EN-6 sites analysed, which included the three candidate UK sites that inform the GSE for the UK HPR1000 GDA. The RP considers the proposed enthalpy values to be suitably conservative given a bounding value for the eight EN-6 sites has been selected. The ONR 'Step 4 Assessment of External Hazards for the UK ABWR' (Ref. 117) concluded that: "Hitachi-GE's approach [is] adequate for GDA. The methodology used to calculate enthalpy is in line with RGP, and the removal of excess conservatism from previous calculations has been adequately explained and evidenced."

306. The proposed GSE values for enthalpy are:

- GSE values for maximum hourly enthalpy
  - Present day: 78.4 kJ/kg
  - 2080 epoch: 90.5 kJ/kg
- GSE values for maximum six hour enthalpy
  - Present day: 78.4 kJ/kg
  - 2080 epoch: 90.5 kJ/kg
- GSE values for maximum 12 hour enthalpy
  - Present day: 78.1 kJ/kg
  - 2080 epoch: 90.2 kJ/kg

307. I have compared the RP's GSE values for enthalpy with information held by ONR for other GDA and new nuclear build projects in the UK. The values are conservative based on this comparison and, on this basis, I judge the proposed GSE values to meet the expectations of SAPs EHA.3 and EHA.4. The RP has not used modern standards to define the climate change allowances for enthalpy, given that suitable data is available for UKCP18. I judge this to be a minor shortfall as the enthalpy values for the GSE are conservatively defined and based on all eight EN-6 sites. A licensee will be expected to use modern standards to define the site-specific enthalpy hazard and associated climate change allowances for a target site.

308. The PCSR (Ref. 3) compares the GSE value for maximum hourly enthalpy of 90.5 kJ/kg with the equivalent FCG3 reference design value of 103 kJ/kg. The PCSR selects the GSE values as the UK HPR1000 design input value. This is inconsistent with the RP's stated approach for selection of UK HPR1000 design input values (Ref. 3). I challenged this approach via RQ-UKHPR1000-0736 (Ref. 217). The RP has justified the approach by arguing that:

- The GSE value is suitably conservative (Ref. 218).
- The cooling coil capacity of relevant enthalpy controlled ventilation systems (Type B systems) has been specified to be the same as the FCG3 reference design (in other words, designed for an enthalpy of 103 kJ/kg) (Ref. 219), which provides margin against cliff-edge effects.

309. I judge the RP's approach to be a minor shortfall against SAP SC.4 and the RP's own stated approach for the selection of UK HPR1000 design input values. Margin against cliff-edge effects would exist if the FCG3 reference design value was selected as the UK HPR1000 design input value, as it bounds the GSE value. It is for the RP to decide how to present their safety case. However, the current approach leads to ambiguity, which could potentially result in the specification of an incorrect maximum enthalpy value. This is judged to be a minor shortfall because the RP has specified the use of the FCG3 reference design cooling coils, which is expected to provide beyond design basis margin.

310. The RP has analysed a sample of relevant ventilation systems in response to RO-UKHPR1000-0039 (Ref. 15) against external hazards. My assessment of the RP's analysis of HVAC systems against relevant hazards is discussed in sub-section 4.10.1.4. With respect to the enthalpy hazard, I highlight that:

- Type B ventilation systems use LCUs to provide sufficient cooling, within specified limits, during normal operation and fault conditions.
- LCUs are sized on enthalpy only, rather than on temperature.
- Extreme temperature and enthalpy provide a bounding, psychrometric envelope and are not considered co-incident.
- Fabric heat gain, which can have a slight impact on enthalpy, has been considered for Type B ventilation systems using three cases.
- The RP's analysis has identified that there is insufficient flowrate for some HVAC systems in extreme summer conditions (in other words high-air temperature and enthalpy hazards) and ventilation systems may need to be enlarged during site-specific stages to provide the required increased flowrates.
- The blending of exterior and recirculated air to maintain the space supply air temperature will be considered further at the site-specific stages.
- The RP's analysis has demonstrated that, with increased flow rates, there is an absence of cliff-edge effects for enthalpy controlled ventilation systems up to and including the FCG3 design input value of 103 kJ/kg.

311. I note that the ONR Mechanical Engineering Inspector has raised the following Assessment Finding relevant to HVAC systems and associated hazards including enthalpy:

- AF-UKHPR1000-0128 for the licensee to justify for the detailed design of the HVAC systems that:

  - local peak internal temperatures are derived from extreme exterior temperature conditions for the site;
  - dependant safety-related equipment remains within its qualified temperature limits;
  - they are resilient against extreme exterior temperature, avoiding cliff-edge effects (e.g. flowrates, heating and thermal failures); and
  - the chiller design accounts for temperature, relative humidity and enthalpy during extreme exterior temperature conditions.

312. I judge this finding addresses my concerns relating to the substantiation of relevant HVAC systems against relevant hazards and that no further findings are needed from an external hazards perspective. The ONR External Hazards Inspector should collaborate with the ONR Mechanical Engineering during assessment of the site-specific safety case for HVAC systems to ensure the identified Assessment Finding is adequately resolved.

313. I have sampled SDMs for relevant HVAC systems to ensure the RP has specified the correct enthalpy values for the cooling coils including:

- SDM Chapter 3 for DVL [EDSBVS] (Ref. 220)
- SDM Chapter 3 for DCL [MCRACS] (Ref. 221)

314. I find the sampled SDMs, both specify incorrect enthalpy values (in other words 90.5 kJ/kg rather than the 103 kJ/kg, which the RP has stated would be used to be consistent with FCG3 reference design). I consider this a minor shortfall against the expectations of SAP SC.4. I highlight that the HVAC analysis performed in response to RO-UKHPR1000-0039 (Ref. 15) has used the correct inputs.

315. Overall, I judge the RP's evaluation of the enthalpy hazard to be adequate for the purposes of GDA. The GSE value for enthalpy is conservatively defined. The selection of the GSE value as the UK HPR1000 design input value is inconsistent with the RP's stated approach, but is mitigated by the RP specifying the same cooling coil capacity for relevant ventilation systems as for the FCG3 reference design. The RP has analysed enthalpy controlled (Type B) ventilation systems as part of RO-UKHPR1000-0039. The ONR Mechanical Engineering Inspector has raised several Assessment Findings relevant to the enthalpy hazard that address my concerns, and no further findings are raised in by my assessment. The ONR External Hazards Inspector should collaborate with the ONR Mechanical Engineering Inspector during assessment of the site-specific safety case for HVAC systems to ensure these findings are adequately addressed. A licensee will be expected to characterise the site-specific enthalpy hazard using modern standards during site-specific stages to demonstrate that the 'site challenge' is bounded by the UK HPR1000 design input value.

4.10.1.7 Maximum Sea-Water Temperature

Table 17: Maximum sea-water temperature hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Maximum sea-water temperature	Present day	28 °C	33.5 °C
	2100 epoch	33.5 °C	33.5 °C

316. The maximum sea-water temperature value has been obtained from EU Stress test data of Bradwell, Hinkley Point and Sizewell (Ref. 145, Ref. 146, Ref. 130). Data for Sizewell was selected as being bounding of the other sites (Ref. 145). This gives a present day, 1×10^{-4} annual probability of exceedance sea-water temperature of 28 °C.

317. The RP has included a climate change allowance for the maximum sea-water temperature based on an upper bound projection for RCP 8.5 sea-water temperatures from the UKCP18 Marine Report (Figure 2.2.1 in the 'UKCP18 Marine report' (Ref. 222)). This is because the UKCP09 multi-level temperature and salinity marine data have not been updated by UKCP18 (Ref. 223). The selected allowance corresponds to a +5.5 °C increase in sea-water temperatures. I have benchmarked this allowance against other projects. This exercise has shown that the proposed value is conservative when compared with other new build and GDA projects, which typically propose a climate change allowance less than 4 °C.

318. The GSE maximum sea-water temperature is defined as:

- Present day: 28 °C
- 2100 epoch: 33.5 °C

319. I have compared the proposed GSE values for the 2100 epoch with the EUR code for light water reactors (Ref. 42) and other new build and GDA projects. The EUR code

suggests a value of 30ºC for the maximum cooling water temperature. This comparison demonstrates that the UK HPR1000 GSE value (including the climate change allowance) is more conservative. On this basis I judge the value adequate for the purposes of GDA and to have met the expectations of SAPs EHA.3 and EHA.4.

320. The PCSR (Ref. 3) compares the GSE value with the FCG3 reference design value for sea-water temperature of 38 °C. The GSE value is selected as the UK HPR1000 design input value. This is inconsistent with the RP's stated approach for selection of UK HPR1000 design input values (Ref. 3). The RP has justified this approach as:

- The GSE value is conservatively derived.
- The same cooling capacity as the FCG3 reference design value has been specified for relevant systems, and therefore provides margin against cliff-edge effects.

321. The RP has adopted the same approach for maximum sea-water temperature as for the enthalpy hazard (sub-section 4.10.1.6). I judge the RP's approach to be a minor shortfall against SAP SC.4 and the RP's own stated approach in the PCSR (Ref. 3). Margin against cliff-edge effects would exist if the FCG3 reference design value was selected as the UK HPR1000 design input value, as it bounds the GSE value. In other words, the RP could have argued that the hazard is a category 1 hazard using the approach specified in the 'Beyond Design Basis External Hazards Evaluation Methodology' (Ref. 61) (sub-section 4.7.1.3). It is for the RP to decide how to present their safety case, but the current approach leads to ambiguity that could potentially result in the specification of an incorrect maximum sea-water temperature for relevant cooling systems.

322. Systems in GDA scope using sea-water as a heat sink include the Essential Service Water System (SEC [ESWS]) and Component Cooling Water System (RRI [CCWS]). I have sampled the requirements for the design of the RRI [CCWS] and can confirm the design requirement for normal operations is specified as 38 °C (Ref. 224, Ref. 225), which is the same as the FCG3 reference design (compare with 33.5 °C for the GSE and UK HPR1000 design input values). This means the relevant UK HPR1000 systems will have inherent margin compared with the UK HPR1000 design input value for maximum sea-water temperature.

323. Overall, I judge the RP's evaluation of the maximum sea-water temperature for the GSE to be adequate for the purposes of GDA. The definition of the GSE value is consistent with the expectations of SAPs EHA.2, EHA.3 and EHA.4. The selection of the GSE value as the UK HPR1000 design input value is inconsistent with the RP's approach, as it does not bound the FCG3 reference design value. The RP has stated that cooling capacity of relevant SSCs has been specified to be the same as the FCG3 reference design value, and this will provide margin compared with the selected UK HPR1000 design input value. I judge this argument acceptable for the purposes of GDA, but highlight the ambiguity this introduces to the safety case. A licensee will need to demonstrate the UK HPR1000 design input value bounds the target site's sea-water temperature hazards during site-specific stages. Any identified gaps will need to be addressed during site-licensing as part of normal business.

4.10.1.8 Minimum Sea-Water Temperature

Table 18: Minimum sea-water temperature hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Minimum sea-water temperature	Present day	-2 °C	-2 °C
	2100 epoch	-2 °C	-2 °C

324. The minimum sea-water temperature value for the GSE is based on the lowest temperature of salt water before freezing. This corresponds to a temperature of -2 °C given the salinity range of coastal regions of the North Sea and Atlantic Ocean (Ref. 50). Whilst not explicitly claimed by the RP, this approach is equivalent to a maximum credible event, for which ONR's expectations are discussed in SAP paragraph 242 (Ref. 2). In my view this approach is reasonable, as it would be illogical to select a temperature for sea-water below its freezing point.

325. For the minimum sea-water temperature, the RP has not included an allowance for climate change. This is because sea-water temperatures are projected to increase in the future due to climate change. This is consistent with the RP's approach to extreme minima hazards. I judge this treatment of climate change to be adequate for in the purposes of GDA.

326. The minimum sea-water temperature hazard for the GSE is defined as:

- Present day: -2 °C
- 2100 epoch: -2 °C

327. I have compared this value with information held by ONR for other GDA and new build projects. The value is similar to the minimum sea-water temperature values used by those projects. I judge the GSE value to be adequate for the purposes of GDA and to meet the expectations of SAP EHA.3.

328. The PCSR (Ref. 3) compares the GSE value with the FCG3 reference value (-2 °C and 8.9 °C respectively). The GSE value is selected as the UK HPR1000 design input value, as it bounds the FCG3 reference design value. This is consistent with the RP's stated approach for selection of UK HPR1000 design input values.

329. The minimum sea-water temperature hazard was identified as a gap during Step 2 of GDA and captured as a potential regulatory shortfall in RO-UKHPR-1000-0002 (Ref. 12) (sub-section 4.18.1.1). The RP has analysed the impact of this gap on relevant SSCs and, if needed, modified the design to meet the UK HPR1000 design input value (Ref. 196).

330. The impact of minimum sea-water temperature has been analysed in the SEC/RRI Analysis Report (Ref. 224). The minimum sea-water temperature can affect the heat exchange safety function of the following systems:

- SEC [ESWS]
- RRI [CCWS]

331. The RP provides optioneering for two modifications based on the Hongyanhe NPP units 1 and 2 (option 1), and units 3 and 4 (option 2). This plant experiences similar minimum sea-water temperatures as those proposed for the UK HPR1000 design input value. The RP has selected option 2 as the preferred modification. This modification introduces a bypass pipeline to the SEC [ESWS] system, downstream of the RRI heat

exchanger. The bypass line takes warm water and reintroduces it with water entering the system, thereby keeping the SEC [ESWS] and RRI [CCWS] within their operating temperature window and preventing loss of the heat exchanger.

332. Given the RP has selected a preferred option, I consider matter 1 from the closure note for RO-UKHPR1000-0002 (Ref. 226) to have been adequately addressed (sub-section 4.18.1.1). However, the RP has not provided an adequate demonstration of this modification's ability to maintain the SEC [ESWS] and RRI [CCWS] within their operating temperature limits (Ref. 224). I judge this is a shortfall and raise Assessment Finding AF-UKHPR1000-0089 for a licensee to demonstrate the UK HPR1000 design can withstand the minimum sea-water temperature hazard during site-specific stages. It is appropriate for this work to be undertaken during site-specific stages as the cooling approach (compare direct and indirect cooling methods) and system design is out of GDA scope and will depend on design choices by the licensee for a target site.

AF-UKHPR1000-0089 – The licensee shall substantiate the detailed design of the modified essential service water system and associated component cooling water system to demonstrate that the required safety functions are delivered in the presence of the minimum sea-water temperature hazard.

4.10.1.9 Precipitation

Table 19: Precipitation hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Precipitation	1 hour – Present day	163 mm	216mm
	1 hour – 2100 epoch	216 mm	216mm
	24 hours – Present day	228 mm	302 mm
	24 hours – 2100 epoch	302 mm	302 mm

333. The derivation of the precipitation (rainfall) hazard is discussed in sub-section 4.9.1.1. I am content with the RP's approach for definition of the GSE value for rainfall and its selection as the UK HPR1000 design input value.

334. The RP has not provided a specific methodology for the evaluation of rainfall, and the plant effects are considered to be the same as external flooding (Ref. 79). This means rainfall is considered in two ways:

- Flooding of structures (discussed in sub-section 4.9).
- Structural load that the civil structures must withstand.

335. External hazards inputs to the civil design are presented in the 'Generic Design Parameters for Civil Engineering' report (Ref. 172). I have sampled this document to ensure the inputs are consistent with the external hazards safety case. For rainfall I note:

- The rainfall hazard input is defined as 250 mm in the 'Generic Design Parameters for Civil Engineering' report (Ref. 172).
- The UK HPR1000 design input value for rainfall defined in the external hazards safety case is 216mm for 1 hour and 302 mm for 24 hours (Ref. 3).

336. I issued RQ-UKHPR1000-1652 (Ref. 227) for the RP to clarify this discrepancy. The RP's response (Ref. 228) indicates that the civil engineering input is based on overflow holes in the parapets that enclose the roof of each structure (except BRX). The top of the overflow holes is located 250 mm above the finished roof level. The overflow holes are a defence-in-depth feature and designed to ensure that the water accumulation height of the roof does not exceed 250mm. The RP also conservatively assumes the Station Sewage System (SEO [SSS]) comprising gutters and drains around each roof becomes blocked, but the overflow holes, located at a higher elevation, remain available.

337. The nuclear island buildings are all reinforced concrete shear wall and slab structures, and designed to resist a seismic event and aircraft impact. The 'Structural Analysis and Design Report for BFX' (Ref. 229) identifies the bounding load combinations for the civil design as those with earthquake. The RP has clarified that an increase in the rain load from 2.5 kN/m^2 (250 mm) to 3.02 kN/m^2 (302 mm) does not challenge the extant substantiation of the civil design.

338. I have discussed the substantiation of the civil structures with the ONR Civil Engineering Inspector. They have confirmed the design methodologies include external hazard loads. The structures that the Civil Engineering Inspector has sampled as part of their assessment have demonstrated the adequacy of the RP's approach in defining bounding load cases. The substantiation of the civil engineering design is presented in the relevant design substantiation reports. The ONR Step 4 civil engineering assessment report should be consulted for further details (Ref. 98).

339. Overall, I judge the RP's evaluation of the rainfall hazard to be adequate for the purposes of GDA. The definition of the GSE value for rainfall meets ONR's expectations in SAPs EHA.3 and EHA.4. The RP has justified the adoption of the GSE value as the UK HPR1000 design input value even though it does not bound the FCG3 reference design value. The RP has provided an appropriate justification for the rainfall loads analysed in the civil structure design, even though these are different to the UK HPR1000 design input value. The ONR Civil Engineering Inspector has confirmed the civil design has considered bounding load combinations.

4.10.1.10 Snow

Table 20: Snow hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Snow	Ground snow load – Present day	1.5 kPa	1.5 kPa
	Ground snow load – 2100 epoch	1.5 kPa	1.5 kPa

340. The RP has defined the snow hazard for the GSE using the EUR code. This recommends use of 1.50 kN/m^2 for ground snow loads. The RP has adopted this value and considers it representative of a 1 x 10^{-4} annual probability of exceedance snow event. Snow loads are also considered by the RP to bound loads from hail and sleet. I consider this a reasonable assumption for GDA. A licensee will need to demonstrate this assumption remains valid for a target site as part of normal business during site-specific phases.

341. The frequency and magnitude of snow events can be impacted by climate change. The RP has considered the UKCP18 data and chosen not to apply a climate change allowance to the snow hazard, as they consider this would reduce the hazard severity.

This is consistent with the RP's stated approach for extreme minima. The UKCP18 factsheet for snow notes a decline in events since the 1960s and predicts a decrease in both falling and lying snow across the UK in the future, despite a predicted increase in winter precipitation rates (Ref. 230). I concur with the RP's proposal based on the evidence provided and judge this approach conservative. The GSE value for snow is:

- Present day ground snow load: 1.5 kPa
- 2100 epoch ground snow load: 1.5 kPa

342. I have compared the ground snow loads with those adopted for previous GDAs and other new nuclear build projects:

- For the UK ABWR project (Ref. 129), Hitachi-GE defined a GSE value for snow of 1.50 kN/m^2 using Eurocode 1991-1-3 (Ref. 231) and the associated National Annex (Ref. 232).
- A value of 1.50 kN/m^2 bounds the site-specific snow hazard at other new build sites.

343. The RP's snow value is consistent with other, comparable projects. In the absence of site-specific data, the EUR code can be considered best available relevant data and I judge meets the expectations of SAP EHA.2.

344. I note that the EUR code used to derive the snow load does not provide any consideration of drifting. Appendix G.10 of the 'UK HPR1000 Generic Site Report' (Ref. 50) is meant to cover snow loading and drifting, but there is no discussion of drifting effects. I judge the omission of drifting in the derivation of the snow hazard to be a minor shortfall. I have identified three mitigating aspects in relation to this:

- The RP has provided evidence to show that snow is not the bounding load case for the civil structure design (Ref. 229).
- Snow loads are expected to reduce in the future due to climate change, and the RP has adopted a conservative approach by not accounting for these effects.
- The RP's chosen design code, ASCE 7-10 (Ref. 175), accounts for drifting via surcharge calculations.

345. I am satisfied that this gap is unlikely to fundamentally challenge the outcomes of my assessment or the RP's substantiation of the civil structures against the snow hazard, particularly given the code-based approach accounts for drifting effects. I judge the RP's approach to determine the snow hazard for the GSE to be adequate for the purposes of GDA.

346. The RP has selected the GSE value for snow as the UK HPR1000 design input value. The FCG3 reference design has not considered snow as an external hazard, given its location near the Tropic of Cancer and prevailing climatic conditions. This was identified as a potential regulatory shortfall in RO-UKHPR1000-0002 (Ref. 12) (sub-section 4.18.1.1). The RP has identified the plant effects of snow to include pressure on the civil structures and clogging of openings, including HVAC openings.

347. The RP's methodology for deriving snow loads for civil structures is presented in the 'Generic Design Parameters for Civil Engineering' report (Ref. 172). The RP selects Safeguard Building C (BSC) as the basis for the calculation, stating that it is the bounding case for nuclear island structures. The RP has used ASCE 7-10 (Ref. 175) for the UK HPR1000 GDA. This code has been superseded by ASCE 7-16 (Ref. 176). I judge this a minor shortfall, as there is no material impact on the hazard derivation. My TSC has compared the RP's selection of variables and clauses from ASCE 7-10 (Ref. 175) with those within ASCE 7-16 (Ref. 176) and found that both codes apply the same input variables and calculation methodology for derivation of snow load and drift

surcharge. A licensee will be expected to use modern standards during site-specific stages of the design development.

348. ASCE 7-10 (Ref. 175) has been used with the following roof snow loads:

- A value of 0.678 kN/m^2 for a 1 x 10^{-2} / yr. event calculated using ASCE 7-10 (Ref. 175) and based on a ground snow load with a 1 x 10^{-2} / yr. annual probability of exceedance of 0.565 kN/m^2 from Eurocode 1991-1-3 (Ref. 231).
- A value of 1.50 kN/m^2 for the 1 x 10^{-4} / yr. event based on the UK HPR1000 design input value.

349. The ASCE 7-10 design code accounts for snow drifting, and a surcharge of up to 2.22 kN/m^2 is calculated on top of the blanket 0.678 kN/m^2 over a length of 3.64m, assuming a triangular load distribution (Ref. 172). My TSC has applied the methodology outlined within Eurocode 1991-1-3 (Ref. 231) and found that the maximum drift loading at the parapets is 2 kN/m^2, which is bounded by the RP's value of 2.22 kN/m^2 calculated using ASCE 7-10 (Ref. 172).

350. It may be possible for loads local to the parapets and other obstacles or structures to potentially exceed the design loads considered by the RP, because the surcharge only appears to have been calculated for a 1 x 10^{-2} / yr. event. More detailed analysis of the drifting load case is needed during detailed design of the civil structures. I consider this normal business post-GDA when site-specific inputs (e.g. wind rose) will be available that may influence the drifting analysis. A licensee will need to consider the effects of snow drifting on the UK HPR1000 design during site-specific stages to understand whether the resultant loads can exceed those based on design codes. The impact of any exceedance should be analysed, and the design modified accordingly, if needed. The licensee will need to also consider the potential for snow loads on other unprotected plant that have not been evaluated during GDA.

351. I have discussed the substantiation of the civil structures with the ONR Civil Engineering Inspector. They have confirmed that snow loads are considered in the civil structure design methodologies (Ref. 233) that the RP has submitted in response to RO-UKHPR1000-0002 (sub-section 4.18.1.1). The structures that the Civil Engineering Inspector has sampled as part of their assessment have demonstrated the adequacy of the RP's approach in defining bounding load cases. The substantiation of the civil engineering design is presented in the relevant design substantiation reports. The ONR Step 4 civil engineering assessment report should be consulted for further details (Ref. 98).

352. The RP has analysed clogging effects from snow in the 'Meteorological Hazards Safety Evaluation Report' (Ref. 71). The analysis concludes that openings are protected from the effects of clogging by inverse-L structures. The analysis has considered clogging of some SSCs located external to the buildings, such as diesel oil tank vent and exhaust pipes (e.g. Figure F-3-10 of 'Meteorological Hazards Safety Evaluation Report' (Ref. 71)). I find the RP's analysis adequate for GDA. I expect a licensee to consider the potential for drifting snow to clog other unprotected SSCs during site-specific stages once the local environmental conditions are known that may influence drifting. This is normal business for site-specific stages.

353. Overall, I judge the RP's evaluation of the snow hazard to be adequate for the purposes of GDA. The RP has derived a GSE value for snow using best relevant data as expected by SAP EHA.2. The RP has selected the GSE value as the UK HPR1000 design input value, as the FCG3 reference design has not been analysed against snow. The RP has identified SSCs impacted by this gap and provided an adequate evaluation during GDA to demonstrate the design can withstand the effects. A licensee will be expected to demonstrate that the UK HPR1000 design input value for snow is bounded by the site-specific hazard during site-specific stages and, if necessary,

analyse any gaps. Further analysis of drifting effects is needed, but I judge this is best undertaken during site-specific stages when site-specific factors can be taken into account.

4.10.1.11 Ice

Table 21: Ice hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Icing	Ice thickness	117 mm	117 mm
	Clear ice density	9 kN/m^3	9 kN/m^3
	Ice load	1.053 kPa	1.053 kPa

354. Different types of ice can form depending on the prevailing environmental conditions of a site (Ref. 50). This includes:

- Frazil ice – forms in supercooled turbulent water.
- Rime ice – forms when water droplets freeze quickly on a surface below 0 °C and in doing so preserve some of the spherical form of the droplet.
- Clear ice – forms through firnification of ground snow or when only part of a supercooled water droplet freezes enabling the remaining water to spread out and coalesce with other droplets before freezing as a solid sheet.

355. For GDA the RP has selected clear ice as bounding other ice types:

- Frazil ice is screened to site-specific phases based on site-specific information being required to characterise the hazard frequency.
- Rime ice includes more void space with a corresponding lower density.

356. I judge the RP's approach adequate for GDA. I highlight that frazil ice formation is possible for the GSE given the RP's UK HPR1000 design input value for minimum sea-water temperature (-2 °C), which is lower than the general freezing point of seawater (-1.6°C to -1.8 °C dependent on salinity). The RP, however, has considered LUHS on a generic basis as a design basis condition (sub-section 4.13.1.2), which could be initiated by frazil ice formation.

357. The RP has defined the icing hazard density parameter based on Eurocode 1993-3-1 (Ref. 234) and the associated National Annex (Ref. 235). The RP has based the clear ice thickness on data taken from the UK ABWR GDA project (Ref. 129). I note that:

- Ice thickness for the UK ABWR GDA was calculated for rime ice, rather than clear ice, but this is likely to be conservative given the greater void space present in rime ice.
- The thickness excludes wind effects as Figure NA.2 of Eurocode 1993-3-1 (Ref. 235) shows this is bounding for ice thickness.
- A bounding value was selected that envelopes the eight EN-6 sites considered for UK ABWR GDA.

358. The RP has not included climate change allowances for the icing hazard. The RP expects climate change to reduce the frequency of icing events in the future, and hence hazard severity. This is consistent with the RP's approach for other hazard extreme minima (e.g. low-air temperature and snow). Climate change projections for ice are not available for either UKCP09 or UKCP18 (Ref. 236). I have consulted with the ONR Expert Panel on Natural Hazards; there are no reasons presented in current

theories that indicate the formation of ice will increase or decrease in future epochs, other than the general global mean temperature trends. Given this uncertainty, I consider the RP's position adequate for GDA. A licensee will need to demonstrate this assumption remains valid for a target site as part of normal business.

359. The GSE hazard values for icing are defined as follows:

- Present day GSE value for icing hazard:
  - Clear Ice Density: 9 kN/m^3
  - Clear Ice Thickness: 117 mm
- 2100 epoch GSE value for icing hazard:
  - Clear Ice Density: 9 kN/m^3
  - Clear Ice Thickness: 117 mm

360. I judge the RP's definition of the GSE values for the icing hazard to be adequate for the purposes of GDA and consistent with the expectations of SAPs EHA.2, EHA.3 and EHA.4 given the use of RGP and conservatisms included.

361. The PCSR (Ref. 3) selects the GSE value for the icing hazard values as the UK HPR1000 design input value. Icing hazards were not considered for the FCG3 reference design due to its prevailing environmental and climatic conditions. The need for the RP to consider icing for the UK HPR1000 was identified as a gap in RO-UKHPR1000-0002 (Ref. 12) (sub-section 4.18.1.1).

362. The plant effects of icing are not identified in the 'External Hazards Schedule Report' (Ref. 79), but are discussed in the 'UK HPR1000 Generic Site Report' (Ref. 50) and include:

- Pressure on structures
- LUHS

363. The effects of icing are evaluated in the 'Meteorological Hazards Safety Evaluation Report' (Ref. 71), along with snow. The effects are consistent with the 'UK HPR1000 Generic Site Report' (Ref. 50) and include:

- Structural load
- Blockage of SEC [ESWS] intakes

364. I have assessed LUHS, which may be initiated by a blockage of SEC [ESWS] intakes, in sub-section 4.13.1.2.

365. The RP's approach to structural loads from icing is presented in sub-section 3.7.2.1 of the 'Meteorological Hazards Safety Evaluation Report' (Ref. 71). The loads resulting from icing are bounded by snow (compare 1.5 kPa and 1.053 kPa), particularly when drifting is taken into account. The ONR Civil Engineering Inspector has confirmed external hazard loads are included in the design of the civil structures and the design has been substantiated against bounding load combinations. The adequacy of the RP's approach has been demonstrated in GDA for the sampled civil structures.

366. The RP claims that the VDA [ASDS] silencer design and high temperature steam flow, when in operation, prevents the accumulation of snow / ice. The RP's evaluation of icing in the 'Meteorological Hazards Safety Evaluation Report' (Ref. 71) does not adequately consider the effects on other unprotected SSCs, such as the ASP [SPHRS] pipes or diesel oil tank vent and exhaust pipes (e.g. Figure F-3-10 of the 'Meteorological Hazards Safety Evaluation Report' (Ref. 71)). It is not clear whether

additional loadings from ice formation on unprotected SSCs or clogging of exhausts / vents etc., could lead to their failure, with loss of associated safety functions. I consider this to be a shortfall in the RP's safety case and I raise Assessment Finding AF-UKHPR1000-0090 for this evaluation to be undertaken during site-specific stages. I consider it reasonable for this work to be undertaken post-GDA as this will enable site-specific inputs to be included that may influence the analysis and design.

AF-UKHPR1000-0090: The licensee shall evaluate the potential effects of ice on unprotected structures, systems and components, taking into account site-specific characteristics and layout, to demonstrate that there are no adverse effects on the plant or loss of safety functions.

4.10.1.12 Lightning

Table 22: Lightning hazard parameters for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Lightning	Peak current	300 kA	300 kA
	Minimum current	2 kA	2 kA
	Thunderstorm days	13 days	13 days
	Lightning flashes	1.3 flashes / km^2 / yr.	1.3 flashes / km^2 / yr.

367. I assessed the RP's approach to define the lightning hazard during Step 3. The RP proposed a 200 kA maximum peak current based on BS EN/IEC 62530 (Ref. 43). In my view this did not meet the intent of the SAPs EHA. 11 and EHA. 4 (paragraph 242), as the RP had not provided any evidence to support the 200kA value being equivalent to an event with a 1 x 10^{-4} annual probability of exceedance. The RP has undertaken a study to derive a GSE value for lightning on a basis consistent with the expectations of the SAPs. A summary is presented in the 'UK HPR1000 Generic Site Report' (Ref. 50). The RP has reviewed scientific and technical papers that have researched lightning strike data globally to determine peak lightning currents (Ref. 237, Ref. 238). This research indicates that the largest negative first return stroke peak current that can exist in nature is about 300 kA for temperate regions (Ref. 237, Ref. 238). The RP considers this to be relevant to the UK, which has a temperate maritime climate.

368. The RP has not included any climate change effects for lightning. This is because UKCP18 does not provide data for lightning and the RP considers 300 kA the largest peak current that can exist for temperate environments. Further work is needed under UKCP18 to determine the adequacy of convection permitting models in representing UK lightning occurrences (Ref. 239, Ref. 236). UKCP09 indicated increased frequency of lightning occurrence in the UK is probable in future epochs (Ref. 240), but there was substantial uncertainty in the estimated changes. I judge the RP's approach adequate for the purposes of GDA given the uncertainty and paucity of data associated with climate change effects for lightning. A licensee is expected to revisit this during characterisation of the site-specific hazard during site-specific stages and, if adequate data exists, to consider the implications of climate change on the lightning hazard for a target site.

369. The RP has combined the information on lightning current with published lightning flash density data from the British Standard for lightning protection (Ref. 241) to derive

the following design basis parameters. The GSE values for the lightning hazard comprise:

- Lightning maximum peak current: 300 kA (for both positive and negative strikes)
- Thunderstorm days: 13 days
- Mean flash frequency: 1.3 flashes / km2 / year

370. The PCSR (Ref. 3) selects the GSE value for lightning as the UK HPR1000 design input value, as it bounds the FCG3 reference design value. I have compared the UK HPR1000 design input value for lightning with new nuclear build projects and previous GDA projects. This has shown the UK HPR1000 design input value is similar to that assessed as being adequate by ONR for the UK ABWR GDA (Ref. 117) and bounding of other projects. I am content with the RP's derivation of the GSE value for lightning hazard and its selection as the UK HPR1000 design input value.

371. The lightning hazard was discussed with the RP at a technical meeting (Ref. 242) in relation to the RP's approach for cliff-edge effects and beyond design basis events (Ref. 61). The RP confirmed the intent to claim the lightning peak current of 300 kA as a maximum credible event, thus negating the need to consider cliff-edge and BDBA for the hazard. I judged the RP had, at the time, provided insufficient evidence to justify this claim. I raised RQ-UKHPR1000-0734 (Ref. 243) seeking supplementary evidence. The RP argues in response to this RQ that (Ref. 244):

- Lightning strikes >300 kA constitute only a very small percentage of 0.061 % (positive) and 0.009 % (negative) respectively of those recorded (Ref. 237).
- To date, no lightning currents >300 kA have been directly measured in the UK.
- Individual cases >300 kA can be explained by the uncertainty involved with deriving peak currents from calculations based on the peak electromagnetic field data from lightning location systems.

372. For the purposes of GDA I judge that the RP has provided sufficient evidence to demonstrate that lightning strikes with a peak current greater than 300 kA value have a low probability of exceedance in temperate regions. On this basis I accept the RP's arguments relating to cliff-edge (SAP EHA.7) and BDBA (SAP EHA.18). Further work is needed post-GDA to demonstrate the adequacy of this claim for a target site, including consideration of RGP and the effects of climate change on the lightning hazard.

373. The plant effects of lightning are identified in the 'External Hazards Schedule Report' (Ref. 245). Compared to other meteorological hazards, the impacts of lightning are more varied. The main risks to a NPP are:

- Physical damage caused by a direct strike.
- Damage to electrical systems caused by the associated current from the strike.

374. The RP has analysed lightning effects in the 'Lightning, Electromagnetic Interference and Space Weather Safety Evaluation Report' (Ref. 73). Lightning as a natural, external hazard cannot be prevented, and must be protected against. The RP's protection strategy for lightning is presented in the 'Earthing and Lighting Protection Scheme' (Ref. 246) and uses an external lightning protection system based on BS EN/IEC 62530 (Ref. 43) and comprising:

- Air termination devices
- Mesh
- Down-comers
- An earthing mat
- An equipotential bonding network

375. BS EN/IEC 62305 (Ref. 43) only codifies the design of lightning protection systems to a maximum current of 200 kA (lightning protection level I). This is a potential gap, given the UK HPR1000 design input value of 300 kA. The RP has evaluated potential options for the design of a lightning protection system to protect against a peak current of 300 kA (Ref. 247). The RP proposes an external lightning protection system and integrated internal lightning protection system in a multiple systems (overlay) approach. The external and internal lightning protection systems are both specified to lightning protection level I (Ref. 43). The integrated system is intended to reduce, via a current sharing approach, the down-conductor lightning current to within the bounds of a lightning protection level I system and class I surge protection devices (in other words <200 kA). The internal system adds a superimposed mesh grid to the foundation slab, floor, exterior wall and the roof of buildings. The RP has provided a preliminary safety justification for this conceptual design (Ref. 73).

376. I raised RQ-UKHPR1000-1085 in relation to the design of this integrated system, given its non-standard approach (Ref. 248). I queried the minimum lightning current parameter, which is used to determine the spacing of air terminations, and how the lightning strike current is transferred to the internal lightning protection system. The RP's response (Ref. 249) clarifies that:

- The internal system is bonded with the external system and shares common air terminations.
- The concrete covering the internal mesh is only 50 mm thick and forms a sacrificial layer.
- The integrated lightning protection system is planned to act as the termination point for the lightning strike in event of air terminations being lost, such as through a combined hazard event (e.g. extreme wind and lightning).

377. Clause 5.2.5 in BS EN/IEC 62305-3 (Ref. 250), referred to by the RP, allows for damage to non-metallic components as long as the damage is considered to be acceptable. Given the sacrificial nature of the overlying concrete layer, I judge such damage to be acceptable and unlikely to impair the delivery of safety functions by the civil structures. The RP has satisfactorily addressed my concerns with issue of the latest version of the 'Lightning, Electromagnetic Interference and Space Weather Safety Evaluation Report' (Ref. 73) that captures the response to RQ-UKHPR1000-1085 and subsequent discussions (Ref. 249).

378. With respect to the minimum lightning current parameter, BS EN/IEC 62530 (Ref. 43) states: "The interception efficiency of an air-termination system depends on the minimum lightning current parameters and on the related rolling sphere radius." The designs from BS EN/IEC 62305 use a minimum current of 3 kA. The smallest current that can exist in nature is expected to be between 1.5 kA and 3 kA, with the most probable value being approximately 2 kA (Ref. 238). Using 2 kA in Equation A.1 of BS EN/IEC 62305 (Ref. 43) gives a recommended rolling sphere radius of 15.69m for air terminations, which is less than the 20m spacing recommended by BS EN/IEC 62305 (Ref. 43) for a minimum current of 3 kA. In response to RQ-UKHPR1000-1085 (Ref. 249), the RP has committed to using a minimum peak current of 2 kA as the UK HPR1000 design input value for the lightning protection system. I have sampled the following reports to ensure this commitment has been captured:

- 'Earthing and Lighting Protection Scheme' (Ref. 246).
- 'Lightning, Electromagnetic Interference and Space Weather Safety Evaluation Report' (Ref. 73).

379. The UK HPR1000 design input value for the minimum lightning current is not specified in the 'Earthing and Lighting Protection Scheme' (Ref. 246), and reference is made to the standard BS EN/IEC 62305 parameters (Ref. 43). I judge this to be a minor

shortfall compared with the expectations of SAP SC.4, which expects a safety case to be accurate and demonstrably complete for its intended purpose.

380. The rolling sphere method prescribed in BS EN/IEC 62530 (Ref. 43) also requires the air terminations to be sufficiently tall to mitigate the potential striking of projections located below the terminations. This could include safety classified SSCs such as VDA [ASDS]. The RP has not defined the height of the air terminations in any documentation relevant to the lightning safety case. I judge this a matter for resolution during detailed design of the lightning protection system, based on discussions with the ONR Electrical Engineering Inspector. I highlight that the 'Lightning Protection Guide' (Ref. 251) provides a formula that can be used to calculate the penetration depth of the rolling sphere and inform the height of air terminations. The Step 4 electrical engineering assessment report should be consulted for further details on the lightning protection system (Ref. 142).

381. Overall, I judge that the RP's evaluation for the lightning hazard is adequate for the purposes of GDA. The RP has defined a GSE value for lightning that is based on best available information as expected by SAP EHA.2. The GSE value has been selected as the UK HPR1000 design input value as it bounds the FCG3 reference design value. A licensee will need to demonstrate that the site-specific lightning hazard is bounded by the UK HPR1000 design input value, including consideration of climate change effects on the lightning hazard using RGP at the time of site-specific stages. Any gaps will need to be addressed as normal business. The RP has provided an ALARP optioneering study to identify credible modifications to the lightning protection system to withstand the UK HPR1000 design input value. Further work is needed during detailed design to substantiate the lightning protection system against the UK HPR1000 design input value. This work is normal business.

4.10.1.13 Electromagnetic Interference

Table 23: Electromagnetic interference hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Electromagnetic Interference	External electromagnetic interference	Not defined	Not defined

382. Electromagnetic interference (EMI) (also called radio frequency interference or RFI) is a disturbance that affects an electrical circuit due to electromagnetic radiation emitted from an external source. The RP considers EMI from two sources:

- Man-made – from radio masts, radar etc.
- Natural – from lightning strike or solar flares.

383. The RP's safety case only screens-in EMI from a lightning strike source:

- Man-made sources of EMI are screened-out as needing site-specific information to characterise the hazard in a meaningful way.
- Solar flares are screened-out as the effects are considered to be bounded by other space weather hazards (sub-section 4.11) and LOOP (sub-section 4.13.1.1).

384. I judge that:

- Man-made EMI is a site-specific hazard and that screening this hazard out from further consideration in GDA is appropriate.

- It is reasonable to not evaluate EMI from space weather during GDA as the consideration of, and protection against sources of EMI other than lightning requires choices that can only be made at the detailed design phase.

385. I am content to accept the RP's analysis of EMI from lightning strikes only for the purposes of GDA. I expect a licensee to consider all sources of EMI at site-licensing and provide an adequate evidential basis for any screened-out sources. I consider this to be normal business.

386. The RP does not define a GSE value for EMI. Rather the RP uses the UK HPR1000 design input value for lightning to calculate magnetic field strengths based on BS EN 62305-4 (Ref. 252). This approach is acceptable for GDA and uses RGP.

387. Plant effects of EMI are identified in the ' External Hazards Schedule Report' (Ref. 79), with a more detailed description provided in other relevant safety case submissions (Ref. 73, Ref. 253). The SSCs affected by EMI are electrical technologies, including C&I and power systems.

388. The principal means of protection against EMI is provided by: "The concrete structure in which the reactor is housed normally acts as a Faraday cage (this is assisted by ensuring the reinforcement is adequately connected and earthed)" (Ref. 50). The RP claims the Faraday Cage mitigates the EMI effects of an external lightning strike on equipment housed within the nuclear island structures. Other protection measures follow the requirements of BS / IEC 62855-1 (Ref. 254) and include:

- An equipotential bonding network
- Shielding of SSCs
- Following good practice for cable layout

389. I judge the RP has identified relevant protection measures and BS / IEC 62855-1 (Ref. 254) to be RGP.

390. I have sought clarity on the RP's claims with respect to the Faraday Cage where it crosses seismic gaps and the design details that bridge over the gaps between civil structures in RQ-UKHPR1000-1085 (Ref. 248). The RP's response (Ref. 249) did not fully satisfy my query, but is commensurate with the level of detail available for the design in GDA. A licensee will need to demonstrate and justify the adequacy of the Faraday Cage during detailed design. This work is normal business.

391. The effects of lightning strikes on buildings are analysed in the 'Lightning Protection Studies Report' (Ref. 253). The RP claims that the overlay lightning protection system (external and integrated internal) and current sharing approach means that the EMI effects in nuclear island buildings are bounded by the protection provided by a lightning protection level I system (Ref. 247). Three lightning protection zones (LPZ) are identified for the Safeguard Buildings (BS_X), which are analysed as an example to show how the Faraday Cage principle is utilised in the design:

- LPZ 1 – rooms with an external wall of reinforced concrete.
- LPZ 2 – equipment in a LPZ 1 room with shielded housing or a room spatially separated from the external walls of the building.
- LPZ 3 – equipment in a LPZ 2 room with a shielded housing.

392. The electromagnetic field strength that SSCs will experience in each LPZ has been calculated by the RP in the 'Lightning Protection Studies Report' (Ref. 253) using the approach described in BS EN 62305-4 (Ref. 252). The RP has used the UK HPR1000 design input value of 300 kA for the lightning peak current (sub-section 4.10.1.12). Calculations in the report 'Design Basis Lightning Current Protection Analysis' (Ref. 247) are preliminary, but show the magnetic field strengths within the LPZ 2 zone are

well below the proposed design level of 300 A/m that has been selected from BS EN / IEC 62003 (Ref. 255) as the electromagnetic compatibility qualification value for SSCs.

393. My TSC has provided an independent check of the RP's magnetic field strengths presented in an earlier revision of the ' Lightning Protection Studies Report' (Ref. 253). The same magnetic field strengths were calculated by my TSC for both 200 kA (H1 of 763.29 A/m) and 300 kA (H1 of 1144.9 A/m) lightning strikes as obtained by the RP. The RP's H_2 of 27.9 A/m is similar to the 27.8 A/m calculated by my TSC, with differences likely due to internal rounding within the RP's calculation. On this basis, I am satisfied that the RP has correctly applied the guidance in BS EN 62305-4 (Ref. 252).

394. The RP's analysis of EMI effects for a limited sample in the BS_X provides confidence that SSCs are sufficiently protected against a 300 kA lightning strike, thus preventing any impact on the delivery of associated safety functions. Further work is needed during detailed design to confirm the magnetic field strengths for all equipment rooms are bounded by the protection provided by a lightning protection level I system and within equipment qualification limits. I consider this to be normal business.

395. Overall, I judge that the RP's evaluation of EMI is adequate for the purposes of GDA. The RP has analysed the effects of EMI from lightning strikes, and demonstrated the conceptual protection scheme can limit magnetic field strengths to within the protection provided by a lightning protection level I system and the qualification level of SSCs. I expect a licensee, as part as their normal site-specific and detailed design work, to:

- Consider all relevant sources of EMI during site-specific stages, including space weather.
- Provide an adequate justification for screening-out of any EMI sources.
- Calculate magnetic field strengths for all equipment rooms during detailed design.
- Provide an adequate safety justification that the risks from EMI are reduced ALARP.

4.10.2 Strengths

396. My assessment of meteorological hazards has identified the following strengths:

- The RP has evaluated an adequate range of meteorological hazards during GDA, with adequate justification provided for screened-out hazards.
- The RP has conservatively derived the GSE values for hazards by either selecting a bounding value for the three candidate sites or using best available information / RGP as expected by SAP EHA.2.
- The RP has calculated climate change allowances using UKCP18, and I judge the approach to be consistent with ONR's guidance.
- The RP has chosen not to apply climate change allowances to extreme minima, and I consider this approach conservative given the general consensus that climate change will reduce the frequency with which extreme events will occur.
- The RP's selection of UK HPR1000 design input values for meteorological hazards is generally consistent with the approach defined in the PCSR of selecting either the bounding GSE value or FCG3 reference design value (Ref. 3). Any exceptions have been justified by the RP.
- The selected UK HPR1000 design input values are expected to bound the site-specific hazard values for a target site.
- The RP has analysed the UK HPR1000 against meteorological hazards, with particular focus on identified gaps where the GSE value exceeds the FCG3 reference design value.

- The RP's analysis uses, and is consistent with, RGP including US NRC Regulatory Guides, Eurocodes and ASCE 7-10.
- The RP has provided ALARP optioneering for any identified gaps and modifications have been identified either for implementation during GDA or post-GDA for a target site once site-specific information is available.
- The RP's analysis has demonstrated the UK HPR1000 is robust against meteorological hazards.
- Sufficient evidence has been provided during GDA to support the conclusions of the safety evaluations for meteorological hazards.

4.10.3 Outcomes

397. Based on my assessment of meteorological hazards I have raised three Assessment Findings:

- AF-UKHPR1000-0088 for a licensee to demonstrate that the site-specific design provides protection against the wind-borne missiles hazard and that risks are reduced to be ALARP, including the implementation of modification options identified during GDA, where necessary.
- AF-UKHPR1000-0089 for a licensee to substantiate the detailed design of the modified essential service water system and associated component cooling water system to demonstrate that the required safety functions are delivered in the presence of the minimum sea-water temperature hazard.
- AF-UKHPR1000-0090 for a licensee to evaluate the potential effects of ice on unprotected structures, systems and components, taking into account site-specific characteristics and layout, to demonstrate that there are no adverse effects on the plant or loss of safety functions.

398. I have not raised any additional Assessment Findings relating to HVAC systems or associated hazards as the ONR Mechanical Engineering Inspector has raised an Assessment Finding via their assessment report that address my concerns (AF-UKHPR1000-0128). During site-specific stages, the ONR External Hazards Inspector is expected to collaborate with the ONR Mechanical Engineering Inspector to ensure this Assessment Finding is adequately resolved, and related risks are reduced to ALARP.

399. I have also identified several minor shortfalls that are discussed in sub-section 4.10.1. I judge that these minor shortfalls do not undermine the conclusions of the external hazards safety case relevant to meteorological hazards.

400. A licensee will need to demonstrate that the meteorological hazards for a target site are bounded by the UK HPR1000 design input values. Any identified gaps will need to be analysed and, if necessary, the design modified to withstand the hazard values of the target site. The licensee will need to supplement the existing safety justification for the UK HPR1000 as the level of design detail progresses to demonstrate that risks from meteorological hazards are reduced ALARP. I consider this work normal business during site-specific stages, and no further findings are raised.

4.10.4 Conclusion

401. I have assessed the RP's safety evaluation for meteorological hazards. I conclude that:

- The screened-in meteorological hazards for GDA are appropriate. Other meteorological hazards are screened-out with appropriate justification as site-specific information is needed to characterise the flooding sources in a meaningful way.
- The definitions of meteorological hazards are based on bounding data for the three candidate sites, best available data and / or RGP. Sufficient evidence has

been provided to demonstrate that the GSE values bounded the three candidate sites. I judge the GSE values to meet the expectations of SAPs EHA.2, EHA.3 and EHA.4.

- The UK HPR1000 design input values are typically selected as the bounding value from either the FCG3 reference design or GSE:
  - Exceptions to this include rainfall, enthalpy and maximum sea-water temperature.
  - For enthalpy and maximum sea-water temperature, the RP has stated that relevant SSCs providing a cooling function will be specified to have the same capacity as the FCG3 reference design. The FCG3 reference design input values are bounding of the GSE values.
- The RP's DBA has:
  - Identified those measures that protect against the meteorological hazards and demonstrated defence-in-depth.
  - Substantiated the civil structures against bounding load cases, which includes consideration of external hazard loadings.
  - Identified protection requirements for other SSCs (e.g. mechanical systems) that will be substantiated during detailed design.
  - Undertaken optioneering where gaps have been identified and implemented the preferred options, where appropriate, to protect against hazard effects.
  - Provided sufficient evidence to demonstrate that the design is robust against the meteorological hazards.
- The RP's BDBA has:
  - Categorised hazards in three ways, which determines the analysis approach.
  - Where the FCG3 reference design value is selected as the UK HPR1000 design value and bounds the GSE, this provides demonstrable beyond design basis margin.
  - Demonstrated an absence of cliff-edge effects, although there is little margin for some hazards where the UK HPR1000 design input value is based on the GSE value (e.g. high-air temperature).
- I have raised three Assessment Findings and highlight that a further Assessment Finding raised by the ONR Mechanical Engineering Inspector is relevant to air temperature and enthalpy hazards (AF-UKHPR1000-0128). I judge that these do not undermine the external hazards safety case or its conclusions:
  - AF-UKHPR1000-0088 for a licensee to demonstrate that the site-specific design provides protection against the wind-borne missiles hazard and that risks are reduced to be ALARP, including the implementation of modification options identified during GDA, where necessary.
  - AF-UKHPR1000-0089 for a licensee to substantiate the detailed design of the modified essential service water system and associated component cooling water system to demonstrate that the required safety functions are delivered in the presence of the minimum sea-water temperature hazard.
  - AF-UKHPR1000-0090 for a licensee to evaluate the potential effects of ice on unprotected structures, systems and components, taking into

account site-specific characteristics and layout, to demonstrate that there are no adverse effects on the plant or loss of safety functions.

- The RP's evaluation has demonstrated that the design is robust against meteorological hazard effects. Further work is needed post-GDA as normal business to demonstrate risks are reduced ALARP including:
  - Demonstrating the site-specific meteorological hazards are bounded by the UK HPR1000 design input values.
  - Analysing any gaps where the site-specific meteorological hazards exceed the UK HPR1000 design input values.
  - Evaluating screened-out hazards.
  - Demonstrating beyond design basis margins to failure.

4.11 Space Weather Hazards

4.11.1 Assessment

402. Space weather (or more specifically solar storms) is a challenge to infrastructure, and can influence the performance and reliability of ground-based technological systems. The challenge from space weather has been studied to advise UK Government policy (Ref. 256), and severe space weather is identified on the UK's 'National Risk Register' (Ref. 257). The potential vulnerability of electric grid and other infrastructure has been highlighted by studies (Ref. 258).

403. The FCG3 reference design has not considered space weather hazards. This was identified as a gap during Step 2 of GDA and captured as a potential regulatory shortfall in RO-UKHPR1000-0002 (Ref. 12) (sub-section 4.18.1.1). The RP's response to RO-UKHPR1000-0002 (Ref. 196) accounts for space weather hazards. Space weather can be characterised in terms of three phenomena:

- Solar flares – bursts of X-rays and other electromagnetic radiation that can cause radio blackouts.
- Solar energetic particles – solar radiation storms that have the potential to create ground-level particle fluxes of neutrons and muons that affect electronic systems.
- Coronal mass ejections – large ejections of plasma and accompanying magnetic field from the solar corona that interact with the Earth's geomagnetic field with the potential to impact and disrupt power grids.

404. The RP has only considered EMI from lightning during GDA (sub-section 4.10.1.13). I judge it is reasonable to not evaluate EMI from space weather during GDA as the consideration of, and protection against sources of EMI other than lightning requires choices that can only be made at the detailed design phase. This is consistent with the ONR judgements for previous GDA projects (Ref. 117). This section focuses on my assessment of solar energetic particles and geomagnetically induced currents.

4.11.1.1 Solar Energetic Particles

Table 24: Solar energetic particles hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Solar Energetic Particles	Ground-level particle fluxes of neutrons and muons	Not defined	Not defined

405. The RP has considered the solar energetic particles hazard in response to RO-UKHPR1000-0002 (sub-section 4.18.1.1). The RP has not characterised the solar energetic particles hazard for the GSE, rather electing to focus on the development of strategies to protect against and mitigate the hazard's effects on susceptible plant (Ref. 259). I am content with the RP's approach as no existing licensee has yet characterised the hazard on a basis consistent with the expectations of the SAP EHA.4 (in other words a conservatively derived 1×10^{-4} / yr. hazard). It would be disproportionate to expect the RP to characterise the hazard during GDA. A licensee is expected to characterise the hazard during site-specific stages for a target site. The RP has captured this requirement as a post-GDA commitment (Ref. 260). I judge this work to be normal business for site-specific stages.

406. There have been attempts to characterise the solar energetic particles hazard in the UK (Ref. 261, Ref. 262). The strongest solar particle event recorded to date occurred on 23rd February 1956 (Ref. 263). This event was estimated as having a return period of 40-70 years. It has been scaled to give the neutron flux for an event with a 1×10^{-4} annual probability of exceedance. There is significant uncertainty with the hazard due to limited data, which leads to very large fluxes at higher percentiles. The studies have shown that the fluxes for a best estimate 1×10^{-4} / yr. event are significant, and the hazard is a credible risk to nuclear safety (Neutron Flux >10 mega-electronvolts (MeV) of 75 neutrons cm^2/s or higher). Given these fluxes, it has been estimated that during a 1×10^{-4} / yr. ground-level event the probability of failure for power metal–oxide–semiconductor field-effect transistor and insulated-gate bipolar transistor is 68% and 52%, respectively (Ref. 264). I judge the RP's screening-in of the hazard for consideration during GDA to be good practice.

407. The plant effects associated with solar energetic particles are identified in the 'External Hazards Schedule Report' (Ref. 79), with more detailed provided in submissions responding to RO-UKHPR1000-0002 (Ref. 265). The RP's initial protection strategy claimed the civil structures would protect susceptible electronic systems against the hazard through attenuation (Ref. 265). Current understanding is that many metres of reinforced concrete are needed to significantly attenuate the high-energy particles that are a significant portion of the flux in a ground-level event. I judged the RP's proposed protection strategy to not be adequately justified to support the safety case claims. The protection strategy also offered no defence-in-depth, which does not meet the expectations of SAP EKP.3.

408. I raised RQ-UKHPR1000-0650 (Ref. 266) following discussions with the ONR C&I Inspector, where I outlined my expectations for the RP to undertake a vulnerability analysis of the UK HPR1000 design against the hazard. The purpose of this analysis would be to:

- Identify potentially vulnerable SSCs.
- Determine means of protecting and mitigating against the hazard's effects.
- Demonstrate defence-in-depth against the hazard.

409. The RP has provided the vulnerability analysis in a standalone 'Space Weather Safety Evaluation Report' (Ref. 267). The C&I Inspector and I have assessed this document (Ref. 267). The report essentially captures presentations provided by the RP at technical meetings where the hazard was discussed (Ref. 214, Ref. 215, Ref. 185) with few additional arguments or evidence provided. Although this report is not very detailed, I note the following:

- The methodology for the vulnerability analysis appears logical and systematic, and consistent with practice seen elsewhere in the UK nuclear industry.
- The scope of the analysis is consistent with ONR's expectations for GDA and includes the centralised C&I systems and relevant electrical and mechanical support systems.

- Application of the methodology has identified a logical group of systems that are likely to include susceptible components and devices.
- The depth of the analysis is commensurate with the level of detail available for the UK HPR1000 in GDA, particularly for the mechanical and electrical support systems where component selection will not take place until detailed design phases.
- There is sufficient information presented to be satisfied that the conclusions are underpinned for the purposes of GDA.
- The RP's analysis of the solar energetic particles hazard goes further than previous GDAs and should be lauded.

410. I judge that the RP has adequately analysed the generic UK HPR1000 design against the solar energetic particles hazard for the purposes of GDA. There are some matters relevant to solar energetic particles hazard that I expect a licensee to consider as the design progresses into the detailed design phase:

- The closure note for RO-UKHPR1000-0002 (Ref. 268) identifies a matter for the implementation of the identified strategies and options developed by the RP for mitigation of the solar energetic particles hazard once the design of C&I and support (mechanical and electrical) systems are sufficiently detailed. There is a commitment in sub-section 4.4.4 of the 'Space Weather Safety Evaluation Report' (Ref. 267) for the measures identified in GDA to "…be implemented in site licensing phase with further analysis". There is also high-level commitments made in relation to space weather hazards in the 'Post-GDA Commitment List' (Ref. 260). In my opinion these commitments lack sufficient detail with regard to the scope of this supplementary analysis or when it will be conducted. For example, the RP does not specify the factors that need to be considered to meet the expectations of SAP EDR.2 and the need to avoid the effects of CCF, including demonstrating adequate diversity of systems and manufacturers of components (e.g. use of different processors, chipsets, feature sizes, etc). The feasibility of any proposed modifications, and the extent to which they can practicably reduce susceptibility to the hazard, needs to be demonstrated.
- Sub-section 4.4.2.2.7 of the 'Space Weather Safety Evaluation Report' (Ref. 267) discusses the variability in feature sizes of various electronic components (metal–oxide–semiconductor field-effect transistor, static random-access memory, etc.) and the effect this has on susceptibility to the hazard. I am satisfied with the report's conclusion that further information from suppliers is required before any decision can be taken on modifications to further reduce the associated risks to be ALARP. As the design develops, it is expected that a licensee will proactively engage with suppliers and manufacturers to seek the necessary information to further understand the susceptibility of systems and components to the hazard. This is particularly important for the Diverse Actuation System (KDS [DAS]), for which the evaluation report makes strong claims relating to the protection that the use of a diverse hardware based backup system provides (Ref. 267).
- I expect a licensee to develop site processes and procedures in relation to space weather hazards, including monitoring and post-event checks to demonstrate equipment remains fit-for-purpose.
- There should ultimately be a justification, based on the GDA and post-GDA analyses to be carried out as the design develops, that the risk posed by solar energetic particles is reduced to ALARP. Section 6 of the 'Space Weather Safety Evaluation Report' (Ref. 267) provides a high-level ALARP assessment that is sufficient for GDA, but this should be refined as more detailed information comes available in future.

411. Given the scope of the above matters that need to be addressed post-GDA, I raise Assessment Finding AF-UKHPR1000-0091 to ensure a licensee undertakes this work in future site-specific phases.

AF-UKHPR1000-0091 – The licensee shall justify that the risks associated with the solar energetic particles hazard (and more generally space weather hazards) have been reduced as low as reasonably practicable by the site-specific design, and that the protection measures and mitigations developed during the UK HPR1000 GDA have been implemented for those susceptible systems and components.

412. Overall, I judge that the RP has provided a proportionate evaluation of the solar energetic particles hazard during GDA. The RP has performed a vulnerability analysis to identify SSCs that are susceptible to the solar energetic particles hazard and identified a range of strategies and options that could be implemented as the design detail increases to protect against the hazard effects. I have raised Assessment Finding AF-UKHPR1000-0091 for a licensee to justify that the risks associated with the solar energetic particles hazard (and more generally space weather hazards) have been reduced ALARP by the site-specific design, and that the protection measures and mitigations developed during the UK HPR1000 GDA have been implemented for those susceptible systems and components.

4.11.1.2 Geomagnetically Induced Current

Table 25: Geomagnetically induced current hazard values for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Geomagnetically induced current	Induced current	6,080 nT/min	6,080 nT/min
	Duration	10 mins	10 mins

413. The RP has considered the geomagnetically induced current hazard in response to RO-UKHPR1000-0002 (sub-section 4.18.1.1). The RP commissioned a bespoke study to characterise the hazard that is presented in the 'Geomagnetic Induced Current Analysis Report' (Ref. 269). The report derives the geomagnetically induced current hazard for three return levels:

- 100 years
- 200 years
- 10,000 years

414. The horizontal magnetic field charge rates are based on extreme value analysis of 35 years of data from the Hartland Observatory, Devon, UK to produce a 1 x 10^{-4} annual probability of exceedance hazard value. Other inputs needed to derive the hazard are based on the three candidate sites that inform the GSE including selection of a bounding transmission line length.

415. The report recognises that there is considerable uncertainty in the derivation of the hazard, leading to a broad distribution with 95% confidence intervals ranging from 385.48 nT/min to 9,722.61 nT/min, depending on the method used to calculate the hazard curve. The RP first selected a hazard value of 2,513 nT/min in Revision C of the 'Lightning, Electromagnetic Interference and Space Weather Safety Evaluation Report' (Ref. 270). I challenged the level of conservatism included in the hazard value via RQ-UKHPR1000-0733 (Ref. 271). The RP's response acknowledged a shortfall

against the expectations of SAP EHA.4 and a revised hazard value of 6,080 nT/min has been selected on a conservative basis (84th percentile) (Ref. 272). This value is adopted in the latest revision of the 'Geomagnetic Induced Current Analysis Report' (Ref. 273) and the 'UK HPR1000 Generic Site Report' (Ref. 50). The GSE values for the geomagnetically induced current are:

- Induced current: 6,080 nT/min
- Duration: 10 minutes

416. The GSE value has been selected for the UK HPR1000 design input value, as the FCG3 reference design has not considered space weather hazards. There are very few studies available for the UK for comparison purposes (Ref. 274). I judge the GSE value to meet the expectations of SAPs EHA.3 and EHA.4 based on the information supplied by the RP. The hazard value is based on bounding values for the three candidate sites (e.g. transmission line length). A licensee will need to characterise the site-specific geomagnetically induced current hazard for a target site and demonstrate whether this is bounded by the GSE value.

417. The plant effects of geomagnetically induced current are identified in the 'External Hazards Schedule Report' (Ref. 79), with more detail provided in the 'Geomagnetic Induced Current Analysis Report' (Ref. 269). The hazard causes an induced current in electrical equipment leading to excessive heating and potential failure of the plant. Several countermeasures options are presented by the RP in section 6 of the 'Geomagnetic Induced Current Analysis Report' (Ref. 269) to mitigate the effects of the hazard and further discussed in other safety case submissions (Ref. 74, Ref. 275). A licensee will select the mitigation measures post-GDA as site-specific inputs are required to determine the most suitable measure(s). This approach is commensurate with the level of design detail available in GDA. I have discussed the RP's approach with the ONR Electrical Engineering Inspector to confirm that the RP's geomagnetically induced current analysis is sufficiently progressed for the purposes of GDA. The ONR Electrical Engineering Inspector and I agree that the RP has:

- Recognised that the geomagnetically induced current hazard is a potential challenge to safety systems.
- Defined a GSE value that is consistent with the expectations of SAP EHA.4.
- Identified the equipment at risk, including electrical transformers.
- Offered mitigation options for the grid connections once the design progresses to a more detailed stage.
- Considered long-term duration LOOP of 168 hours (seven days), and demonstrated the UK HPR1000's defence-in-depth against this fault condition (sub-section 4.13.1.1).

418. The ONR Electrical Engineering Inspector has raised Assessment Finding AF-UKHPR1000-0171 within the Step 4 electrical engineering assessment report (Ref. 142). This finding expects a licensee to develop the protection measures for the electrical power system against geomagnetically induced current and incorporate these requirements into purchase specifications for electrical equipment. I judge this finding adequately addresses my concerns, and I do not raise an additional finding. The RP has identified the requirement for a licensee to collaborate with National Grid in relation to the hazard. A licensee will need to provide an adequate demonstration of the plant's overall response to the hazard at the detailed design stage to show that adequate protection is provided and that the risks associated with geomagnetically induced current are reduced ALARP.

419. Overall, I judge that the RP's evaluation of the geomagnetically induced current hazard is adequate for the purposes of GDA. The RP has defined a UK HPR1000 design input value for the geomagnetically induced current, which has been defined on a basis consistent with the expectations of SAP EHA.4. The RP has analysed the effects of the

hazard on the UK HPR1000 plant and offered several mitigation measures that can be implemented at the site-specific phase. The RP has demonstrated the UK HPR1000 is resilient against a long-term LOOP duration of 168 hours. I judge the RP's approach commensurate with the level of detail available for the UK HPR1000 design in GDA.

4.11.2 Strengths

420. My assessment of space weather hazards has identified the following strengths:

- The RP has progressed the evaluation of both solar energetic particles and geomagnetically induced current beyond that of any previous GDA – this is commendable.
- The RP has provided a proportionate vulnerability analysis of the UK HPR1000 against the solar energetic particles that is commensurate with the level of detail available at the current time.
- The RP has identified a range of strategies and options that can be implemented during detailed design of the UK HPR1000 to protect and mitigate against the effects of the solar energetic particles hazard.
- The RP has defined the geomagnetically induced current hazard on a basis consistent with the expectations of SAP EHA.4.
- The RP has identified options for protection and mitigation of the geomagnetically induced current that will be considered post-GDA as the design detail develops.
- The RP has analysed the UK HPR1000 against a long-term LOOP duration of 168 hours and demonstrated the design has sufficient defence-in-depth available.

4.11.3 Outcomes

421. My assessment of space weather hazards has raised one Assessment Finding in relation to solar energetic particles:

- Assessment Finding AF-UKHPR1000-0091 for a licensee to justify that the risks associated with the solar energetic particles hazard (and more generally space weather hazards) have been reduced ALARP by the site-specific design, and that the protection measures and mitigations developed during the UK HPR1000 GDA have been implemented for those susceptible systems and components..

422. The ONR Electrical Engineering Inspector has raised an Assessment Finding AF-UKHPR1000-0171 in relation to the geomagnetically induced current hazard. This finding expects a licence to develop the protection measures for the electrical power system against geomagnetically induced current and incorporate these requirements into purchase specifications for electrical equipment. I judge this finding adequately captures the matters required to be addressed post-GDA by a licensee, and no additional finding is raised in this assessment report.

423. A licensee will need to undertake further work during site-specific phases to:

- Analyse the design against EMI effects from space weather and demonstrate the risks from the hazard are reduced ALARP.
- Characterise the solar energetic particles hazard and provide a safety demonstration that the design reduces risks from the hazard to be ALARP.
- Demonstrate that the UK HPR1000 design input values for geomagnetically induced current adequately bounds the site-specific hazard and provide a safety demonstration that the design reduces risks from the hazard to be ALARP.

424. I judge this characterisation work can be undertaken as normal business, and no further finding is raised here.

4.11.4 Conclusion

425. I have assessed the RP's safety evaluation for space weather hazards. I conclude that:

- The screened-in space weather hazards for GDA are appropriate. Space weather EMI effects are screened-out with appropriate justification.
- The definition of the geomagnetically induced current hazard for the GSE is based on bounding inputs for the three candidate sites. I judge the GSE values to meet the expectations of SAPs EHA.2, EHA.3 and EHA.4.
- The UK HPR1000 design input value for geomagnetically induced current is taken as the GSE value. This is adequate as the FCG3 reference design has not been analysed against this hazard.
- The RP's DBA has:
  - Identified those SSCs that may contain components and devices that are vulnerable to the solar energetic particles and geomagnetically induced current hazards.
  - Developed a range of strategies and options to protect and / or mitigate against the effects of space weather hazards.
- I have raised an Assessment Finding related to the solar energetic particles hazard and highlight that the ONR Electrical Engineering Inspector has raised an Assessment Finding relevant to the geomagnetically induced current hazard. I judge these matters do not undermine the external hazards safety case or its conclusions:
  - AF-UKHPR1000-0091 for a licensee to justify that the risks associated with the solar energetic particles hazard (and more generally space weather hazards) have been reduced ALARP by the site-specific design, and that the protection measures and mitigations developed during the UK HPR1000 GDA have been implemented for those susceptible systems and components.
- The RP has progressed the evaluation of space weather hazards further than any previous GDA and developed a range of options and strategies to protect and mitigate against the hazardous effects of space weather. Further work is needed post-GDA to demonstrate risks are reduced ALARP.

4.12 Man-Made Hazards

4.12.1 Assessment

426. SAPs paragraph 228 defines external hazards as: "…those natural or man-made hazards to a site and facilities that originate externally to both the site and its processes." Relevant expectations for man-made hazards include:

- EHA.4 defines the frequency of man-made hazards as being 1 in 100 000 years, consistent with internal hazards.
- EHA.8 provides expectations for accidental aircraft impact.
- EHA.14 expects sources that could give rise to fire, explosion, missiles, toxic gas release, collapsing or falling loads, pipe failure effects, or internal and external flooding to be identified.
- Further guidance is provided in NS-TAST-GD-013 and Annex 4 for accidental aircraft impact.

427. I have considered relevant safety case submissions against these expectations to determine the adequacy of the UK HPR1000 design against man-made hazards.

428. The RP has identified several man-made hazards that could challenge nuclear safety (Ref. 51). Most man-made hazards are, however, screened-out of GDA for evaluation by a licensee post-GDA. This is justified by the RP as site-specific inputs are needed to identify and characterise the hazard sources. I concur with the RP's position that most man-made hazards and their potential severity are typically site-specific in nature in comparison with natural hazards, where the phenomena driving the hazards often operate on larger scales. This approach also aligns with previous GDA projects where man-made hazards, except aircraft impact, have been typically screened-out.

429. The RP has screened-in external explosion, which has been considered on a generic basis, and both accidental and malicious aircraft impact. I am content with this approach for the purposes of GDA. My assessment of these hazards is provided in the following sections.

4.12.1.1 External Explosion

Table 26: External explosion hazard parameters for the GSE and UK HPR1000 design input

Hazard		GSE values	UK HPR1000 Design Input value
External explosion	Incident Pressure	10 kPa	20 kPa
	Maximum Pressure (reflection factor of 2)	20 kPa	20 kPa
	Blast wave velocity	300 m/s	300 m/s
	Duration	300 milliseconds	300 milliseconds

430. The RP identifies external explosion hazard as requiring site-specific inputs (Ref. 88). However, the RP has a requirement to consider the hazard on a generic basis for GDA (Ref. 52). This is a conservative position given the hazard could justifiably be screened-out from GDA based on the need for site-specific information to characterise the hazard.

431. As the hazard is being considered on a generic basis, the RP does not define an explosion source. A generic overpressure wave is defined for the UK HPR1000 design input (Ref. 52). This is a triangular pressure wave with a tight front, reaching a maximum overpressure of 10 kPa at 0 milliseconds that reduces to 0 kPa by 300 milliseconds. The RP assumes the hazard originates some distance off-site.

432. I have compared the RP's approach with RGP, previous GDA projects and discussed with the ONR Internal Hazards Inspector:

- The definition of the hazard is similar to the standard load-time function for an explosion pressure wave presented in Safety Standards Series NS-G-1.5 (Ref. 276), albeit the IAEA load-time function has a duration of 200 milliseconds based on US Army documentation (Ref. 277). The US Army document referenced in the IAEA Safety Standards Series NS-G-1.5 (Ref. 276) has been superseded (Ref. 278), but triangular load-time functions remain RGP for detonations producing shock waves (Ref. 279).
- Shock waves are produced by the detonation of sources such as high explosives and hydrocarbon tanks, as well as boiling liquid expanding vapour explosions. Given the assumption that the explosion occurs some distance off-

site, I consider a 10 kPa overpressure on the building to represent a large off-site explosion.
- The RP's approach of considering a generic blast wave is consistent with previous GDA projects (Ref. 280).

433. The explosion is expected to occur at the off-site accident location and is assumed to arrive in a horizontal direction at the generic site. The incident pressure wave interacts with buildings, and is reflected and refracted. This means, for external explosions, the superposition of reflected waves must be considered as this can result in pressures greater than the incident wave. The RP has not provided a detailed analysis of possible wave reflections based on the generic plot plan for the UK HPR1000 in GDA; rather the RP has chosen to apply a reflection factor of two for vertical walls, giving a maximum over-pressure of 20 kPa. The reflection factor is not justified by the RP in 'The General Requirements of Protection Design against Internal and External Hazards' (Ref. 52) or an approach described for reflections onto roofs of structures. I sought the justification for this approach via RQ-UKHPR1000-0333 (Ref. 281). The RP's response (Ref. 282) confirms the approach is based on IAEA Safety Standards Series NS-G-1.5 (Ref. 276) and that it is not considered feasible for a reflected wave to increase the overpressure by more than a factor of two based on the assumption the wave is normal to the vertical wall. I have confirmed the RP's approach is consistent with Safety Standards Series NS-G-1.5 (Ref. 276), which states: "The maximum overpressure on vertical walls exposed to reflection from higher buildings is taken to be equal to twice the maximum incident overpressure wave value. The maximum overpressure on roofs exposed to reflections from higher buildings is taken to be equal to 1.5 times the maximum incident overpressure wave value." I have also considered other good practice for a normal reflection (in other words no angle of incidence) and, based on this and the assumptions in GDA (in other words, the explosion occurs some distance from the site and the blast wave arrives in a horizontal direction), I judge a reflected pressure coefficient of two to be adequate for GDA (Ref. 279, Ref. 283).

434. A licensee will need to characterise possible off-site sources of harm once a target site is identified. I highlight that IAEA Safety Guide NS-G-3.1 (Ref. 284) states: "It should be noted that the layout of structures at the site can result in substantial superposition of reflected pressure waves with a resultant increase in the pressure. Some knowledge of the conceptual or preliminary design of the proposed plant should be acquired for the purpose of establishing the design basis." Other RGP shows the maximum overpressure can be larger than a factor of two greater than the incident wave depending on the angle of incidence and nature of the explosion (e.g. compare ground, air and free-air bursts) (Ref. 283). It is important that a detailed analysis of blast waves is undertaken for the target site should such hazards exist in the local vicinity. Such work will be undertaken as normal business and no formal finding is raised here.

435. The UK HPR1000 design input value for the external explosion hazard is defined as:

- Incident over-pressure – 10 kPa
- Blast wave velocity – 300 m/s
- Duration – 300 milliseconds
- Maximum over-pressure – 20 kPa (factor of 2 applied)

436. In the absence of site-specific data, I judge the RP's proposed approach and definition of the external explosion hazard to be adequate for the purposes of GDA. It is good practice that the RP has demonstrated the design's withstand against the hazard on a generic basis.

437. The plant effects of external explosion are presented in the 'External Hazards Schedule Report' (Ref. 79) and comprise:

- Pressure on structures.
- Missiles on structures.
- LOOP.
- Challenge to ventilation systems.

438. This is not an exhaustive list of effects and IAEA NS-G-1.5 (Ref. 276) identifies that external explosions are also associated with ground motion, fire and heat effects. I consider the omission of these effects to be a minor shortfall, as the impact on the plant will depend on site-specific conditions (e.g. distance of the explosion source to the target site). The RP's analysis in the 'External Hazards Schedule Report' (Ref. 79) considers pressure effects on the external boundary of buildings. According to the response to RQ-UKHPR1000-0333 (Ref. 282), the UK HPR1000 design input value for external explosion is applied to the following external SSCs as a loading:

- EPW dampers.
- External doors.
- Overpressure relief devices.
- Civil structure external walls, including the inverse-L structures, which protect openings in the external walls.

439. EPW dampers protect HVAC systems against the effects of the external explosion hazard. This requirement is captured in the hazard schedule (Ref. 79). The EPW dampers design will be substantiated against the external explosion hazard during detailed design, post-GDA. The RP has confirmed the FCG3 reference design dampers have been qualified against 20 kPa overpressure. This approach is also adopted by the RP for external doors and over-pressure relief devices. I judge the RP's approach to identify the requirements on these features acceptable, given their detailed design is out of scope for GDA. A licensee will need to substantiate these SSCs against the external explosion hazard, if applicable, during detailed design as part of normal business.

440. I have discussed the substantiation of the civil structures with the ONR Civil Engineering Inspector. They have confirmed the design methodologies include external hazard loads. The structures that the Civil Engineering has sampled as part of their assessment have demonstrated the adequacy of the RP's approach in defining bounding load cases. The substantiation of the civil engineering design is presented in the relevant design substantiation reports. The ONR Step 4 civil engineering assessment report should be consulted for further details (Ref. 98).

441. I queried the omitted plant effects via RQ-UKHPR1000-0333 (Ref. 281). The RP's response (Ref. 282) provides an adequate justification for the approach taken in GDA:

- LOOP is a design basis condition (fault) that can be initiated by external hazards and is addressed in sub-section 4.13.1.1.
- Missiles arising from external explosion are screened-out to be dealt with in site-specific phases (Ref. 51). I judge this approach acceptable for GDA noting that:
    - A hazard source is needed to characterise missiles.
    - The RP has considered a range of missiles in both the external and internal hazards generic UK HPR1000 safety cases including missiles from tornado, aircraft impact and turbine disintegration hazards (Ref. 93). The RP's analysis demonstrates the adequacy of protection against missiles screened-in to GDA. I would expect missiles arising from an aircraft impact or turbine disintegration to bound most off-site, man-made missiles from other sources.

- Fire and heat effects are screened-out from GDA on the assumption the explosion occurs some distance of off-site. These effects will need to be considered for a target site by a licensee if a credible external explosion source (or sources) is identified for the target site.
- The RP has not defined any ground motion for the generic external explosion hazard. The RP has analysed the generic UK HPR1000 design against the earthquake hazard (sub-section 4.8). It is likely that ground motions resulting from an off-site explosion will be bounded by an earthquake.

442. Overall, I judge the RP's evaluation of the external explosion hazard to be adequate for the purposes of GDA. The RP's analysis has only considered pressure on structures, justifying the evaluation of associated plant effects will be undertaken in site-specific phases. For pressure effects the RP has identified relevant SSCs that need to withstand the hazard and captured this requirement in the External Hazards Schedule. The ONR Civil Engineering Inspector has confirmed the civil structure design has considered external hazards loadings and substantiated the design against bounding load cases. A licensee will need to identify, characterise and screen all man-made hazards for a target site during site-specific stages. Where a credible external explosion source is identified for a target site, the licensee will need to provide appropriate analyses of the design's withstand against all relevant hazard effects, including those screened-out of GDA, to demonstrate that risks are reduced to be ALARP. This work is normal business for site-specific stages.

4.12.1.2 Accidental Aircraft Impact

Table 27: Accidental aircraft crash rates for the UK and the GSE

Hazard		Background crash rates*	GSE crash frequency**
Accidental aircraft impact	Light aircraft	1.76×10^{-5} km^{-2} yr^{-1}	6.25×10^{-7} / yr.
	Helicopters	0.97×10^{-5} km^{-2} yr^{-1}	3.13×10^{-7} / yr.
	Small transport aircraft	0.06×10^{-5} km^{-2} yr^{-1}	0.21×10^{-7} / yr.
	Large transport aircraft	0.08×10^{-5} km^{-2} yr^{-1}	0.28×10^{-7} / yr.
	Military combat aircraft	0.28×10^{-5} km^{-2} yr^{-1}	0.99×10^{-7} / yr.
	Total	3.19×10^{-5} km^{-2} yr^{-1}	10.86×10^{-7} / yr.

*Background crash rate for UK
**Probability of a crash occurring on the generic site

443. I have assessed the RP's accidental aircraft impact safety case against ONR's expectations in SAP EHA.8 (Ref. 2) and Annex 4 of NS-TAST-GD-013 (Ref. 285).

444. The RP has calculated the crash frequency for the GSE and compared this with the expectations of SAP EHA.4 to determine whether the accidental aircraft impact hazard needs to be evaluated as a design basis event (SAP EHA.3) or beyond design basis event (SAP EHA.18). The annual probability of exceedance for aircraft impact on the GSE is found by multiplying the background crash rate for the whole of the UK by the effective target area of the generic site. The background crash rates for different aircraft types in the UK are presented in the 'UK HPR1000 Generic Site Report' (Ref. 50). The background crash rates are based on a 2014 study using data from 1988 – 2012 (Ref. 286). The background crash rates are on a best-estimate basis, which is consistent with the expectations in SAP EHA.4 for man-made hazards.

445. The background crash rates for the whole UK are defined as:

- Light aircraft: 1.76×10^{-5} km^{-2} yr^{-1}

- Helicopters: 0.97 x 10^{-5} km^{-2} yr^{-1}
- Small transport aircraft: 0.06 x 10^{-5} km^{-2} yr^{-1}
- Large transport aircraft: 0.08 x 10^{-5} km^{-2} yr^{-1}
- Military combat aircraft: 0.28 x 10^{-5} km^{-2} yr^{-1}
- Total background crash rate: 3.19 x 10^{-5} km^{-2} yr^{-1}

446. The GSE crash frequency is presented in the PCSR (Ref. 3). The RP has confirmed the approach to calculate the GSE crash frequency rate in response to RQ-UKHPR1000-0560 (Ref. 287). The Byrne model has been used to determine the effective target area of the generic site (Ref. 288). ONR guidance considers the Byrne model to be RGP in the UK (Ref. 285). The effective target area is based on the size of the nuclear island (160m x 130m x 63.5m). The RP considers this conservative as the height for the effective target area is set as that of the reactor building, which is higher than all other nuclear island structures. The effective target area also accounts for BEJ and BD_x buildings.

447. The annual probability of exceedance for an aircraft impact on the GSE is defined as:

- Light aircraft: 6.25 x 10^{-7} / yr.
- Helicopters: 3.13 x 10^{-7} / yr.
- Small transport aircraft: 0.21 x 10^{-7} / yr.
- Large transport aircraft: 0.28 x 10^{-7} / yr.
- Military combat aircraft: 0.99 x 10^{-7} / yr.
- Total impact frequency for GSE: 10.86 x 10^{-7} / yr. (or 1.086 x 10^{-6} / yr.)

448. Alternative background crash rates are available for the UK in a Health and Safety Executive (HSE) study, published in 2019 and using data from 1990 to 2013 (Ref. 289). I have calculated the crash frequency for the GSE in Table 28 (Ref. 290) using the background crash rates from the HSE study (Ref. 289) and the RP's assumptions for the effective target area. This results in a slightly greater impact frequency for the GSE of 13.30 x 10^{-7} / yr. compared with 10.86 x 10^{-7} / yr. calculated by the RP. Both impact frequencies are lower than the expectations of SAP EHA.4 for man-made hazards of 1 x 10^{-5} / yr. My TSC has also considered crash rates using an older data source for the UK (Ref. 291), and concludes accidental aircraft impact is a beyond design basis event (Ref. 45). I judge the RP has adequately calculated the crash frequency for the GSE and the hazard can be treated as a beyond design basis event (e.g. SAP EHA.18).

Table 28: Accidental aircraft crash rates for the UK and GSE based on HSE aircraft crash rates to 2013

Hazard		Background crash rates*	UK generic site crash frequency
Accidental aircraft impact	Light aircraft	18.5 x 10^{-6} km^{-2} yr^{-1}	6.57 x 10^{-7} / yr.
	Helicopters	10.3 x 10^{-6} km^{-2} yr^{-1}	3.3 x 10^{-7} / yr.
	Small transport aircraft	2.2 x 10^{-6} km^{-2} yr^{-1}	0.78 x 10^{-7} / yr.
	Large transport aircraft	0.7 x 10^{-6} km^{-2} yr^{-1}	0.25 x 10^{-7} / yr.
	Military combat aircraft	6.7 x 10^{-6} km^{-2} yr^{-1}	2.38 x 10^{-7} / yr.
	Total	38.4 x 10^{-6} km^{-2} yr^{-1}	13.30 x 10^{-7} / yr.

*Note: 1 x 10^{-6} probability of exceedance. This is consistent with how the crash rates are presented in the HSE report: Update of aircraft crash rates used by HSE in assessing hazards from chemical, process and other major hazard installations (Ref. 289).

449. Accidental aircraft loads are likely to be bounded by malicious aircraft loads when accidental impact is considered as a beyond design basis event. The RP has chosen to consider light aircraft impact as a design basis event (SAP EHA.3 definition) for the

UK HPR1000 civil structures in GDA scope, despite the hazard being a beyond design basis event on a frequency basis. The RP has adopted this approach as an additional conservatism and to be consistent with the FCG3 reference design. The RP has selected bounding load-time functions for two light aircraft as the UK HPR1000 design input values (Ref. 172), which are based on Appendix 1, Figure 1.5, of IAEA safety guide NS-G-1.5 (Ref. 21). All structures within GDA scope are designed to withstand the loadings. The adoption of light aircraft impact as a design basis hazard is a conservative approach, and the proposed load-time functions are based on RGP.

450. The plant effects resulting from aircraft impact include pressure, missiles and external fire (Ref. 79). The RP's DBA for accidental aircraft impact has focused on the structural damage effects, with no consideration of aircraft-related missiles, consequential fire, vibration or local damage. The ONR Civil Engineering Inspector's sampling of the structural analysis for BNX has shown that load combinations for accidental aircraft impact may govern the design of some structural elements (Ref. 292). If the site-specific hazard evaluation indicates that accidental aircraft impact cannot be screened-out from DBA on a frequency basis, then the approach adopted in GDA will need further consideration by the licensee to include all relevant hazard effects. This matter can be addressed as normal business during site-licensing once the licensee has characterised the accidental aircraft crash frequency for the target site. For the purposes of GDA, I judge the RP's approach to be conservative given that the application of loadings from accidental aircraft impact is not required based on the frequency of initiating event (compare with the expectations of SAP EHA.4).

451. I have discussed the substantiation of the civil structures with the ONR Civil Engineering Inspector in relation to aircraft impact. The ONR Civil Engineering Inspector has confirmed the design methodologies include external hazard loads. The structures that the Civil Engineering Inspector has sampled as part of their assessment have demonstrated the adequacy of the RP's approach in defining bounding load cases. The substantiation of the civil engineering design is presented in the relevant design substantiation reports. The ONR Step 4 civil engineering assessment report should be consulted for further details (Ref. 98).

452. Overall, I judge that the RP's evaluation of the accidental aircraft impact hazard to be adequate for the purposes of GDA. The RP has defined the GSE value for accidental aircraft impact frequency using RGP and latest data. Accidental aircraft impact hazard is a beyond design basis event on a frequency basis. The RP has chosen to define UK HPR1000 design input values for light aircraft based on RGP and included these loadings in the design of the civil structures. The ONR Civil Engineering Inspector has confirmed the adequacy of the RP's approach for substantiation of the civil design. A licensee will need to recalculate the crash rate for a target site based on the effective target area and taking into consideration local aircraft flight plans and traffic. If the site-specific accidental aircraft impact frequency meets the expectations of SAPs EHA.3 and EHA.4 (Ref. 2) then the licensee will need to reconsider the approach adopted in GDA to include all relevant plant effects. I judge this work is normal business during site-specific stages and no finding is raised.

4.12.1.3 Malicious Aircraft Impact

453. ONR expects RPs to consider protection against malicious aircraft impact as part of the external hazards safety case. My assessment of the RP's safety case has considered the following aspects, which are discussed below:

- Adequacy of the hazard definition and associated load-time function generation.
- Acceptance criteria and SSCs needed to meet the criteria (both primary and support systems).

- Protection strategy, including extent of protection and mitigations to prevent CCFs.
- Resilience against consequential hazards resulting from aircraft impact.
- Adequacy of the holistic safety case for malicious aircraft impact.

Hazard Definition

454. I have assessed the RP's hazard definition against ONR's expectations for malicious aircraft impact. ONR's expectations were provided to the RP via letter (Ref. 293) during Step 2, which was based on an existing document (Ref. 294). The RP's responses during technical engagements and to RQ-UKHPR1000-0087 (Ref. 295) did not provide sufficient confidence in the completeness of the planned aircraft impact safety case or the ability of the UK HPR1000 generic UK HPR1000 design and analysis to reflect UK expectations. I raised RO-UKHPR1000-0007 (Ref. 13) (sub-section 4.18.1.2) to address the following potential regulatory shortfalls:

- How different / additional aircraft impact analyses expected in the UK may challenge the design and how overall, relevant risks will be managed.
- Development of a complete external hazards safety case for the malicious aircraft impact hazard that will provide appropriate inputs into the civil engineering and other assessments, required for UK HPR1000.

455. In response to RO-UKHPR1000-0007, the RP undertook a gap analysis (Ref. 296). The analysis highlighted differences between the aircraft types used for the FCG3 reference design and those expected in the UK. The report recommended aircraft categories for use in the design of the UK HPR1000 that are aligned with ONR's expectations, namely:

- Military aircraft
- Medium commercial aircraft
- Large commercial aircraft

456. I judge the revised hazard definitions presented in the 'Aircraft Impact Gap Analysis Report' (Ref. 296) to meet ONR's expectations (Ref. 293). The nature of malicious hazard definition is not discussed further in this report.

457. NEI guidance for aircraft impact (Ref. 41) states that global structural damage can be evaluated using either:

- Force time history analysis method
- Missile-target interaction method

458. The RP has chosen to use the force time history analysis method. Load-time functions have been developed for the military and large commercial aircraft hazards using finite element models impacted into a rigid element (Ref. 296). This approach allows the load to be split into different portions corresponding to different parts of the aircraft and provides a more realistic distribution of the impact load (Ref. 297).

- The large commercial aircraft loads are split between the fuselage, central wings, inner wings, outer wings and engines. The total force time history for a normal impact case has been compared to that from the Riera method (Ref. 298) and shows good agreement.
- The military aircraft load is not split into different portions. The total load is applied on an area which is roughly the size of the fuselage. This leads to a concentrated load, which is conservative. The modelled results have been validated by comparison with empirical data and show good agreement.

459. The medium commercial aircraft load time functions have been generated using the Riera function. This is because the RP considers the loadings from the medium commercial aircraft to be bounded by the impacts of the military and large commercial aircraft:

- The peak impact forces are bounded by the large commercial aircraft.
- The peak impact pressure is bounded by the military aircraft.
- The force per unit length around the circumference from the fuselage is bounded by that of the military aircraft.

460. I judge the RP’s arguments relating to the medium commercial aircraft to be adequate. Sufficient evidence has been provided to support these claims for the purposes of GDA.

461. The RP has also identified relevant missiles for each aircraft type including, where relevant, cargoes or modifications. Load-time functions have been produced for the selected missiles. Adequate arguments have been provided for the purposes of GDA as to why the chosen missiles are representative and bounding. I raise the Assessment Finding AF-UKHPR1000-0121 for the RP to demonstrate during detailed design of the civil structures that load-time functions for the selected missiles that are used in the design and substantiation of the civil structures are bounding as per the RP's commitment in ONR-NR-CR-19-288 (Ref. 299).

AF-UKHPR1000-0121: The licensee shall demonstrate that the detailed civil structure design substantiates that the load-time functions for the selected malicious aircraft impact missiles (including cargoes and other modifications) are bounding of other credible missiles from this hazard.

462. Overall, I judge the RP’s hazard definitions and associated load-time functions are adequate for the purpose of GDA. The hazard definitions used in the analysis are consistent with ONR’s expectations. The development of load-time functions is consistent with RGP, and sufficient evidence has been provided to demonstrate that the results are consistent with other methods and data. The resultant load-time functions have been used to analyse the response of the civil structures. The ONR Civil Engineering Inspector has assessed the following aspects in their Step 4 assessment report (Ref. 98):

- Substantiation of the civil structures against malicious aircraft loads.
- Derivation of response spectra and consideration of dynamic effects on SSCs.
- Civil structure detailing between buildings.

Acceptance Criteria

463. The RP’s acceptance criteria for malicious aircraft impact are presented in the ‘Aircraft Crash Safety Evaluation Report’ (Ref. 70) and based on NEI 07-13 (Ref. 41), albeit with both criteria to be achieved:

- The reactor core remains cooled, or the containment remains intact.
- Spent fuel cooling or SFP integrity is maintained.

464. In IAEA Safety Reports Series No. 87 (Ref. 29) events are categorised as either design basis events, or design extension events (DEE) levels 1 or 2. Plant and structural acceptance criteria vary depending on the category. DEE-2 is reserved for the most extreme events and only requires one means of reactor shutdown or core cooling. DEE-1 events require two means of each. I consider DEE-2 an appropriate classification for malicious aircraft impact, as the lower classification DEE-1 requires

multiple heat removal and shutdown paths, which are not required to meet the acceptance criteria defined in section 6 of NEI 07-13 (Ref. 41).

465. IAEA Safety Reports Series No. 86 (Ref. 28) recommends applying a tiered approach, with less onerous acceptance criteria for the most extreme hazards. The RP has chosen different acceptance criteria for the different malicious aircraft hazards, as shown in Table T-5.2-1 of the 'Aircraft Impact Evaluation Report' (Ref. 300). Military aircraft and large commercial aircraft are assessed to DEE-1 with a variant of the commercial aircraft in cargo configuration assessed to DEE-2. It is not obvious that the large cargo aircraft represents a more extreme hazard than the other aircraft types. I judge the RP's approach to be conservative by applying the more onerous DEE-1 acceptance criteria to these aircraft types.

466. The RP has identified in Table T-4-2 of the 'Aircraft Crash Safety Evaluation Report' (Ref. 70) the SSCs needed to achieve the acceptance criteria, including those systems required for safe shutdown and heat removal. These systems have been identified by taking each building in turn and identifying any PIEs that would be induced by an impact on that building and the loss of all SSCs within it. The 'UK HPR1000 Fault Schedule' (Ref. 301) has then been used to determine the systems required to achieve safe shutdown under each of these PIEs.

467. IAEA TECDOC-1834 (Ref. 302) sub-section 3.2 states that the following supporting systems should be identified:

- Electric power systems
- Safeguard actuation systems
- Service water systems
- Component cooling water systems
- Essential air
- Heating, ventilation and air conditioning systems
- Structures supporting or shielding required equipment (e.g. buildings)

468. I raised:

- RQ-UKHPR1000-0906 (Ref. 303) for the RP to identify the supporting systems for those SSCs needed to achieve safe shutdown and heat removal.
- RQ-UKHPR1000-1345 (Ref. 304) for the RP to provide evidence to support the claim that the different trains of the supporting systems are spatially separated.

469. The RP has listed the locations of the supporting systems and adequately demonstrated the spatial separation in Table T-4-3 of the 'Aircraft Crash Safety Evaluation Report' (Ref. 70) by consolidating the responses to RQ-UKHPR1000-0906 (Ref. 305) and RQ-UKHPR1000-1345 (Ref. 306).

470. Overall, I judge that the RP has defined suitable acceptance criteria for the malicious aircraft impact safety case and has identified SSCs needed to achieve these requirements, including relevant support systems. I have confirmed that the claims made by the RP in relation to these systems are supported by adequate evidence, on a sampling basis. The RP has used RGP.

Protection Strategy

471. The protection strategy is based on meeting the acceptance criteria and ensuring between one and two heat removal and shutdown paths remain available following an aircraft impact event. The SSCs needed to achieve the acceptance criteria are located in various nuclear island buildings. The protection strategy can be summarised as follows:

- All buildings in GDA scope are protected against light aircraft loads (sub-section 4.12.1.2).
- Enhanced protection is provided for BRX, BFX and BSC against loads associated with malicious aircraft impact.
- Shielding analysis informs the extent of enhanced protection.
- Arguments are presented for physical separation of other safety trains located in different buildings.

472. IAEA Safety Reports Series No. 86 (Ref. 28) sub-section 3.1.4.2 identifies the need for shielding or screening analysis to demonstrate the walls of a structure that can be impacted by aircraft, which informs the extent of protection. The aircraft protection shell was presented by the RP during a technical engagement (Ref. 307). I challenged a number of areas where enhanced protection was not provided, and it was not apparent that claimed shielding from other buildings would prevent an impact occurring. Initial submissions from the RP did not provide sufficient evidence to support the shielding arguments. These concerns have been addressed in two ways:

- The RP has addressed some design shortfalls through Modification 27 (Ref. 308, Ref. 309, Ref. 310), which has been accepted into GDA (Ref. 216). This modification extends the enhanced protection shell to include the identified shortfalls. The adequacy of the modified structural elements has been substantiated by the RP's analysis (Ref. 98).
- The RP has provided calculations to substantiate the shielding provided by multiple walls in response to RQ-UKHPR1000-0978 (Ref. 311).

473. Shielding arguments have been consolidated in sub-section 9.1 of the 'Basis of Design for Aircraft Impact' (Ref. 312). I am satisfied with the arguments presented by the RP and the resulting impact locations, with the exception of shielding of BSC from the turbine building (BMX), the design of which is out of GDA scope. I note that:

- BMX is a steel frame structure, with a solid reinforced concrete slab at the +16m level.
- BMX does not contain any reinforced concrete walls of a sufficient thickness to prevent malicious aircraft loads or missiles.

474. NEI 07-13 (Ref. 41) is clear that only reinforced concrete walls can be considered in the analysis to provide shielding. The RP has sought to justify the shielding of BSC based on the reinforced concrete slab in BMX and considering the impact angles in response to RQ-UKHPR1000-0978 (Ref. 311). However, the impact angles selected for each aircraft type are the maximum angle, and angles lower than this (including horizontal flight) are still credible. I judge that further justification is needed for shielding of BSC or impacts on lower parts of the structure should be analysed. I raise Assessment Finding AF-UKHPR1000-0092 relating to this matter.

AF-UKHPR1000-0092: The licensee shall justify the claims relating to aircraft impact on the Safeguard Building C below the +13.2m level giving consideration to the site-specific design and layout.

475. There also remain several potential design shortfalls that the RP has not addressed in GDA via Modification 27 or other modifications (Ref. 313, Ref. 45). The RP considers these potential design shortfalls to be out of GDA scope and best addressed by the site-specific layout of the plant. I accept the RP's arguments and consider these outstanding potential design shortfalls are best resolved during site-specific stages. I raise Assessment Finding AF-UKHPR1000-0093 to ensure these matters are adequately addressed.

> **AF-UKHPR1000-0093**: The licensee shall justify site-specific design features that are considered out of GDA scope against the malicious aircraft impact hazard, to demonstrate that the acceptance criteria are met, and risks are reduced as low as reasonably practicable.

476. Overall, I consider the RP's approach for determining the extent of the aircraft impact protection shell to be based on RGP. Modification 27 implemented during GDA has addressed a number of shortfalls in the protection design. The RP has provided sufficient evidence to support arguments relating to shielding for those features in GDA scope. Further work is needed by a licensee during site-specific stages to demonstrate that the risks from malicious aircraft impact have been reduced ALARP for potential design shortfalls.

Hazard Effects

477. Aircraft impact has a number of effects and associated consequences. I have worked closely with the ONR Civil Engineering Inspector for the assessment of the RP's analysis of malicious aircraft impact. The effects of malicious aircraft impact loads on civil structures are addressed in the ONR Step 4 civil engineering report (Ref. 98), and not repeated here. The ONR civil engineering assessment includes:

- Local damage (scabbing, perforation and punching shear).
- Global structural damage.
- Global stability.
- Dynamic effects.

478. My assessment focuses on consequential fire spread and explosion damage. The RP's protection strategy means that some buildings are not designed to withstand malicious aircraft loads. Fuel and fire might enter these buildings and then spread to other parts of the plant. Fire spread has received considerable attention during Step 4 and the RP's fire strategy was identified as an area for improvement by the ONR Step 3 civil engineering assessment report (Ref. 314). I expect the RP to provide an adequate assessment of fire spread into and through the nuclear island buildings using RGP and to determine the impact on SSCs needed to meet the acceptance criteria. I raised RQ-UKHPR1000-0583 for the RP to explain the aircraft impact fire strategy. The response stated:

- The strategy is to keep fuel and fire outside the buildings.
- Where this is not practicable, detailed analysis would be provided.
- Safety fire compartments within buildings are claimed to reduce fire spread.
- Different safety trains are located in separate fire compartments.
- Fire-fighting systems and fire-fighter interventions could be used to limit fire damage.

479. I judge that this forms a reasonable strategy, particularly the compartmentalisation and separation of safety trains. The RP has conservatively not relied upon fire-fighting systems in the fire spread analysis. This approach is consistent with RGP that only credits fire barriers (Ref. 41).

480. The RP has applied the fire spread rules from NEI 07-13 (Ref. 41). This guidance is RGP. The RP's application of the NEI fire spread rules identified some design shortfalls. These design shortfalls have been addressed via Modification 81 that was accepted into GDA (Ref. 315). The modification includes thickened wall elements to prevent cracking, and prevent fuel and fire entering the buildings. The RP has provided analysis to demonstrate that any through thickness cracks would be <2 mm and not a significant fuel path for fire spread (Ref. 316).

481. The RP's fire spread analysis has claimed that certain fire barriers are 3-hour fire rated. The supporting analysis demonstrates that the concrete walls could withstand a 3-hour fire. I raised RQ-UKHPR1000-1278 (Ref. 317) for the RP to confirm the walls have been rated for 3 hours, since there is a difference between being able to withstand a 3-hour fire and being rated for a 3-hour fire. The RP's safety case now explicitly captures this requirement for relevant fire barriers (Ref. 318).

482. NEI 07-13 (Ref. 41) contains specific rules for the treatment of openings. I expect the RP to provide an adequate fire-spread analysis for relevant openings in accordance with NEI 07-13 (Ref. 41). There were fundamental differences between ONR and the RP on the application of the fire spread rules for openings. I raised RQ-UKHPR1000-1540 (Ref. 319) to clarify my expectation for the RP to apply the fire spread rules based on ONR's understanding in order to identify any potential design shortfalls. The RP's response (Ref. 320) provides the requested analysis and shows the consequences would be unacceptable. The consequences could be mitigated by increasing the fire rating of certain fire barriers. The latest revision of the 'Aircraft Crash Safety Evaluation Report' (Ref. 70) presents the fire spread analysis based on ONR's understanding, and the requirement for relevant fire barriers to be 3 hours rated has been captured. Further work is needed post-GDA to either substantiate the barriers for 3 hours, including consideration of penetrations through the barriers for SSCs out of scope for GDA, or to provide more detailed analysis that demonstrates the increased fire rating is not required. I raise Assessment Finding AF-UKHPR1000-0094 to ensure this work is adequately undertaken given its potential nuclear safety significance.

AF-UKHPR1000-0094: The licensee shall substantiate the detailed design of fire barriers, including penetrations through the barriers, to demonstrate that the fire rating requirements are met by all relevant barriers, including the three safety fire cells in the reactor building and the fire barrier between safety fire cells A and B in the fuel building.

483. HVAC openings on the external walls of the UK HPR1000 buildings are protected by EPW dampers. NEI 07-13 (Ref. 41) notes that some dampers cannot respond fast enough to prevent overpressure fire spread through a fireball. The EPW dampers for UK HPR1000 do not meet the 3-hour fire and 35kPa overpressure requirements in NEI 07-13 (Ref. 41). The RP's safety case has captured the requirement for EPW dampers on the boundary of relevant structures to have sufficient overpressure resistance (Ref. 70). I judge this acceptable for GDA and given the level of design detail. A licensee will need to demonstrate dampers can meet these requirements post-GDA. This is normal business to be undertaken as the level of design detail increases.

484. NEI 07-13 (Ref. 41) sub-section 3.3.2, "Physical Damage Rules" states that: "…features at grade such as access covers to underground pipe/cable chases are considered to be at the interface boundary (as defined under the Fire Damage Rules) for ground elevation strikes and may be subject to fire damage." I queried the RP's approach to fire spread through underground passages via RQ-UKHPR1000-1334 (Ref. 321). The RP has not considered underground galleries connected to the nuclear island buildings during GDA, as these are out of scope (Ref. 322). A licensee will need to analyse the effects of fire spread within relevant underground openings and passages during site-licensing. I judge this is normal business.

485. I have queried the effects of explosion damage on unprotected SSCs located outside of buildings via RQ-UKHPR1000-0977 (Ref. 323). The RP's response (Ref. 324) argues that:

- The VDA [ASDS] silencers are physically separated and cannot all be damaged from an aircraft impact event.
- The ASP [SPHRS] is not required to meet the acceptance criteria for malicious aircraft crash.
- The EHR [CHRS] is not required following aircraft impact due to the spatial separation of BD_X.
- External openings for the PTR [FPCTS] pipes are not required because these openings are only required for water makeup.

486. I judge the RP’s arguments for unprotected SSCs to be adequate based on the analysis in the ‘Aircraft Crash Safety Evaluation Report’ (Ref. 70) and associated Tables T-4-2 and T-4-3.

Holistic Safety Case

487. I have, with the ONR Civil Engineering Inspector, sampled other aspects of the aircraft impact safety case to determine:

- The completeness and holistic adequacy of the RP’s aircraft impact safety case.
- Whether or not the risks from malicious aircraft impact have been reduced ALARP.

488. I have sampled the following aspects during Step 4:

- Damage from falling cranes
- Maintenance activities
- Impacts across multiple buildings
- Design modifications to BFX
- Radiological consequences

489. Each of these samples is addressed in the following paragraphs.

490. NEI 07-13 (Ref. 41) states that consideration should be given to damage caused by falling cranes. The cranes in the BFX building are supported on the external walls, which can experience large deflections under aircraft impact loads. I requested the RP provide clarity on what analysis was available for damage resulting from falling cranes in the BFX via RQ-UKHPR1000-0979 (Ref. 325). The RP argues that a falling crane is unlikely to damage the SFP or other nuclear safety systems on a time at risk basis (Ref. 326). SAP NT.2 (Ref. 2) states: “Any period in which the risk is elevated (e.g. due to any of the reasons a) to c) listed in paragraph 760 [of the SAPs]) must be subject to a specific demonstration that risks are controlled to ALARP. The period of elevated risk should be as short as reasonably practicable. The short duration of the increased risk should not be used as the sole argument for justifying risks are ALARP.” Given the expectations of SAP NT.2, I judge this to be a shortfall in the RP’s safety demonstration and raise Assessment Finding AF-UKHPR1000-0095. I expect a licensee to provide an adequate demonstration that the nuclear safety risks associated with falling cranes resulting from an aircraft impact are controlled to ALARP during the detailed design of the BFX building.

AF-UKHPR1000-0095: The licensee shall demonstrate that nuclear safety risks from falling cranes, resulting from an aircraft impact, are reduced as low as reasonably practicable by the detailed, site-specific design.

491. RGP expects maintenance activities to be considered in the malicious aircraft impact safety case (Ref. 293, Ref. 41). The RP has demonstrated that maintenance activities

have been considered in response to RQ-UKHPR1000-1330 (Ref. 327) and has identified the safety and safety-related systems that are needed to deliver fundamental safety functions and meet the acceptance criteria for each of the permitted operating modes. I have confirmed that this information has been consolidated into the safety case in the ‘Aircraft Crash Safety Evaluation Report’ (Ref. 70).

492. With respect to maintenance activities, I judge that the RP has demonstrated that sufficient systems remain available following an aircraft impact event to meet the acceptance criteria and deliver required safety functions based on the evidence provided in the ‘Aircraft Crash Safety Evaluation Report’ (Ref. 70) and ‘Examination, Maintenance, Inspection and Testing (EMIT) Windows’ report (Ref. 328). However, the RP’s fire analysis has shown that two trains of PTR [FPCTS] could be damaged by fire spread in some scenarios. One train of PTR [FPCTS] could be under maintenance during an aircraft impact event as the system is always needed, and maintenance must be undertaken when the plant is in operation. The RP argues that the time for maintenance of PTR [FPCTS] is short, and any maintenance started before an aircraft impact event could be completed before evaporation of water in the SFP leads to exposure of spent fuel. I do not accept this argument given the potential extent of fire damage in BFX will likely have implications for operator access and safety. The ASP [SPHRS] is likely to be available to provide makeup water for the SFP following an impact and, on this basis, I judge the design can withstand an aircraft impact during maintenance.

493. Aircraft impact can occur across multiple buildings, potentially leading to multiple PIEs. The RP lists the combinations of buildings that could be damaged by an impact in the response to RQ-UKHPR1000-1331 (Ref. 329). The RP’s analysis shows that BSA and BSB are separated by sufficient distance, such that it makes it unlikely that both buildings would be directly damaged in the same impact. I judge the RP has provided adequate evidence to demonstrate that, for military aircraft and large commercial aircraft, there remain available sufficient paths for heat removal and reactivity control following an impact.

494. The RP has modified the BFX in response to potential regulatory shortfalls identified in RO-UKHPR1000-0014 (Ref. 330) and RO-UKHPR1000-0056 (Ref. 80). The analysis provided by the RP for BFX in relation to malicious aircraft impact is based on the design prior to the implementation of these modifications. The RP evaluates the potential challenges to the extant analysis for BFX in the report ‘Impact Analysis of Design Modification on Civil Engineering’ (Ref. 331). Sub-section 4.6 of that report (Ref. 331) identifies the effects of the modifications on the malicious aircraft impact safety case. The ONR Civil Engineering Inspector has raised Assessment Finding AF-UKHPR1000-0223 in relation to these matters as it is difficult to accurately predict the effect of the increased spans on the response to malicious aircraft loadings. The RP claims that no intrusion of fire into BFX is expected as local failure is prevented. I do not accept this argument as the design modifications do not prevent fire spread into BFX through openings or adjacent buildings. However, I judge it unlikely that the modifications would worsen the results of the fire spread analysis that the RP has undertaken.

495. Sub-section 4.6 of the ‘Impact Analysis of Design Modification on Civil Engineering’ report (Ref. 331) does not evaluate the modifications to the BFX building on the consequential falling cranes hazard, resulting from a malicious aircraft impact. I have therefore assessed this with support from my TSC. The design modifications to BFX place two PTR [FPCTS] heat exchangers underneath crane maintenance positions. Should an aircraft impact occur during maintenance of the PTR [FPCTS] system, then damage from falling cranes could potentially lead to a loss of the safety functions delivered by PTR [FPCTS]. In these circumstances, the RP claims the ASP [SPHRS] could provide makeup water for the SFP. Further justification is needed to demonstrate that this is an ALARP position. I judge this matter can be resolved as part of

Assessment Finding AF-UKHPR1000-0095 relating to falling cranes. I expect the location of the PTR [FPCTS] heat exchangers to be justified during detailed design of the BFX.

496. The RP has evaluated aircraft impact on the SFP crane modification in sub-section 4.3.3.3 of the 'Aircraft Crash Safety Evaluation Report' (Ref. 70). The spent fuel crane is modified from an overhead crane (running on corbels on the inside of the BFX wall) to a gantry crane (running on rails on the floor of the BFX). The RP states that there is space between the rails and the boundary walls, and the crane will not be damaged during an aircraft impact. I accept this argument for GDA. A licensee will need to substantiate this during site-specific stages as part of normal business.

497. ONR's expectations for radiological consequences were provided to the RP in Letter REG-GNS-0017N (Ref. 293). I raised RQ-UKHPR1000-0789 (Ref. 332) for the RP to quantify the dose consequences that might arise from malicious aircraft impact on those structures not designed to withstand the malicious aircraft impact loads. I have discussed the RP's response (Ref. 333) with ONR Fault Studies and Radiological Protection Inspectors. The RP's analysis meets ONR's expectations and demonstrates that the radiological consequences remain acceptable as per the expectations in Letter REG-GNS-0017N (Ref. 293) following an aircraft impact. This evidence corroborates the extent of enhanced protection against malicious aircraft impact loads provided in the generic UK HPR1000 design.

498. Overall, I have undertaken a detailed assessment of the RP's malicious aircraft impact safety case during GDA. The RP's approach is aligned with RGP and ONR's expectations. My assessment has identified several matters that will need to be addressed post-GDA once site-specific information is available or as the level of design detail develops. I have raised Assessment Findings to ensure this work meets ONR's expectations and adequately addresses these matters.

4.12.2 Strengths

499. Through my assessment of man-made hazards, I have identified the following strengths:

- The RP has considered an adequate range of man-made hazards during GDA, recognising that many man-made hazard sources are site-specific.
- The RP's consideration of external explosion during GDA is good practice.
- The RP's evaluation of the external explosion hazard on a generic basis has enabled the identification of SSCs that will protect against the hazard's effects and safety functional requirements to be assigned to them.
- The RP has demonstrated that the accidental aircraft hazard is a beyond design basis event on a frequency basis.
- The RP's consideration of light aircraft impact in the design of civil structures is conservative
- All buildings in GDA scope are designed withstand the light aircraft hazard.
- The hazards used in the malicious aircraft impact are aligned with ONR's expectations.
- RGP has been used to derive load-time functions for the malicious aircraft impact hazards.
- The RP's acceptance criteria for malicious aircraft impact are based on RGP and consistent with ONR's expectations.
- The RP's protection strategy is based on RGP.
- The extent of enhanced protection provided against malicious aircraft impact is designed to ensure sufficient safety systems (and associated support systems) are available to meet the acceptance criteria.
- The RP's analysis demonstrates that the radiological consequences meet ONR's expectations for impacts on structures not designed to withstand

malicious aircraft loads. This corroborates the extent of enhanced protection against malicious aircraft impact loads provided in the generic UK HPR1000 design.

- The RP has provided sufficient evidence to support shadowing and shielding arguments, with some residual potential design shortfalls to be addressed during site-specific stages.
- The RP has analysed the effects of fire spread using RGP.
- The RP has considered maintenance activities and shown the acceptance criteria can be met during all normally permitted operating modes.
- The RP has demonstrated the withstand of the protected buildings against malicious aircraft impact hazards.
- The RP has demonstrated the UK HPR1000s ability to meet the acceptance criteria.

4.12.3 Outcomes

500. My assessment of man-made hazards has identified five Assessment Findings related to the malicious aircraft impact safety case:

- AF-UKHPR1000-0121: a licensee shall demonstrate that the detailed civil structure design substantiates that the load-time functions for the selected malicious aircraft impact missiles (including cargoes and other modifications) are bounding of other credible missiles from this hazard.
- AF-UKHPR1000-0092: a licensee shall justify the claims relating to aircraft impact on the BSC building below the +13.2m level giving consideration to the site-specific design and layout.
- AF-UKHPR1000-0093: a licensee shall justify site-specific design features that are considered out of GDA scope against the malicious aircraft impact hazard, to demonstrate that the acceptance criteria are met, and risks are reduced ALARP.
- AF-UKHPR1000-0094: a licensee shall substantiate the detailed design of fire barriers, including penetrations through the barriers, to demonstrate that the fire rating requirements are met by all relevant barriers, including the three safety fire cells in BRX and the fire barrier between safety fire cells A and B in the BFX.
- AF-UKHPR1000-0095: a licensee shall demonstrate that nuclear safety risks from falling cranes, resulting from an aircraft impact, are reduced ALARP by the detailed, site-specific design.

501. The ONR Civil Engineering Inspector has raised Assessment Findings relevant to this hazard (AF-UKHPR1000-0223 and AF-UKHPR1000-0235).

502. I judge that these matters can be resolved post-GDA when information is available for a target site and as the design detail develops. The licensee will need to provide an adequate safety demonstration that these matters have been resolved and that the risks associated with aircraft impact have been reduced to be ALARP.

503. I have also identified a minor shortfall, which is described in sub-section 4.12.1.1.

504. A licensee will need to provide during site-specific stages:

- An adequate hazard identification, characterisation and screening process to identify credible man-made hazard sources in the vicinity that could impact nuclear safety.
- Define the UK HPR1000 design input values for relevant man-made hazards in accordance with the expectations of the SAPs.

- If accidental aircraft impact meets the expectations of SAP EHA.4 for DBA, then the licensee will need to consider all relevant effects including missiles, fire and vibration.
- If credible off-site explosion sources are identified, then a licensee will need to analyse all relevant effects including missiles, fire and vibration.
- Provide an adequate evaluation of the UK HPR1000's withstand against screened-in man-made hazards.
- Provide optioneering for any identified shortfalls and implement selected modifications.
- Provide an adequate justification that residual risks are reduced ALARP.

505. I judge the aforementioned work to be normal business.

4.12.4 Conclusion

506. I have assessed the RP's safety evaluation for man-made hazards. I conclude that:

- The screened-in man-made hazards for GDA are appropriate. The RP has also included external explosion on a generic basis. Other man-made hazards are screened-out, with appropriate justification as site-specific information is needed to characterise the hazard sources in a meaningful manner.
- The definition of the external explosion and accidental aircraft impact hazards for the GSE is conservative and based on best available data and RGP. I judge that GSE values are adequate for GDA. The definition of the malicious aircraft impact hazards is consistent with ONR's expectations.
- The UK HPR1000 design input value for man-made hazards is taken as the GSE value. I judge this acceptable for GDA.
- The RP's analysis has:

  - Identified those measures that protect against the hazards effects and demonstrated defence-in-depth.
  - Demonstrated that good engineering practice has been adopted and the CCF effects of external hazards are protected against.
  - Substantiated the civil structures against bounding load cases, which includes consideration of external hazard loadings.
  - Identified protection requirements for other SSCs (e.g. mechanical systems) that will be substantiated during detailed design.
  - Undertaken optioneering where gaps have been identified and implemented the preferred options, where appropriate, to protect against hazard effects.
  - Provided sufficient evidence to demonstrate a safe shutdown of the reactor can be achieved and maintained for malicious aircraft impact events.
  - Provided sufficient evidence to demonstrate that the design is robust against man-made hazards.

- I have raised Assessment Findings related to the malicious aircraft impact hazard and highlight that the ONR Civil Engineering Inspector has also raised Assessment Findings that are relevant to this hazard. I judge these matters do not undermine the external hazards safety case or its conclusions:

  - AF-UKHPR1000-0121 for a licensee to demonstrate that the detailed civil structure design substantiates that the load-time functions for the selected malicious aircraft impact missiles (including cargoes and other modifications) are bounding of other credible missiles from this hazard.

- AF-UKHPR1000-0092 for a licensee to justify the claims relating to aircraft impact on the BSC building below the +13.2m level giving consideration to the site-specific design and layout.
- AF-UKHPR1000-0093 for a licensee to justify site-specific design features that are considered out of GDA scope against the malicious aircraft impact hazard, to demonstrate that the acceptance criteria are met, and risks are reduced ALARP.
- AF-UKHPR1000-0094 for a licensee to substantiate the detailed design of fire barriers, including penetrations through the barriers, to demonstrate that the fire rating requirements are met by all relevant barriers, including the three safety fire cells in BRX and the fire barrier between safety fire cells A and B in the BFX.
- AF-UKHPR1000-0095 for a licensee to demonstrate that nuclear safety risks from falling cranes, resulting from an aircraft impact, are reduced ALARP by the detailed, site-specific design.

■ The RP has demonstrated the UK HPR1000 design is robust against man-made hazards evaluated in GDA. Further work is needed post-GDA to demonstrate risks are reduced ALARP including:

- Evaluation of those man-made hazards screened-out of GDA.
- Further consideration of other plant effects associated with external explosion and accidental aircraft if the site-specific hazards meet ONR's expectations for DBA.

4.13 Design Basis Conditions Relevant to External Hazards

4.13.1 Assessment

507. The RP has identified a number of design basis conditions (fault scenarios) that can be initiated by external hazards. I have assessed the RP's approach to these design basis conditions to ensure external hazards are considered in the RP's analysis and that adequate protection measures are identified. My assessment is described in the following sub-sections.

4.13.1.1 Loss of Off-Site Power

Table 29: Loss of off-site power frequencies for the GSE and UK HPR1000 design input

Hazard		GSE value	UK HPR1000 Design Input value
Loss of off-site power	Short-term duration – 2 hours	5×10^{-2} / yr.	5×10^{-2} / yr.
	Medium-term duration – 24 hours	5×10^{-3} / yr.	5×10^{-3} / yr.
	Long-term duration – 168 hours	5×10^{-5} / yr.	5×10^{-5} / yr.

508. The RP's definition of the GSE includes consideration of LOOP. The RP has defined LOOP durations as follows:

■ Short term duration – 2 hours (5×10^{-2} / yr.)
■ Medium term duration – 24 hours (5×10^{-3} / yr.)
■ Long term duration – 168 hours (5×10^{-5} / yr.)

509. I have compared these durations and frequencies with previous GDA projects and consider them consistent with those accepted for UK ABWR (Ref. 117). I judge the RP's definition of LOOP for the GSE acceptable.

510. There are a number of external hazards that are identified as being able to initiate a LOOP event (Ref. 79). The RP has identified both short term (2 hours) and medium term (24 hours) LOOP as frequent design basis faults. Long term (168 hours) LOOP has been identified as an infrequent design basis fault. According to the 'External Hazards Schedule Report' (Ref. 79), external hazards are assumed to result in long-term LOOP, albeit in my opinion could also initiate short- and medium-term events. The 'UK HPR1000 Fault Schedule' (Ref. 301) includes long-term LOOP (168 hours) and identifies the relevant safety systems to mitigate its effects. The primary means of protection against LOOP are three emergency diesel generators located in BDA, BDB and BDC. LOOP is further discussed in the ONR fault studies assessment report (Ref. 162), but the ONR Fault Studies Inspector concludes that the fundamental safety functions including heat removal can be delivered for longer than a week during a long term LOOP event.

511. I have discussed LOOP with the ONR Electrical Engineering Inspector. The Step 4 electrical engineering assessment report provides a deterministic analysis of safety case submissions relevant to LOOP (Ref. 142). The ONR electrical engineer has confirmed that the emergency diesel generators can operate at full-rated power for 168 hours, albeit the fuel and oil resupply arrangements required to support this continuous operation need to be demonstrated post-GDA. Redundancy, separation and segregation are considered in the design of the emergency diesel generators. This is consistent with the expectations of SAP EDR.2. The emergency diesel generators buildings provide protection against a number of external hazards and have been substantiated against UK HPR1000 design input values for relevant external hazards. The emergency diesel generators and their support systems, such as DVD [DBVS] are also designed to withstand external hazards, including air temperature.

512. The RP has considered lessons learned relating to the Fukushima Dai-ichi NPP accident and implemented engineering measures to enhance the design's defence-in-depth and resilience against LOOP (Ref. 137). Additional measures include:

- Two SBO diesel generators that can operate at full-rated power for 72 hours.
- Battery DC power for 2 hours (LAA/B/C/D [NI-DCPS]) and 24 hours (LAP/Q [NI-DCPS]).
- Mobile diesel generators.
- The secondary passive heat removal system (ASP [SPHRS]) and extra cooling systems (ECS [ECS]).

513. The RP has analysed combinations of external hazards with design basis conditions to demonstrate that the design is robust against the hazards that may have initiated the design basis condition. For example, the high-air temperature hazard may cause a LOOP condition. The RP has analysed the DVD [DBVS] against the UK HPR1000 design input value for high-air temperature to demonstrate the emergency diesel generators are maintained within their qualification temperature limit of 60 °C. The RP has provided sufficient evidence in the 'Analysis Report of the HVAC Sample Systems' (Ref. 203) to demonstrate the emergency diesel generators can operate at full-rated power and be within their qualification temperature with an external high-air temperature of 48.5 °C. The analysis also demonstrates some beyond design basis margin and an absence of cliff-edge effects. This provides confidence that the safety measures included in the design against design basis conditions are robust against external hazards that may have initiated the LOOP condition.

514. I judge the RP has provided sufficient evidence that the UK HPR1000 design has adequately considered LOOP and implemented appropriate engineering measures to mitigate against its effects based on RGP.

4.13.1.2 Loss of Ultimate Heat Sink

515. The RP has considered LUHS as a design basis condition for the UK HPR1000 and protection against it is included in the design. The ‘UK HPR1000 Fault Schedule’ (Ref. 301) considers an extended LUHS for 100 hours as a design extension condition - A event. IAEA SSR-2/1 introduced guidance for design extension conditions following the Fukushima Dai-ichi NPP accident (Ref. 19). Analysis of an extended LUHS is provided in the report ‘Loss of Ultimate Heat Sink (LUHS) for 100 Hours (States A and B)’ (Ref. 334). The ONR Step 4 fault studies assessment report should be consulted on the adequacy of the design against fault conditions and LUHS (Ref. 162), but concludes that fundamental safety functions can be maintained during a LUHS event.

516. There are a number of external hazards identified in the ‘External Hazards Schedule Report’ (Ref. 79) that can initiate either a partial or total LUHS event. This includes frazil or barrier ice formation due to the minimum sea-water temperature. The RP has analysed LUHS on a generic basis in the ‘Heat Sink Specific Hazards Safety Evaluation Report’ (Ref. 76). This report provides a safety evaluation for the Essential Service Water Pump Station A (BPA) and Essential Service Water Pump Station B (BPB) that provide water for SEC [ESWS]. SEC [ESWS] provides a cooling support function for the safety classified RRI [CCWS] system. The following potential hazard sources are evaluated:

- Clogging, including frazil ice.
- Hydrocarbon pollution.
- Underwater explosion.
- Ship collision.
- Low-water level.

517. The RP identifies mitigations against the potential hazard sources that might cause LUHS. No design modifications are implemented in GDA as site-specific inputs are required to inform the frequency of external hazards initiating a LUHS event, and the selection of relevant protection measures. I judge the RP’s approach reasonable for GDA, given the need for site-specific inputs including the overall cooling strategy (compare between direct and indirect cooling).

518. The RP also identifies the safety systems that provide defence-in-depth against LUHS including:

- Safety Injection System (RIS [SIS])
- Emergency Feedwater System (ASG [EFWS])
- VDA [ASDS]
- ASP [SPHRS]

519. ASP [SPHRS] would be used to provide makeup water to the ASG [EFWS] system. The RP has modified ASP [SPHRS] during GDA to withstand the low-air temperature hazard and prevent freezing of water in the tank.

520. Overall, I judge that the RP’s evaluation of LUHS is adequate for GDA. The RP has analysed the generic UK HPR1000 design against an extended LUHS condition and has identified defence-in-depth measures that are provided in the design to mitigate the effects. The RP has considered potential external hazards that could initiate a LUHS event and identified potential protection measures and mitigations that could be implemented during site-specific stages. A licensee will need to identify, characterise, and screen hazards that might cause a LUHS during site-specific stages. A safety

evaluation of site-specific hazards should consider the options identified by the RP to protect and mitigate against LUHS (Ref. 76). The licensee will need to demonstrate that risks associated with LUHS are reduced ALARP. I judge this work is normal business.

4.13.2 Strengths

521. My assessment of design basis conditions that can be initiated by external hazards has identified the following strengths:

- The RP has considered LOOP and LUHS as design basis conditions and protection against them is included in the design.
- The RP has identified external hazards that can initiate LOOP and LUHS in the external hazards schedule.
- The RP has considered combinations of hazards with design basis conditions to demonstrate that the design is robust against the hazard that may have initiated the design basis condition.
- The RP's definition of LOOP is consistent with previous GDAs.
- Defence-in-depth is provided against LOOP based on lessons learned from the Fukushima Dai-ichi NPP accident, including emergency diesel generators, SBO diesel generators, batteries and mobile diesel generators.
- A range of potential heat sink hazard sources have been analysed that could initiate a partial or total LUHS.
- Defence-in-depth is provided against LUHS based on lessons learned from the Fukushima Dai-ichi NPP accident, including the ASP [SPHRS] system.
- ASP [SPHRS] has been modified to withstand the low-air temperature hazard that could initiate a LUHS event.
- Mitigations are identified against heat sink specific hazards, which can be considered by a licensee for a target site.

4.13.3 Outcomes

522. My assessment has identified no findings or minor shortfalls in relation to design basis conditions that can be initiated by external hazards. A licensee will need to identify, characterise, and screen external hazards during site-specific stages and demonstrate that the design is robust against the hazards' effects, which may include initiating LOOP and LUHS. A licensee may need to include additional protection and mitigation measures against some external hazards that may initiate design basis conditions to demonstrate that the risks are reduced ALARP. The RP's analysis of heat sink specific hazards identifies some potential modifications that could be implemented at site-specific stages, if needed. This work is normal business during site-specific stages.

4.13.4 Conclusion

523. I have assessed the RP's safety evaluation for design basis conditions that could be initiated by external hazards. I conclude that:

- The design basis conditions considered in GDA are appropriate. The RP has identified the possible initiating external hazards in the External Hazards Schedule.
- The definition of the LOOP design basis condition for the GSE is consistent with best available data and RGP. I judge that GSE values are adequate for GDA.
- The RP's analysis has:
    - Identified those measures that protect against design basis conditions and demonstrated defence-in-depth.

- Identified options to protect and / or mitigate external hazards effects that might cause design basis conditions.
- Demonstrated the design is resilient against combinations of external hazards with design basis conditions.
- Implemented lessons learnt from the Fukushima Dai-ichi NPP accident, including additional cooling and power supply systems.
- Provided sufficient evidence to demonstrate that the design is robust against design basis conditions.

- I have not identified any Assessment Findings or minor shortfalls relating to design basis conditions.
- The RP has demonstrated the UK HPR1000 design is robust against design basis conditions initiated by external hazards. Further work is needed post-GDA as normal business to demonstrate risks are reduced ALARP including:

  - Evaluate the design against the effects of external hazards screened-out of GDA, which may include initiating LOOP and LUHS.
  - Consider the need for additional protection and mitigation measures against some external hazards that may initiate design basis conditions to demonstrate that the risks are reduced ALARP.

4.14 Assessment of Hazard Combinations

4.14.1 Assessment

524. I have assessed the adequacy of the RP's detailed analysis for the following hazard combinations:

- Earthquake and snow
- Wind and lightning
- Earthquake and internal fire
- Earthquake and dropped loads

525. I have collaborated with the ONR Internal Hazards Inspector to assess submissions made in response to RO-UKHPR1000-0055 (Ref. 16) for potential regulatory shortfalls relating to combinations of earthquake and consequential internal fire, and dropped loads (sub-section 4.18.1.5). The RP has provided an adequate safety evaluation for these hazards in GDA, including the implementation of some design modifications and identification of additional requirements to protect against the hazard effects.

526. My assessments of earthquake and snow, and wind and lightning are discussed below

4.14.1.1 Earthquake and Snow

527. I have sampled this combination because earthquake and snow apply structural loads. The FCG3 reference design did not consider snow hazard, given its location and the prevailing environment conditions. Therefore, I wanted to confirm that the combination was being adequately analysed by the RP during GDA for the UK HPR1000 design.

528. The RP has categorised the combination as an independent (coincidental) combination of hazards. This means the RP applies one hazard at the UK HPR1000 design input value level (equivalent to 1×10^{-4} annual probability of exceedance or lower) and the other at normal operational levels. The bounding load case is earthquake taken as the 1×10^{-4} / yr. event and snow as the 1×10^{-2} / yr. event. This approach is consistent with guidance in NS-TAST-GD-013 for independent hazard combinations (Ref. 6).

529. The RP provided the 'Structural Analysis and Design Report' (Ref. 335) in response to RO-UKHPR1000-0002 (Ref. 12). This report presents the load combinations for

hazards not considered in the FCG3 reference design, including snow. In this report the RP has calculated snow loads at 1 x 10^{-2} / yr. as 0.565 kN/m^2 based on Eurocode 1991-1-3 (Ref. 231). This value is used to calculate snow loads on flat roofs, which gives a 1 x 10^{-2} / yr. snow load of 0.678 kN/m^2 (Ref. 171).

530. The RP has compared the snow loads with ice loads to select a bounding value in the 'Structural Analysis and Design Report' (Ref. 335). The value of icing load calculated with a return period of 50 years is 0.54 kN/m^2 (Ref. 172) derived from Eurocode 1993-3-1 (Ref. 234) based on:

- A 50 year return period
- Ice thickness of 60 mm
- An ice density of 9 kN/m^3 (Ref. 171)

531. Eurocode lacks the formula to derive the icing hazard on a 1 x 10^{-2} basis (Ref. 335). Consequently, the RP recommends use of an ice load of 1.053 kN/m^2 for a 10^{-2} / yr. event, which is the same as the UK HPR1000 design input value (Ref. 335). The recommended ice load bounds the snow load for a 1 x 10^{-2} /yr. event. I have followed this thread into the 'Basis of Design for BFX' (Ref. 178) and note that data is provided for the 50 year and UK HPR1000 design input value icing events. I consider it unlikely that the RP has applied the proposed value for a 1 x 10^{-2} / yr. icing event in the load combinations. I judge this a minor shortfall. It is unlikely that this invalidates the RP's analysis as sub-section 4.1 of the 'Structural Analysis and Design Report' (Ref. 335) report states that live roof loads of 2 kN/m^2 bound both the 1 x 10^{-2} / yr. snow (0.678 kN/m^2) and rain (1.5 kN/m^2) loads. It can also be demonstrated that the live roof loads bound the icing load (compare 2 kN/m^2 and 1.053 kN/m^2).

532. I have discussed the RP's approach for designing against load combinations with the ONR Civil Engineering Inspector. The ONR Civil Engineering Inspector has confirmed the design methodologies include relevant external hazard loads. The structures that Civil Engineering has sampled as part of their assessment have demonstrated the adequacy of the RP's approach in defining bounding load cases. The substantiation of the civil engineering design is presented in the relevant design substantiation reports. The ONR Step 4 civil engineering assessment report should be consulted for further details (Ref. 98).

4.14.1.2 Wind and Lightning

533. I sampled this combination because it challenges the plant's defence-in-depth. My Step 3 assessment identified this as a credible combination that had been omitted from the RP's analysis. I have sampled this combination to confirm that the RP has adequately analysed the combination.

534. The RP has categorised the combination of wind / wind-borne missiles with lightning as a correlated hazard. I concur with the categorisation as both hazards might occur during a storm event. The RP has screened-in this hazard combination because it could challenge nuclear safety with wind or a wind-borne missile damaging the lightning protection system air terminators, making the plant more vulnerable to a subsequent lightning strike. This provides evidence that the RP has considered combination effects in the screening process, rather than simply applying the design basis screening criteria from IAEA Safety Reports Series No. 92 (Ref. 115).

535. 'The External Hazards Combination Safety Evaluation Report' (Ref. 77) identifies the combination of tornado / tornadic-missiles and lightning as consequential in the appendix, which contradicts the 'Tornado Safety Evaluation Report' (Ref. 72). It is not clear why this combination is categorised as consequential, rather than correlated. The phenomena driving tornado and lightning are similar and could foreseeably occur together. I consider this a minor shortfall given that the combination is screened-in to

GDA for analysis in other relevant submissions (Ref. 72). I judge this inconsistency has no effect on the RP's analysis.

536. The RP has adopted an overlay lightning protection system comprising external and internal meshes with shared air terminations (sub-section 4.10.1.12). Loss of the air terminations requires the internal mesh to provide the termination point. The RP's conceptual design is for the concrete covering the internal mesh to be only 50 mm thick and form a sacrificial layer. This is consistent with clause 5.2.5 in BS EN/IEC 62305-3 (Ref. 250) that allows for damage to non-metallic components, so long as damage is considered to be acceptable. The sacrificial nature of this overlying concrete layer means the damage is acceptable and unlikely to prejudice the delivery of safety functions by the civil structures.

537. The loss of air termination points may enable a lightning strike on other metallic elements projecting above roof level such as:

- VDA [ASDS].
- Exhaust and vent pipes associated with the emergency diesel generator diesel oil tank.

538. The RP has clarified that any metallic rooftop elements will be bonded to the lightning protection system. This approach is identified in sub-section 7.4 of the 'Design Basis Lightning Current Protection Analysis' report (Ref. 247), which states: "Equipment and exterior conductive elements mounted to the structure are equipotentially bonded to the integrated building [lightning protection system]". I judge this acceptable for GDA. A licensee will need to substantiate the adequacy of the lightning protection system during its detailed design. This is normal business.

4.14.2 Strengths

539. I have sampled the RP's analysis of hazard combinations. My assessment has identified the following strengths:

- The RP has developed a methodology for the identification, categorisation, screening and evaluation of hazard combinations based on RGP.
- The RP has considered combination effects in its screening criteria as expected by RGP.
- The RP has analysed a range of credible hazard combinations during GDA.
- The RP's analysis of hazard combinations sampled in GDA is consistent with the approaches described in the 'External Hazards Combination Safety Evaluation Report' (Ref. 77) for different combination types.
- The RP's analysis approach is aligned with ONR's guidance in NS-TAST-GD-013 (Ref. 6).
- The RP has demonstrated the UK HPR1000's resilience against hazard combinations.

4.14.3 Outcomes

540. My assessment of hazard combinations has not identified any Assessment Findings. I have identified minor shortfalls, which are described in sub-section 4.14.1. I judge these minor shortfalls have no meaningful impact on the RP's analysis or safety case.

541. A licensee will need to undertake further work on hazard combinations during site-specific stages. Relevant combinations screened-out of GDA will need to be characterised and evaluated to demonstrate that the design is robust against the combined hazard effects. I judge this work normal business, and no additional findings are raised in relation to this work.

4.14.4 Conclusion

542. I have assessed the RP's safety evaluation for hazard combinations. I conclude that:

- The screened-in hazard combinations for GDA are appropriate. Other hazard combinations are screened-out with appropriate justification as site-specific information is required to characterise the hazard sources in a meaningful manner.
- The definition of a hazard combination is dependent on the categorisation of the relationship. The RP has defined three combination types that align with ONR's guidance in NS-TAST-GD-013:
  - Correlated – both hazards taken as the UK HPR1000 design input value.
  - Consequential – a consequence analysis is provided for the secondary hazard.
  - Independent (coincidental) – the primary hazard taken as the UK HPR1000 design input value and the secondary hazard taken at the upper bound of normal operational levels.
- The RP's analysis has:
  - Considered combination effects.
  - Identified those measures that protect against the hazards effects and demonstrated defence-in-depth.
  - Substantiated the civil structures against bounding load cases, which includes consideration of hazard combination loadings.
  - Provided sufficient evidence to demonstrate that the design is robust against hazard combinations.
- I have not identified any Assessment Findings related to hazard combinations, although I highlight that the ONR Civil Engineering Inspector has raised an Assessment Finding that is relevant to hazard combination load cases applied in the civil structure design. I judge this matter does not undermine the external hazards safety case or its conclusions.
- The RP has demonstrated the UK HPR1000 design is robust against hazard combinations in GDA. Further work is needed post-GDA to demonstrate risks are reduced ALARP, including evaluation of relevant hazard combinations screened-out of GDA. This is normal business.

4.15 External Hazard Schedule

4.15.1 Assessment

543. It is good practice in the UK to summarise key aspects of a nuclear facility's safety case in tabular format called a schedule. The RP has produced various schedule reports in response to RO-UKHPR1000-0004 Action 4 (Ref. 336), which expects the RP to produce a suite of schedules that identify safety functional requirements and the link with the SSCs that deliver the functions. The 'External Hazards Schedule Report' (Ref. 79) is one of the schedules developed in response to this RO. The RP's understanding of requirements management between the various schedules that have been developed is shown in Figure 11. ONR's assessment of submissions made in relation to RO-UKHPR1000-0004 is described in the cross-cutting assessment report (Ref. 337).

544. The 'External Hazards Schedule Report (Ref. 79) has been developed using the methodology in the 'Internal and External Hazards Schedule Methodology Report'

(Ref. 338). The purpose of the external hazard schedule is to provide: "… linkage between hazards, fault and protection measures." The schedule only presents information for design basis events (SAP EHA.3 definition) with initiating event frequencies consistent with the expectations of SAP EHA.4. Beyond design basis hazards are explicitly not included in the schedule, although the following should be noted:

- Human-based safety claims (HBSCs) have considered some relevant external hazards from a beyond design basis perspective to identify any required operator actions that are needed to achieve a safe shutdown of the reactor.
- Accidental aircraft crash is included in the schedule as the RP has chosen to protect against light aircraft impact, even though this hazard is not a design basis event on a frequency basis (sub-section 4.12.1.2).
- The RP refers to the malicious aircraft impact hazard in the schedule as "beyond design basis aircraft crash", although the hazard is not defined by an annual probability of exceedance (sub-section 4.12.1.3).

545. I have assessed the external hazards schedule on a sampling basis to determine its adequacy and to address AFI-6 from my Step 3 assessment (Annex 3). I have assessed:

- Requirements management between the external hazards schedule and the civil engineering safety case documentation.
- Requirements management between the external hazards schedule and the 'Engineering Schedule for Mechanical Engineering' (Ref. 339).
- The capture of HBSCs relevant to the external hazards safety case.

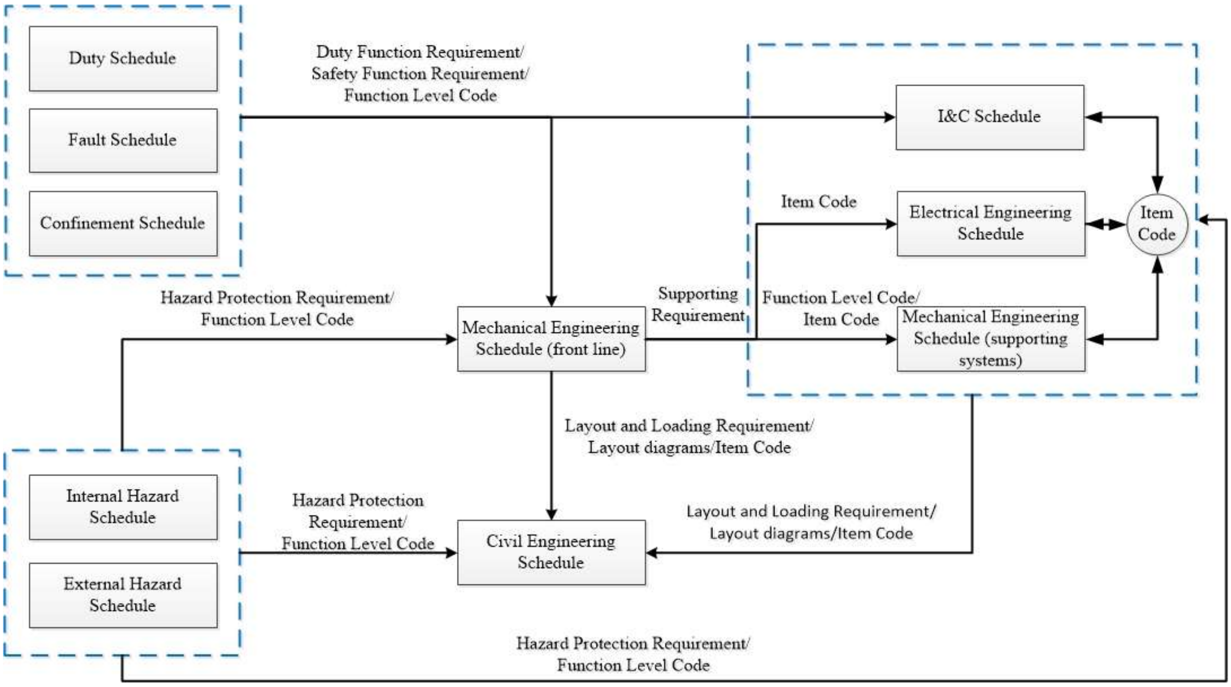

Figure 11: Flow of requirements between UK HPR1000 schedules. *(Ref. 340)*

546. These samples are discussed in the following sub-sections. The flow of requirements is managed via a coding system that has been adopted by the RP (Ref. 341). The code comprises four fields separated by "-". Each field comprises 2-3 alphanumeric digits:

- Field 1 – SSC code (e.g. BFX for the fuel building or DCL for the MCR air conditioning system (DCL [MCRACS])).

- Field 2 – Abbreviation for functional requirement type. This clarifies the schedule from which the requirement originates (e.g. E## for external hazards. ## represents the external hazard type e.g. TN for tornado).
- Field 3 – Serial number (e.g. sequential numbering for the hazard 01, 02, 03).
- Field 4 – Supplement code defines the means of safety function delivery (e.g. A## for automatic; P## for passive; M## for manual; L## for local. ## is a serial number, such as 01, 02, 03).

547. Figure 11 does not show a link between the external hazards and fault schedules (Ref. 301). External hazards can initiate a number of design basis conditions (faults), such as LOOP and LUHS (sub-section 4.13). The "Potential Consequences caused by External Hazards" column in the 'External Hazards Schedule Report' (Ref. 79) identifies the design basis conditions that can be initiated by the various hazards. A footnote in Appendix A of the 'External Hazards Schedule Report' (Ref. 79) states that: "For conservative reason, if a design basis fault corresponds to several events with different conditions in Fault Schedule, the design basis fault caused by external hazards is linked to the most severe one. For instance, the LOOP caused by tornado is linked to the "Long Term LOOP of 168 Hours Duration" by default." I judge the RP's approach conservative for the purposes of GDA. A licensee may wish to enhance the links between the external hazards and fault schedules as part of normal business.

4.15.1.1 Requirements Management between External Hazards Schedule and Civil Engineering

548. I have sampled the exchange of requirements from the external hazards schedule to the civil engineering safety case documentation for the BFX building. The BFX building was chosen as it is both one of the ONR Civil Engineering Inspector's samples and a nuclear safety significant structure containing other SSCs.

549. I have extracted hazard entries relevant to civil engineering aspects of the BFX from the external hazards schedule (Ref. 79). This gave a total of 22 requirements. I have checked that these requirements are adequately represented in relevant civil engineering safety case documentation, including the 'Basis of Safety Case for BFX' (Ref. 342). Many examples of the hazard protection measures and relevant safety functional requirements correctly feed directly into the 'Basis of Safety Case for BFX' (Ref. 342).

550. I have also compared the extracted requirements for hazard combinations with the 'External Hazards Combination Safety Evaluation Report' (Ref. 77). This has demonstrated that the combinations identified in the 'External Hazard Schedule Report' (Ref. 79) relevant to civil engineering SSCs are consistent with those external hazard combinations presented as T-4.1-3 of the 'External Hazards Combination Safety Evaluation Report' (Ref. 77).

551. Overall, I judge that traceability between the external hazards and the civil engineering safety case documents has been demonstrated based on my sample. The use of the hazard protection code enables requirements to be efficiently and logically transferred between relevant safety case documentation. On this basis I consider the RP has satisfied AFI-6 from my Step 3 assessment (Annex 3).

4.15.1.2 Requirements Management between External Hazards Schedule and Mechanical Engineering

552. I have sampled the exchange of requirements from the external hazards schedule (Ref. 79) to the 'Engineering Schedule for Mechanical Engineering' (Ref. 339). The engineering schedule has been developed for a small number of sample systems to demonstrate the adequacy of the RP's requirements management process. I have chosen to sample the DCL [MCRACS] system as it is included in both the mechanical

engineering and external hazards schedules. Some HVAC requirements are also identified on the 'Confinement Schedule' (Ref. 343). This schedule includes requirements for the DCL [MCRACS] and they are traceable from the engineering schedule into the confinement schedule. The requirements in the 'Confinement Schedule' (Ref. 343) do not form part of my sample as they do not originate from the external hazards schedule.

553. The requirements for the DCL [MCRACS] are directly traceable into the 'Engineering Schedule for Mechanical Engineering' (Ref. 339) using the hazard protection requirement code from the 'External Hazards Schedule Report' (Ref. 79), minus the supplement code (last three digits). I identified four of the hazard protection requirements identified for DCL [MCRACS] from the 'External Hazards Schedule Report' (Ref. 79) in the mechanical engineering schedule (Ref. 339). Four hazard protection requirements relating to external hazard combinations are not included in the mechanical engineering schedule (Ref. 339), namely:

- SYS-EHC-01-A01
- SYS-EHC-02-A01
- SYS-EHC-03-A01
- SYS-EHC-04-A01

554. I judge the omission of the hazard protection requirements relating to external hazard combinations to be a minor shortfall only, given the purpose of the mechanical engineering schedule is to demonstrate the adequacy of the RP's requirements management process. I consider this purpose has been adequately demonstrated for GDA given requirements for DCL [MCRACS] are traceable between the external hazards and mechanical engineering schedules. A licensee will further develop the schedules during site-specific stages to include all safety functional requirements, including those relating to hazard combinations. I consider this to be normal business.

555. I have been able to trace the DCL [MCRACS] and DEL [SCWS] performance requirements, function class and design provision class relevant to high-air temperature from the 'Engineering Schedule for Mechanical Engineering' (Ref. 339) to the relevant SDM chapters (Ref. 344, Ref. 345). My sampling confirmed the requirements are accurately presented in the SDMs. I judge this consistent with the expectations of SAP SC.4 for an accurate safety case.

556. Overall, I find that there is traceability between the external hazards schedule and the mechanical engineering schedule via the hazard protection requirement code. I have also traced requirements from the schedules in to relevant SDMs for DCL [MCRACS]. The mechanical engineering schedule needs to be further developed post-GDA for all other relevant systems. I have confidence that this is achievable based on my sampling of the requirements management process developed by the RP.

4.15.1.3 Requirements Management between External Hazards Schedule and Human Factors

557. ONR's expectation for the capture and assessment of Human Based Safety Claims (HBSCs) are presented in SAPs: EHF.2 and EHF.3. These SAPs establish the principles of minimising the dependency on human actions to maintain a safety function and, where actions cannot be allocated to technology, the need to capture all HBSCs that can have an impact on safety. This includes explicit and implicit claims.

558. I assessed the "External Hazards Schedule Report" (Ref. 79) to ensure HBSCs supporting hazard protection and mitigation of external hazards are captured, and to establish whether the RP has met the expectations of the SAPs.

559. The omission of HBSCs was identified following assessment of Revision E of the ‘External Hazards Schedule Report’ (Ref. 346) as there were no manual supplementary codes identifiable in Appendix A. The failure to identify HBSCs was discussed at technical meetings jointly attended by the ONR Human Factors and Internal Hazards Inspectors (Ref. 347, Ref. 348). ONR judged that there was a shortfall against SAP EHF.3 (Ref. 2) as the RP had failed to suitably and sufficiently identify the HBSCs that form part of the wider hazard protection and mitigation strategy.

560. Given the potential significance of this shortfall, I raised RQ-UKHPR1000-1435 (Ref. 349) to: “…understand the RP’s approach to identifying, classifying, analysing, and manging human-based safety functional requirements, within the practicalities of GDA, for UKHPR1000 and to gain confidence that the risk important human-based safety functional requirements, from a safety and/or design perspective, which are related to hazards are adequately captured.” The RP’s response to this RQ (Ref. 350) described the approach for HBSCs relevant to hazards as:

- The hazards assessment has principally focused on ensuring engineered safety functions are the primary safety systems.
- The analysis of the hazards scenarios included human-factors input and the RP has recognised, where necessary, human action is required.
- The RP has recognised that there are additional defence-in-depth actions that will be undertaken by operators. These have not been credited as they are not the primary protection measures.

561. A total of three HBSCs have been identified as a result of the RP’s additional analysis that are relevant to the external hazards safety case:

- Two relate to the closure of external doors to protect against the tornadic event and external flooding. Door closure is managed by a docket system, similar to that in place for Chinese NPPs. It is claimed this mitigates the potential for the doors to be open during the postulated events.
- One requirement relates to the manual operation of the ASP [SPHRS] heating system during a low-air temperature event.

562. These requirements are captured in the latest revision of the ’External Hazards Schedule Report’ (Ref. 79). As none of the external hazards related HBSCs are Class 1 safety functions, the RP has proposed that the human reliability assessment should be performed post-GDA on the basis that the actions are of low risk importance and there is unlikely to be foreclosure of options due to design changes. This is a reasonable approach, as the human reliability assessment will need to take account of the UK concept of operations, safety management system, personnel levels, and the site-specific layout. I judge that this work is normal business during site-specific stages.

563. Overall, I judge the RP’s approach adequate for the purposes of GDA. The RP has provided sufficient evidence to show that HBSCs have been identified, for the generic UK HPR1000 design, relevant to external hazards and with adequate input from the RP’s human factors discipline. A licensee will need to expand on the work undertaken for GDA by the RP to include all site-specific hazards and to consider the results of the human reliability assessment that needs to be undertaken. CGN has committed (commitment – human factors, human reliability analysis 17) to identify and substantiate HBSCs within the wider fault, hazards, and engineering schedules during site-specific stages (Ref. 351). This is normal business for site-specific stages.

4.15.2 Strengths

564. My assessment of the external hazards schedule has identified the following strengths:

- The RP's external hazards schedule provides links between hazards, protection measures and safety functional requirements as expected by the SAPs.
- The RP has demonstrated that requirements are traceable between the external hazards schedule and engineering safety case documentation via the hazard protection requirement code.
- The RP has provided sufficient evidence for the purposes of GDA to demonstrate that HBSCs relevant to external hazards have been captured.

4.15.3 Outcomes

565. My assessment of the external hazards schedule has identified no Assessment Findings. A minor shortfall is identified relevant to the mechanical engineering schedule (sub-section 4.15.1.2), but I judge that this does not undermine the validity of the RP's requirements management process. Further work is needed post-GDA to develop comprehensive schedules for the site-specific design, including the capture and substantiation of relevant HBSCs. I judge this is normal business.

4.15.4 Conclusion

566. I have assessed the adequacy of the RP's external hazards schedule. I conclude that:

- The external hazards schedule establishes the links between hazards, protection measures and safety functional requirements.
- The RP has captured HBSCs relevant to the external hazards schedule.
- Traceability of safety functional requirements between the external hazards schedule and engineering schedules is achieved via the protection requirement code.
- I judge that the RP has demonstrated the applicability of its requirements management process via the external hazards schedule.
- A licensee will need to further develop the schedules post-GDA including the capture and substantiation of relevant HBSCs. This is normal business.

4.16 Cliff-edge Effects and Beyond Design Basis Events

4.16.1 Assessment

567. I have assessed the RP's analysis of cliff-edge effects and beyond design basis events to determine the adequacy of the design's beyond design basis margins (in other words, comparison of the UK HPR1000's design input value against the GSE value). I have assessed relevant safety case submissions against the expectations of SAPs EHA.7, EHA.18 (Ref. 2) and ONR NS-TAST-GD-013 (Ref. 6). I have sampled the following hazards:

- Earthquake: which the RP argues is a bounding beyond design basis hazard in terms of strength design and lateral stability for civil structures (sub-section 4.8.1.2).
- Flooding: to ensure lessons learned from the Fukushima Dai-ichi NPP accident have been adequately implemented in the UK HPR1000 design (sub-section 4.9.1.2).
- Air temperature and enthalpy: in relation to HVAC system design (sub-section 4.10.1.4).
- Tornado: to understand arguments in relation to the UK HPR1000 design input value exceeding the GSE value.
- Snow: to understand arguments made in relation to the UK HPR1000 design input value being the same as the GSE value.

568. The RP has applied the methodology from the 'Beyond Design Basis External Hazards Evaluation Methodology' for the tornado hazard (Ref. 61). Tornado is identified as a category 1 hazard, meaning the RP's safety case has argued that there is an absence of cliff-edge effects because the UK HPR1000 design input value exceeds the GSE value (89 m/s and 65 m/s respectively, see section 4.10.1.1). The RP's arguments in section 4 of the 'Tornado Safety Evaluation Report' (Ref. 72) are consistent with the approach described in the 'Beyond Design Basis External Hazards Evaluation Methodology' (Ref. 61). The bounding load cases for structures are from aircraft impact and seismic. On this basis, I judge that there are no cliff-edge effects from tornado hazards, and that there is credible margin against the hazard.

569. Snow is identified by the RP as a category 2 hazard. This is because the FCG3 reference design did not consider snow as a hazard. The category 2 definition means that the RP's BDBA should demonstrate withstand against a best estimate 1×10^{-5} /yr. event (Ref. 61). The RP has calculated the snow load for BFX as 1.55 kPa, which is claimed to be a 1×10^{-5} /yr. value (Ref. 118). This value is consistent with that derived in equation 6-10 of the 'Beyond Design Basis External Hazards Evaluation Methodology' (Ref. 61) for a 1×10^{-5} /yr. snow hazard. The RP has demonstrated that the vertical seismic load for BFX is a factor of 12 greater than snow loading (Ref. 118). The arguments in section 4 of 'Meteorological Hazards Safety Evaluation Report' (Ref. 71) highlight the conservative derivation of the snow loads by not including a climate change allowance. I judge the RP has provided sufficient evidence to demonstrate the absence of cliff-edge effects for snow and has met the expectations of SAP EHA.7 (Ref. 2).

570. I judge the RP's methodology from the 'Beyond Design Basis External Hazards Evaluation Methodology' (Ref. 61) to be adequate for the purposes of GDA. The RP has provided an adequate demonstration that cliff-edge effects are absent for the UK HPR1000, based on the evidence I have assessed during my sampling. I judge the RP has met the expectations of SAP EHA.7 (Ref. 2). However, I find that the RP has not identified the margins to failure for UK HPR1000 SSCs against beyond design basis external hazards and the point at which safety functions are lost, as expected by SAP EHA.18 (Ref. 2). I consider this to be a minor shortfall, as the margins to failure can only be effectively calculated when the site-specific hazard values for a target site are known. A licensee should, as normal business, demonstrate that beyond design basis risks are reduced ALARP during site-specific stages and once site-specific data is known. The focus should be on those hazards where there is expected to be little beyond design margin, such as where the GSE value has been selected as the UK HPR1000 design input value.

4.16.2 Strengths

571. My assessment of cliff-edge effects and BDBA for the UK HPR1000 GDA has identified the following strengths:

- The RP has developed a process for categorising hazards screened-in to GDA, which determines how they are analysed from a BDBA perspective. This process is logical and aligned with guidance provided in NS-TAST-GD-013.
- The RP has systematically applied the process and has analysed hazards in accordance with the methodology.
- The RP has demonstrated, for the hazards sampled, that there are no cliff-edge effects.
- The RP's approach to selecting UK HPR1000 design input values provides confidence that there is credible beyond design basis margin where the FCG3 reference design value bounds the GSE value.

4.16.3 Outcomes

572. My assessment of cliff-edge effects and BDBA for the UK HPR1000 GDA has identified one minor shortfall as described in sub-section 4.16.1. I judge that this minor shortfall does not undermine the generic UK HPR1000 safety case. A licensee, as normal business, will need to demonstrate that risks associated with beyond design basis hazards are understood and managed, with emphasis on those hazards where there is likely to be little beyond design basis margins, such as those where the GSE value has been selected as the UK HPR1000 design input value.

4.16.4 Conclusion

573. I have assessed the RP's approach to cliff-edge effects and BDBA. I conclude that:

- The RP's approach to BDBA is adequate for GDA and aligned with RGP.
- The RP has systematically applied the approach to categorise and analyse hazards screened-in to GDA.
- The RP has provided sufficient evidence to demonstrate an absence of cliff-edge effects.
- The RP has not demonstrated the margins to failure as expected by SAP EHA.18. I judge that this is most effectively addressed post-GDA, for a target site, when the actual margins to failure can be calculated by comparison of the UK HPR1000 design input values with the site-specific hazard values.

4.17 External Hazards Safety Case for Fuel Building

4.17.1 Assessment

574. I have assessed the external hazards safety case for the BFX from a holistic perspective to ensure that:

- The safety case "golden thread" (in other words narrative between CAE) is traceable into the civil engineering safety case documentation (sub-section 4.15.1.1).
- The extant external hazards safety case for the BFX is robust and suitable for a generic nuclear island building.
- External hazards and combinations applied to the BFX are consistent with those identified at GDA and any selection or dismissal of external hazards has been followed through to a logical conclusion (sub-sections 4.3 and 4.4).
- The analysis performed by the RP for sampled external hazards is consistent with RGP including:
    - Flooding (sub-section 4.9).
    - Wind, including the RP's application of ASCE-7-10 to the derivation of the local wind pressures is suitable by comparison with the approach suggested in Eurocode EC-1991-1-4 (sub-section 4.10.1.2).
    - Snow, including the RP's application of EUR to the derivation of the snow loads is suitable by comparison with the approach suggested in Eurocode BS EN 1991-1-3:2003+A1:2015 (sub-section 4.10.1.10).
    - Malicious aircraft impact (sub-section 4.12.1.3).

575. The RP's logic flow for the external hazards safety case for BFX was presented during a technical meeting (Ref. 352) (Figure 12). The logic flow is consistent with the RP's approach to the external hazards safety case. The safety case for BFX is based on the same documentation as the rest of the external hazards safety case, and which underpins the PCSR (Ref. 4).

576. My assessment of documentation shown in Figure 12 has identified the following:

- The RP has analysed the BFX against a range of hazards and combinations that is consistent with those screened-in to GDA.
- On a sampling basis, the UK HPR1000 design input values presented in the 'Basis of Design for BFX' (Ref. 178) are consistent with those identified in the PCSR (Ref. 3, Ref. 4) and underpinning documents (Ref. 172, Ref. 171).
- The RP's approach for translation of wind and snow hazards to loadings is consistent with RGP.
- The RP's analysis of external hazards is commensurate with that provided for other nuclear island buildings.
- There is an opening at 1.15m above platform level (0.85m to opening base and 0.3m building threshold) that is unprotected against external flooding. I have raised Assessment Finding AF-UKHPR1000-0087 for a licensee to consider the need to protect this opening during site-specific stages for a target site and once the design basis event for flooding is known.
- The malicious aircraft impact safety case has identified a number of potential design shortfalls that need to be protected. The RP has committed to undertaking this work during site-specific stages once the site-specific layout is known, and I have raised Assessment Finding AF-UKHPR1000-0093 to ensure the adequacy of this work.
- Links are present between the external hazards schedule and civil engineering safety case documentation and requirements are traceable.
- The RP has provided qualitative arguments that the modified design of BFX remains robust against external hazards.

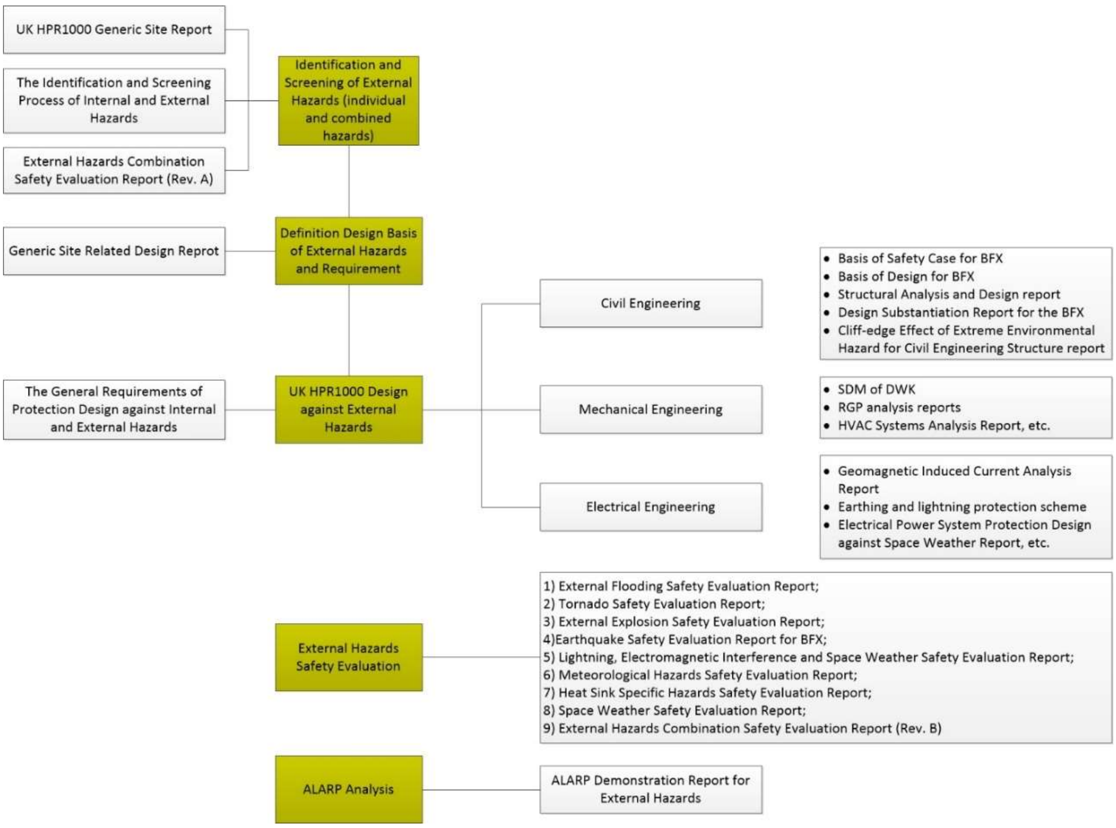

Figure 12: Logic flow diagram for BFX external hazards evaluation. *(Ref. 353)*

577. Overall, based on the documentation I have sampled, I am satisfied that the safety justification for BFX against external hazards is consistent with the wider external hazards safety case for GDA.

4.17.2 Strengths

578. My assessment of the external hazards safety case for BFX has identified the following strengths:

- The RP's approach for developing the safety justification for BFX is consistent with the wider external hazards safety case.
- The external hazards analysed for BFX is consistent with the wider external hazards safety case for GDA, and there are no additions or omissions specific to the BFX.
- RGP has been used in developing the safety justifications for external hazards.
- Requirements arising from the external hazards safety case for BFX can be traced into the civil engineering safety documentation.

4.17.3 Outcomes

579. My assessment of the external hazards safety case for BFX has identified no additional Assessment Findings or minor shortfalls compared with those raised elsewhere in this assessment report. Assessment Findings AF-UKHPR1000-0087 and AF-UKHPR1000-0093 are relevant to BFX as they relate to openings on the building's external boundary that are vulnerable to external flooding and aircraft impact respectively. I judge it is appropriate for these design shortfalls to be addressed at site-specific stages once site-specific inputs are available to inform the optioneering. A licensee will need to revisit the safety justification for BFX for a target site to demonstrate that the risks from external hazards are reduced ALARP.

4.17.4 Conclusion

580. I have assessed the external hazards safety case for BFX. I conclude that:

- The safety case for BFX is consistent with the wider external hazards safety case that has been developed for the UK HPR1000 GDA.
- My assessment has identified shortfalls in the external hazards safety case relevant to the BFX against which I have raised Assessment Findings.
- I judge these Assessment Findings are most effectively addressed during site-specific stages when site-specific information can be used to inform the optioneering.

4.18 Regulatory Observations

4.18.1 Assessment

581. During GDA I have raised and actively contributed to the assessment of a number of ROs. All ROs have been closed during Step 4. These ROs and any matters are discussed in the following sub-sections.

4.18.1.1 RO-UKHPR1000-0002

582. Based upon the submissions made by the RP early in GDA, I judged there to be potential regulatory shortfalls associated with:

- The totality of external hazards screened-in for a generic UK site was greater than those considered for the reference plant FCG3.
- The FCG3 reference design values were not bounding of all the GSE parameters.

583. The following shortfalls were identified:

- Seismic hazard shear-wave velocity – GSE values not bounded by the reference design (sub-section 4.8).
- Air temperatures – GSE values not bounded by the reference design (sub-sections 4.10.1.4 and 4.10.1.5).
- Water temperature (minimum) – GSE value not bounded by the reference design (sub-section 4.10.1.8).
- Snow – not considered in the FCG3 reference design (sub-section 4.10.1.10).
- Icing – not considered in the FCG3 reference design (sub-section 4.10.1.11).
- Space weather – not considered in the FCG3 reference design (sub-section 4.11).

584. I considered the RP's submissions provided insufficient information to form a judgement on the suitability of the UK HPR1000 design for deployment in the UK due to the aforementioned shortfalls. RO-UKHPR1000-0002 (Ref. 12) was raised to:

- Articulate ONR's regulatory expectations.
- Ensure resolution of these shortfalls during the GDA of UK HPR1000.
- Obtain confidence and the necessary assurances that the UK HPR1000 design is robust against external hazards.

585. The RP submitted the following documentation in accordance with their resolution plan (Ref. 196):

- 'External Hazards Gap Identification and Evaluation Report' (Ref. 197) – this report identifies and evaluates the gaps between the reference design and the GSE in terms of both hazards considered in the UK HPR1000 design and the selection of design bases.
- 'External Hazards Gap Resolution Strategy Report' (Ref. 354) – this report provides the strategy to address the gaps.
- 'HVAC Systems Analysis Report' (Ref. 210) – this report looks to address the gaps identified for the HVAC design with regards to the external hazards parameters for air temperature and enthalpy.
- 'SEC/RRI System Analysis Report' (Ref. 224) – this report evaluates the SEC/RRI system design with respect to the GSE water temperature hazard parameters.
- 'Structural Analysis and Design Report' (Ref. 335) – the report seeks to address gaps identified for the civil structure design with respect to hazards and associated loads not considered in the reference design (e.g. snow and ice) and also hazard load combinations.
- 'Seismic Analysis for Structure Report' (Ref. 355) – the report seeks to address the gap for seismic design with respect to shear wave velocities for the GSE.
- 'Control & Instrumentation System Protection Design against Space Weather' (Ref. 265) – the report looks to address the gap for C&I systems against the space weather hazard. The report considers the effects of space weather, the general requirements of space weather protection and identifies protection measures.
- 'Electrical Power System Protection Design against Space Weather' (Ref. 275) – the report looks to address the gap for electrical systems against the space weather hazard. The report considers the effects of space weather, the general requirements of space weather protection and identifies protection measures.
- 'Modification of UK HPR1000 Design for External Hazards' (Ref. 356) – this report presents the modifications to the UK HPR1000 resulting from the identification and evaluation of gaps under RO-UKHPR1000-0002.

586. I assessed the submissions during previous GDA steps in collaboration with the relevant ONR inspectors from impacted disciplines, namely: Civil Engineering, Mechanical Engineering, Electrical Engineering, and C&I. My assessment of these submissions is reported in ONR-NR-AN-20-018 (Ref. 357), and summarised in

relevant sections and sub-sections of this assessment report. Overall, based on my assessment of submissions relevant to RO-UKHPR1000-0002, I am satisfied that the RP has adequately analysed impacted SSCs against those hazard gaps identified in the RO, and modified the design where appropriate. The RP has provided a suitable and sufficient justification of the generic UK HPR1000 design's withstand against the hazards. On this basis I judged that the RP had satisfied RO-UKHPR1000-0002 and this was closed during Step 4 (Ref. 358).

587. My assessment of RO-UKHPR1000-0002 identified a total of three matters to be addressed (Table 30). These matters have been assessed during Step 4 and, where necessary, Assessment Findings have been raised to ensure these are adequately addressed post-GDA.

Table 30: Matters associated with RO-UKHPR1000-0002 and their status following assessment during Step 4 of the UK HPR1000 GDA

Matter		Assessment	Status
1	Once the site-specific plant cooling design is known, a licensee should, if necessary, adequately implement appropriate design changes identified by the RP to ensure that the SEC [ESWS] / RRI [CCWS] can withstand the GSE value for the minimum sea-water temperature hazard.	Sub-sections 4.10.1.8 and 4.13.1.2	Assessment Finding AF-UKHPR1000-0089
2	Once site-specific geomagnetically induced current hazard, the electrical loads and grid connection are known, a licensee should adequately implement the identified options for mitigation of the GIC hazard that have been developed by the RP.	Sub-section 4.11.1.2 and Step 4 electrical engineering assessment report (Ref. 142)	Assessment Finding AF-UKHPR1000-0171 (Ref. 142)
3	Once the C&I and support (mechanical and electrical) systems designs are sufficiently developed and detailed, a licensee should adequately implement the identified options and strategies for mitigation of the solar energetic particles hazard that have been developed by the RP.	Sub-section 4.11.1.1	Assessment Finding AF-UKHPR1000-0091

4.18.1.2 RO-UKHPR1000-0007

588. Based upon the submissions made by the RP early in GDA, I judged there to be potential regulatory shortfalls associated with the aircraft impact safety case for UK HPR1000. Two RQs were raised in relation to the RP's safety case; RQ-UKHPR1000-0087 (Ref. 359) sought clarity on the RP's strategy for development of the aircraft impact safety case and RQ-UKHPR1000-0112 (Ref. 360) sought to capture information exchanged via a technical workshop including the UK HPR1000 protection measures against the aircraft impact hazard. I judged the RP's response to these RQs to be inadequate and lacked confidence that the RP's approach would result in an adequate aircraft impact safety case for the UK HPR1000 given the gaps that had been identified. Consequently, I raised RO-UKHPR1000-0007 (Ref. 13) to ensure that the UK HPR1000 aircraft impact safety case would satisfy UK expectations, and in particular provide a demonstration of how:

- The generic UK HPR1000 design would be optimised considering the differing/additional aircraft impact analysis expectations relevant to the UK context and how, overall, relevant risks will be managed.
- The external hazards' safety case would be complete and provide appropriate inputs into the civil engineering and other assessments required for UK HPR1000.

589. The RP submitted the safety documentation in accordance with their resolution plan (Ref. 361). The documentation and purposes is as follows:

- 'Aircraft Impact Gap Analysis Report' (Ref. 296) – this report compares the reference design and associated analysis with the UK expectations for aircraft impact to identify gaps that need to be addressed. It also recommends the hazards for the RP to use in the UK HPR1000 design.
- 'Aircraft Impact Safety Evaluation Methodology Report' (Ref. 362) – provides a high-level methodology to be applied in the deterministic safety case to identify any shortfalls in the UK HPR1000 design against the aircraft impact hazard.
- 'Development of Aircraft Impact Force-Time Functions for UK-HPR1000 Report' (Ref. 297) – presents the derivation of load time functions for the identified hazards.
- 'Basis of Safety Case for Aircraft Impact' (Ref. 318) – provides a more detailed breakdown of the high-level safety claims made in the PCSR for civil structures and provides the link between the safety claims and engineering (safety functional) requirements. The document focuses on those structures that need to withstand the aircraft impact hazard.
- 'Basis of Design for Aircraft Impact' (Ref. 312) – identifies the engineering provisions needed to meet the safety functional requirements relevant to the aircraft impact hazard. The report also presents the boundaries, loads and other information needed to undertake analysis and design development.
- 'Aircraft Impact Evaluation Method Statement' (Ref. 363) – presents the methodology for analysis of aircraft impact on the civil structures.
- 'Aircraft Impact Evaluation Report' (Ref. 300) – presents the application of the methodology for analysis of aircraft impact on the civil structures.
- 'Aircraft Impact Dynamic Analysis Report' (Ref. 364) – presents the dynamic (vibratory) analysis associated with the aircraft impact hazard on SSCs).
- 'Design Substantiation for Aircraft Impact' (Ref. 365) – presents the results of the analysis of the civil structures and demonstrates whether the acceptance criteria for civil structures are met.
- 'Aircraft Crash Safety Evaluation Report' (Ref. 366) – summarises the aircraft impact safety case and applies the deterministic methodology from the Aircraft Impact Safety Evaluation Methodology Report to identify any shortfalls in the UK HPR1000 protection design against the hazard. Modifications are proposed in this report to address any shortfalls.

590. The linkages between the safety documentation is presented in Figure 13.

591. I have assessed the submissions during Step 4 in collaboration with the ONR Civil Engineering Inspector, and with support from my TSC. My assessment of these submissions is reported in ONR-NR-AN-20-019 (Ref. 367), and summarised in sub-sections 4.12.1.2 and 4.12.1.3 of this report. Overall, based on my assessment, I am satisfied that the RP has developed an adequate scope for the aircraft impact safety case. The RP has optimised the generic UKH HPR1000 design to meet UK expectations; hazard definitions are consistent with ONR's expectations (Ref. 293) and the associated load-time functions have been applied in design of relevant civil structures. On this basis, I judged that the RP had satisfied RO-UKHPR1000-0007 and this was closed during Step 4 (Ref. 368).

592. My assessment of submissions relevant to RO-UKHPR1000-0007 identified a total of five matters (Table 31). These matters have been assessed during Step 4, and where necessary Assessment Findings have been raised to ensure these are adequately addressed post-GDA.

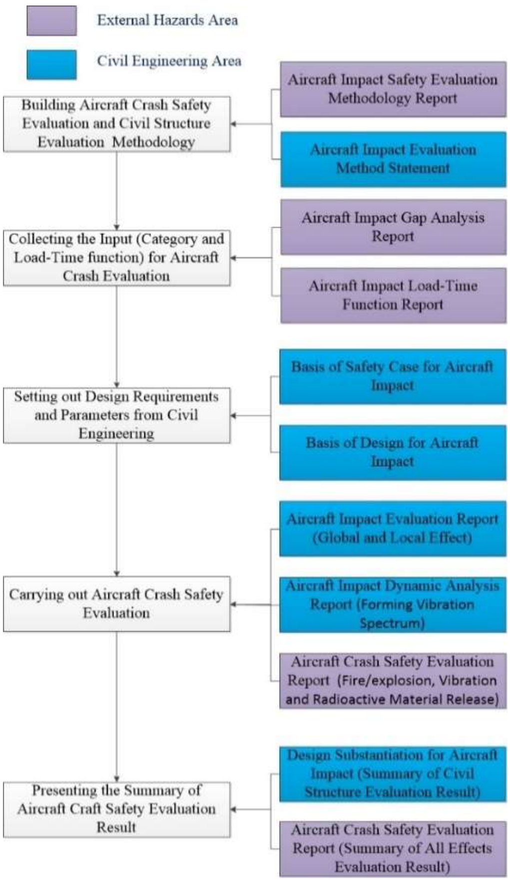

Figure 13: Documentation map for aircraft impact. *(Ref. 70)*

Table 31: Matters associated with RO-UKHPR1000-0007 and their status following assessment during Step 4 of the UK HPR1000 GDA

Matter		Assessment	Status
1	The RP will need to substantiate any revisions to the BFX building design against hazards including the aircraft impact hazard.	Step 4 civil engineering assessment report (Ref. 98)	Assessment Finding AF-UKHPR1000-0223 (Ref. 98)
2	Residual potential design shortfalls, not addressed by Modification 27, will need to be addressed post-GDA.	Sub-section 4.12.1.3	Assessment Finding AF-UKHPR1000-0093
3	Uprated three-hour fire barriers (including associated penetrations) are to be substantiated post-GDA when the design becomes sufficiently detailed.	Sub-section 4.12.1.3	Assessment Finding AF-UKHPR1000-0094
4	The Step 4 civil engineering assessment report will present the detailed assessment of the RP's design methodologies and substantiation of the civil structures	Step 4 civil engineering assessment report (Ref. 98)	Closed by the Step 4 civil engineering assessment report

Matter		Assessment	Status
	withstand against the aircraft impact hazard.		
5	The Step 4 external hazards assessment report will provide a summary of the holistic aircraft impact safety case and sentence matters raised in this closure note.	Sub-sections 4.12.1.2 and 4.12.1.3	Closed by this assessment report

4.18.1.3 RO-UKHPR1000-0009

593. Based upon the submissions made by the RP early in GDA for UK HPR1000, the ONR Civil Engineering Inspector and I judged there to be potential regulatory shortfalls associated with the geotechnical design parameters to be used to define the GSE and the methodology that would be applied. The ONR Civil Engineering Inspector raised RO-UKHPR1000-0009 (Ref. 14) to address these concerns. A summary of the intent of the regulatory shortfalls that the RO sought to address is:

- The justification and definition of a consistent set of dynamic and static geotechnical parameters for the GSE that adequately represents a UK site.
- The development and articulation of adequate analysis and design methodologies for the application of the geotechnical GSE to demonstrate the adequacy of the overall design concept.
- The adequate substantiation of the generic UK HPR1000 design for the geotechnical characteristics of the GSE, and a demonstration that it is deployable given appropriate levels of site-specific design optimisation.

594. The ONR Civil Engineering Inspector's assessment of the submissions for RO-UKHPR1000-0009 is provided in ONR-NR-AN-20-032 (Ref. 369). I have consulted with the ONR Civil Engineering Inspector, and I have judged that the RP has defined a consistent set of dynamic and static geotechnical parameters that adequately represent the GSE. The Civil Engineering Inspector has concluded the RP has provided sufficient evidence to meet the intent of RO-UKHPR1000-0009 and has addressed the issues which led to it being raised. RO-UKHPR1000-0009 was closed during Step 4 (Ref. 370).

595. A total of six matters were identified in ONR-NR-AN-20-032 (Ref. 369), of which two I consider relevant to the GSE (Table 32). I have confirmed with the ONR Civil Engineering Inspector that these matters have been resolved to their satisfaction.

Table 32: Matters associated with RO-UKHPR1000-0009 that are relevant to the GSE and their status following Step 4 assessment of the UK HPR1000 GDA

Matter		Assessment	Status
1	Within GDA the RP is expected to address the inconsistency between (higher) values of static springs for 'Very Soft' (150m/s) site presented in T-5-4 of the 'Raft Foundation and Design Method Statement' (Ref. 371) compared to the (lower) values presented in T-6-6 of the 'Basis of Design for Common Raft Foundation' (Ref. 372)and in T-B.3-2 of the	Step 4 civil engineering assessment report (Ref. 98)	Closed by the Step 4 civil engineering assessment report

Matter		Assessment	Status
	'Generic Design Parameters for Civil Engineering' (Ref. 373). This is recorded by RQ-UKHPR1000-1477 (Ref. 374), the response to which requires consolidation into the safety case documentation (Ref. 375).		
2	Within GDA the RP is expected to address the inconsistency in the 'UK HPR1000 Generic Site Report' (Ref. 50) and 'Generic Design Parameters for Civil Engineering' (Ref. 373) with respect to the 'proposed generic site envelope'. Currently the bearing pressure in the 'UK HPR1000 Generic Site Report' (Ref. 50) is shown to be compatible with the range of generic allowable pressures derived from the generic shear wave velocities presented in the 'Generic Design Parameters for Civil Engineering' (Ref. 373). However, as the magnitudes differ it is inconsistent to present both as "generic". This is recorded by RQ-UKHPR1000-1586, the response to which requires consolidation in the safety case documentation.	Step 4 civil engineering assessment report (Ref. 98)	Closed by the Step 4 civil engineering assessment report

4.18.1.4 RO-UKHPR1000-0039

596. ONR judged there to be potential regulatory shortfalls associated with the level of analysis performed for the design of the HVAC systems. This judgement was based on the submissions made by the RP during the GDA for UK HPR1000, including those submissions provided to address RO-UKHPR1000-0002, such as the 'HVAC Systems Analysis Report - Site Adaptability Modification in UK HPR1000' (Ref. 376), and the responses to relevant RQs (Ref. 377, Ref. 378). In particular, the RP had not provided sufficient justification for the approach and robustness of HVAC systems' environmental modelling against extreme meteorological conditions (linked to RO-UKHPR1000-0002). Also, ONR considered the RP had not identified all safety demands associated with HVAC systems. Consequently, ONR raised RO-UKHPR10000-0039 (Ref. 15) to articulate its position in relation to the shortfalls and requested the RP to:

- Develop, and agree with ONR, a strategy to adequately model a sample of risk important UK HPR1000 HVAC systems, rooms and their contents during a selection of plant transients.
- Justify the samples chosen in the strategy.
- Adopt a graded approach to the analysis.
- Implement the strategy to demonstrate the sample of UK HPR1000 HVAC systems can adequately deliver operational and safety demands placed upon them. This specifically relates to environmental demands on a sample of HVAC systems.
- Confirm via independent verification that the UK HPR1000 HVAC systems environmental modelling approach is satisfactory.

- Identify whether there are gaps in the design of the UK HPR1000 HVAC systems.
- Undertake an ALARP study against gaps identified.

597. The RP's submissions in response to RO-UKHPR1000-0039 comprise:

- 'Strategy of the HVAC Environmental Modelling and Analysis' (Ref. 202).
- 'Analysis Report of the HVAC Sample Systems' (Ref. 203).
- 'Optioneering Study for Identified Gaps of Sample of HVAC Systems' (Ref. 211).

598. Following assessment of the RP's submissions for RO-UKHPR1000-0039, the ONR Mechanical Engineering Inspector, with input from all relevant internal stakeholders, was satisfied that:

- The RP has provided a suitable and sufficient strategy and analysis. Through optioneering, the RP has demonstrated whether reasonably practicable improvements can be made to its HVAC systems (where gaps or shortfalls were identified).
- The RP has demonstrated it understands the impact of temperature, enthalpy, and external variations in temperature on the performance requirements of its HVAC systems. The RP also understands the subsequent impact on room design and equipment qualification.
- The RP has performed a suitable and sufficient analysis of its HVAC systems commensurate with the expectations for GDA. The RP also has developed a suitable plan for the work that needs to be undertaken by a licensee during the site-specific design stages.

599. The ONR Mechanical Engineering Inspector's assessment of the submissions for RO-UKHPR1000-0039 is provided in ONR-NR-AN-21-030 (Ref. 379). I have provided input to this assessment, and I concur with the overall conclusions of the ONR Mechanical Engineering Inspector. On the basis of this assessment, the RO was closed during Step 4 (Ref. 380). A total of four matters were identified by the assessment of RO-UKHPR1000-0039 (Table 33). I agreed with the need for the matters to be addressed and that they are relevant to external hazards. These matters have been sentenced in the Step 4 mechanical engineering assessment report (Ref. 381).

Table 33: Matters associated with RO-UKHPR1000-0039 and their status following assessment during Step 4 of the UK HPR1000 GDA

Matter		Assessment	Status
1	The potential for local temperature variations in spaces will need to be investigated using computational fluid dynamics at site-specific stages during detailed design	Step 4 mechanical engineering assessment report (Ref. 381)	Assessment Finding AF-UKHPR1000-0128
2	The RP should demonstrate that cliff-edge risks are ALARP during site-specific stages (once site-specific data is known).	Step 4 mechanical engineering assessment report (Ref. 381)	Assessment Finding AF-UKHPR1000-0128
3	Whilst current flow rate can satisfy the requirement for cooling, there is insufficient safety margin (e.g. less than 10%). Hence, ventilation systems may need to be enlarged during site-	Step 4 mechanical engineering assessment report (Ref. 381)	Normal business

Matter		Assessment	Status
	specific stages to provide adequate flowrate.		
4	Additional local heaters are required to resolve the heating related gaps. The exact size of additional heating will be determined at site-specific stages once site-specific environmental data is known.	Step 4 mechanical engineering assessment report (Ref. 381)	Normal business

4.18.1.5 RO-UKHPR1000-0055

600. The ONR Internal Hazards Inspector and I judged there to be potential regulatory shortfalls associated with the evaluation provided for the generic UK HPR1000 design against consequential hazards initiated by earthquake. This was based on an assessment of the earthquake safety evaluation reports submitted early in GDA (Ref. 62, Ref. 63, Ref. 64, Ref. 65, Ref. 66, Ref. 67, Ref. 68). RO-UKHPR10000-055 (Ref. 16) was raised to obtain demonstration based on key examples that the generic UK HPR1000 design is robust against consequential internal hazards initiated by an earthquake, and results reported in the earthquake safety evaluation reports are underpinned by a robust evidential basis through the provision of:

- Documentation demonstrating that a detailed, comprehensive, and systematic identification and characterisation of the consequential internal hazard loads on targets as a result of a design basis seismic event has been undertaken.
- Documentation to demonstrate that the consequences from the identified loads on targets are bounded where appropriate by the existing hazard analysis or, where this is not the case, provide justification why the risks are tolerable.

601. The purpose of this RO was to address the most significant gaps in the seismic induced hazards assessment; namely dropped loads and fire. The ONR Internal Hazards Inspector and I agreed that these were the most significant gaps identified during our assessment. The sample buildings selected for the RO were BSB, BSC and BFX. For seismic fire, the BSC was selected to provide confidence that the MCR and RSS remain operational post-seismic event. For dropped loads, the BFX was selected to determine if any non-seismically qualified equipment could result in dropped loads and impact the spent fuel pond. BSB was selected as it contains exception to segregation areas.

602. The RP's submissions in response to this RO comprise:

- 'Earthquake Induced Internal Fire Safety Evaluation Report (Based on Safeguard Building C)' (Ref. 382).
- 'Earthquake Induced Dropped Loads Effects Safety Evaluation Report (Based on Fuel Building and Safeguard Building B)' (Ref. 383).
- Provision of 2D drawings.

603. The ONR internal hazards assessment of submissions provided in response to this RO is presented in ONR-NR-AN-21-047 (Ref. 384). The RO was closed on the basis of this assessment (Ref. 385). No matters were identified in relation to the submissions. Further assessment of consequential internal hazards resulting from an earthquake initiator is provided in the Step 4 internal hazards assessment report (Ref. 93). From an external hazards perspective, I consider the RP's screening-in and analysis of consequential internal fire and dropped loads consistent with the 'External Hazards Combination Safety Evaluation Report' (Ref. 77). I also consider this to be consistent

with RGP, including ONR’s expectations in SAP EHA.9 and EHA.14 (Ref. 2). My assessment of consequential internal hazards resulting from an earthquake initiator is provided in sub-section 4.8.1.2.

4.18.1.6 RO-UKHPR1000-0056

604. ONR judged there to be potential regulatory shortfalls associated with the generic UK HPR1000 safety case and design for the fuel route. As such, ONR considered that the UK HPR1000 fuel route for the BFX did not demonstrate that relevant risks have been reduced to ALARP. Consequently, RO-UKHPR1000-0056 (Ref. 80) was raised for the RP to provide a suitable and sufficient safety case for the handling of spent fuel casks within the BFX.

605. There have been several modifications to the BFX as a direct result of RO-UKHPR1000-0056 (and RO-UKHPR1000-0014 (Ref. 330) previously). I have assessed these changes as part of the ONR assessment of RO-UKHPR1000-0056 impacts. The key changes from an external hazards perspective include:

- Changes to the footprint of the BFX
- Modification to the spent fuel handling crane
- Changes to the internal layout of SSCs

606. The potential impact of these modifications on the external hazards safety case include:

- Changing the resulting pressures that the BFX must withstand (e.g. snow and wind loads may increase due to the larger walls and roof).
- The modified spent fuel handling crane needs to be appropriately seismically qualified and shown to be robust against other dynamic loads generated by external hazards, including aircraft impact.
- Seismic hazard and consequential internal hazards need to be considered for the revised layout of SSCs.

607. The RP has provided the report ‘Impact Analysis of Design Modification on Civil Engineering’ (Ref. 331), which analyses the potential implications of this design change for civil engineering including external hazard loadings for:

- Earthquake in sub-section 4.3
- Aircraft impact in sub-section 4.6
- Wind, snow, external explosion and rain in sub-section 4.7

608. The results of this analysis show that the behaviour of BFX and the common raft remain acceptable, although some individual elements may need enhancing to withstand increased loads. I have discussed this with the ONR Civil Engineering Inspector, who has raised Assessment Finding AF-UKHPR1000-0223 for this work to be undertaken post-GDA. I concur with this position.

609. I have considered the potential impact of the modified spent fuel handling crane and revised layout of SSCs for malicious aircraft impact to determine if it undermines any of the claims made in relation to falling cranes and vibration effects. The RP analyses the modified crane in sub-section 4.3.3.3 of the ‘Aircraft Crash Safety Evaluation Report’ (Ref. 70). The RP considers that the revised design is more robust to induced vibration and the SFP crane will not fail during an aircraft impact. I consider this reasonable for GDA, given the crane is no longer mounted on corbels located in the external wall of BFX, but I expect further analysis to be provided during the detailed design to justify this position. I judge this to be normal business.

610. The revised layout of BFX places two PTR [FPCTS] heat exchangers under crane maintenance positions. If the remaining PTR [FPCTS] train was under maintenance when an aircraft impact occurred and these cranes failed, then no PTR [FPCTS] trains would be available. In this scenario, the ASP [SPHRS] could provide makeup water for the SFP. I have raised Assessment Finding AF-UKHPR1000-0095 for a licensee to demonstrate that nuclear safety risks from falling cranes, resulting from an aircraft impact, are reduced ALARP by the detailed, site-specific design.

4.18.2 Strengths

611. My assessment of ROs during GDA has identified the following strengths:

- The RP has submitted all relevant documentation in accordance with the resolution plans.
- The RP's submissions have supplemented the existing safety case and provided additional evidence to demonstrate the design's withstand against external hazards.
- Modifications have been implemented during GDA to address gaps identified via the RP's analysis.
- All ROs relevant to external hazards have been closed during Step 4.
- Matters have been sentenced and Assessment Findings raised where appropriate for work to be undertaken by a licensee during the site-specific / detailed design stages.

4.18.3 Outcomes

612. My assessment of ROs has sentenced some matters as Assessment Findings. I have raised Assessment Findings relevant to RO-UKHPR1000-0002 and the gaps identified therein:

- AF-UKHPR1000-0089: for a licensee to substantiate the detailed design of the modified essential service water system and associated component cooling water system to demonstrate that the required safety functions are delivered in the presence of the minimum sea-water temperature hazard.
- AF-UKHPR1000-0091: for a licensee to justify that the risks associated with the solar energetic particles hazard (and more generally space weather hazards) have been reduced ALARP by the site-specific design, and that the protection measures and mitigations developed during the UK HPR1000 GDA have been implemented for those susceptible systems and components.

613. The ONR Electrical Engineering Inspector has also raised Assessment Finding AF-UKHPR1000-0171 that is relevant to the GIC hazard and RO-UKHPR1000-0002.

614. With regards to RO-UKHPR1000-0007, the following Assessment Findings are raised that relate to matters:

- AF-UKHPR1000-0093: for a licensee to justify site-specific design features that are considered out of GDA scope against the malicious aircraft impact hazard, to demonstrate that the acceptance criteria are met, and risks are reduced ALARP.
- AF-UKHPR1000-0094: for a licensee to substantiate the detailed design of fire barriers, including penetrations through the barriers, to demonstrate that the fire rating requirements are met by all relevant barriers, including the three safety fire cells in the BRX and the fire barrier between safety fire cells A and B in the BFX.

615. I have raised an Assessment Finding relating to modifications to the BFX resulting from RO-UKHPR1000-0056:

- AF-UKHPR1000-0095: for a licensee to demonstrate that nuclear safety risks from falling cranes, resulting from an aircraft impact, are reduced ALARP by the detailed, site-specific design.

616. The ONR Civil Engineering Inspector has also raised Assessment Finding AF-UKHPR1000-0223 relevant to the changes to the BFX building, which is relevant to both RO-UKHPR1000-0007 for aircraft impact and RO-UKHPR1000-0056.

617. These findings require addressing post-GDA. Where appropriate, the ONR External Hazards Inspector should liaise with other ONR disciplines to ensure these Assessment Findings are adequately addressed.

4.18.4 Conclusion

618. I have assessed ROs and related submissions during GDA. I conclude that:

- The RP has submitted the documentation identified in relevant resolution plans.
- All ROs relevant to external hazards have been closed during Step 4.
- Modifications have been identified in response to some ROs and implemented in the design.
- Matters have been sentenced and, where appropriate, Assessment Findings raised for a licensee to address post-GDA.

4.19 Demonstration that Relevant Risks Have Been Reduced to ALARP

4.19.1 Assessment

619. I have assessed the adequacy of the external hazards safety case for UK HPR1000 against RGP including the ONR SAPs to judge whether the proposed design reduces risks from external hazards to ALARP. The RP has submitted a number of documents that explicitly present claims and arguments that risks have been reduced ALARP. I have assessed the following documents:

- PCSR Chapter 33 (Ref. 386)
- ‘Holistic ALARP Demonstration Report’ (Ref. 387)
- ’ALARP Demonstration Report for External Hazards’ (Ref. 78)

620. The RP’s external hazards safety case has demonstrated that:

- The generic UK HPR1000 design has been evaluated against a range of external hazards and combinations for GDA, based on application of the RP’s identification and screening methodologies.
- An adequate GSE has been defined for the purposes of GDA that is based on either bounding hazard values for the three candidate sites that inform the generic site or selection of a value using best available data.
- GSE values have been defined on a basis that is consistent with the expectations of SAP EHA.3 and EHA.4 (Ref. 2).
- UK HPR1000 design input values have been typically selected as the bounding hazard value from either the FCG3 reference design or the GSE: any exceptions have been justified by the RP.
- Credible beyond design basis margin exists where the FCG3 reference design is selected as the UK HPR1000 design input value, and is bounding of the GSE value.
- The RP has analysed the impact on SSCs where the GSE value is selected as the UK HPR1000 design input value and bounds the FCG3 reference design.
- DBA using deterministic means demonstrates that adequate protection measures are provided to minimise the effects of external hazards on items

important to safety and safe shutdown of the reactor can be achieved and maintained.
- External hazards do not adversely affect the functionality or reliability of systems important to safety and defence-in-depth is provided.
- The design adopts good engineering practice including redundancy, diversity and segregation of SSC trains to mitigate CCF effects of external hazards.
- The design is resilient against a range of reasonably foreseeable hazard combinations and combination effects have been adequately considered.
- BDBA demonstrates an absence of cliff-edge effects.
- Optioneering has been undertaken to address identified gaps and the preferred options have been implemented in the design to protect against relevant hazard effects.
- The design implements lessons learned from the Fukushima Dai-ichi NPP accident, including the provision of additional cooling and power systems.

621. Several shortfalls relevant to the external hazards safety case have been identified. These have been sentenced as Assessment Findings or minor shortfalls based on ONR's guidance in ONR-GEN-IN-021 (Ref. 388). The Assessment Findings are matters for a licensee to address in their site-specific safety submissions. I judge that these matters do not undermine the generic safety case submissions. The matters are best addressed during detailed design for a target site when site-specific information will be available to inform the licensee's evaluation and, if necessary, optioneering processes.

622. In summary, I judge that:

- Sufficient evidence has been supplied by the RP to demonstrate that the UK HPR1000 design incorporates adequate protection and defence-in-depth measures to be robust against the external hazards evaluated during GDA.
- The UK HPR1000 design input values for external hazards have been conservatively defined and this provides confidence that the design will likely bound the characteristics of a UK site on which the technology might be deployed.
- The risks from external hazards for the generic UK HPR1000 design, at this stage of design development, have been reduced to ALARP.
- The generic UK HPR1000 design will be further developed during site-specific stages to account for the conditions and hazards at a target site. Only once all site-specific conditions and hazards have been accounted for via the site-specific safety case will it be possible to form a final judgement on whether the detailed design reduces risks from external hazards to ALARP.
- If a licensee chooses to optimise the UK HPR1000 design during site-specific stages, then this would challenge the basis of the ONR external hazards assessment at GDA. Optimisation may involve additional safety analysis and / or plant redesign of those elements assessed at GDA.

4.19.2 Strengths

623. My assessment of external hazards safety case submissions for UK HPR1000 has identified the following strengths:

- Sufficient evidence has been supplied by the RP to demonstrate that the UK HPR1000 design is robust against the external hazards and combinations evaluated during GDA.
- External hazards do not adversely affect the functionality or reliability of systems important to safety and defence-in-depth is provided.
- Potential CCF effects of external hazards have been adequately addressed through the adoption of good engineering practice.
- The RP's BDBA demonstrates an absence of cliff-edge effects.

- The conservatively defined UK HPR1000 design input values for external hazards provide confidence that the design will bound the characteristics of the target site.
- The design is aligned with RGP including the EHA SAPs.

4.19.3 Outcomes

624. My assessment has not identified any Assessment Findings or minor shortfalls in relation to RP's ALARP demonstration for GDA. The RP has, within the constraints of GDA, demonstrated that the generic UK HPR1000 design is robust against the external hazards evaluated in GDA and reduces associated risks to be ALARP.

625. The generic UK HPR1000 design will be influenced by conditions and hazards at a target site, including those hazards that have been screened-out from consideration in GDA. A licensee will need to further develop both the design and the external hazards safety case by considering all site-specific conditions and hazards and, in doing so, demonstrate that the detailed design of the UK HPR1000 reduces the risks from external hazards to be ALARP. This is normal business for site-specific phases.

626. If a licensee chooses to optimise the UK HPR1000 design during site-specific stages, then this may involve additional safety analysis and / or plant redesign of those elements assessed at GDA

4.19.4 Conclusion

627. I have assessed the RP's safety case submissions to form a judgement on whether the design reduces risks from external hazards to ALARP. I conclude that:

- The RP has provided sufficient evidence to demonstrate that the UK HPR1000 design is resilient against the external hazards evaluated in GDA.
- RGP has been considered in the protection design for UK HPR1000.
- Any shortfalls identified by my assessment are judged not to undermine the overall safety evaluation provided for the UK HPR1000, and these matters can be addressed at site-specific stages.
- An ALARP judgement cannot be made in relation to the UK HPR1000 design until all site-specific conditions and hazards have been considered for a target site.
- The development of an ALARP demonstration is normal business for a licensee during site-specific phases.
- If a licensee chooses to optimise the UK HPR1000 design during site-specific stages, then this may involve additional safety analysis and / or plant redesign of those elements assessed at GDA.

4.20 Consolidated Safety Case

4.20.1 Assessment

628. ONR expects the RP to have updated safety case documentation to adequately reflect relevant responses to RQs and ROs, modifications, feedback and other changes that have occurred during GDA. The RP's approach for external hazards has been to revise documents throughout GDA to reflect changes in the safety case. I consider this to be good practice and consistent with the expectations of SAP SC.7 for the safety case to be kept up-to-date.

629. Safety case consolidation was explicitly discussed with the RP at a technical engagement (Ref. 389). Following this engagement, the RP provided a summary of RQ consolidation (Ref. 390). I have used this to inform my sampling of the RP's external hazards safety case documentation to ensure that relevant changes have

been implemented. I issued RQ-UKHPR1000-1764 (Ref. 85) for the RP to explain inconsistencies that I had identified during my assessment in the information presented between safety case documentation. I have assessed the response and confirmed revised documentation has included the necessary changes (Ref. 87). Based on my sampling, I am content that the RP has adequately implemented the responses to my RQs in the formal GDA safety case submissions.

630. The assessment reported herein has identified some additional inconsistencies in the information presented in the documents forming the external hazards safety case. I have judged these to be minor shortfalls against SAP SC.4. I am satisfied that these do not undermine the conclusions of the external hazards safety case or the findings of my assessment.

631. I highlight that the RP's approach for the external hazards safety case documentation is to:

- Present the UK HPR1000 design input values in multiple documents.
- include extracts of the external hazards schedule in recent revisions of the safety evaluation reports (Ref. 72).

632. The RP's approach increases the likelihood of inconsistencies occurring and makes updating the safety case more burdensome. Whilst the safety case is the RP's to develop, I would advise against this approach being pursued during development of the site-specific safety case by a licensee.

4.20.2 Strengths

633. My assessment of the consolidated safety case has identified the following strengths:

- The RP's approach has been to update the safety case throughout GDA, which is consistent with SAP SC.7.
- Based on my sampling, I am satisfied that the RP has updated relevant documentation to reflect responses to RQs and ROs, modifications, feedback and other changes that have occurred during GDA.

4.20.3 Outcomes

634. Based on my assessment of the consolidated safety case, I did not identify any additional Assessment Findings or minor shortfalls, other than those already identified elsewhere in this assessment report.

4.20.4 Conclusion

635. I have assessed the RP's consolidated safety case for external hazards. I conclude that:

- The RP has updated relevant documentation to reflect responses to RQs and ROs, modifications, feedback and other changes that have occurred during GDA.
- I judge the RP's maintenance of the safety case throughout GDA to be good practice.

4.21 Comparison with Standards, Guidance and Relevant Good Practice

636. I have assessed the RP's external hazards submissions against those standards and criteria defined in sub-section 2.4. In this regard, my overall conclusions are:

- SAPs:

- The RP's safety case submissions have generally met the expectations of the SAPs.
- I have made efforts during Step 4 to ensure that the RP is aware of the SAPs expectations for the safety case, and this has been reflected in the quality of recent submissions, particularly relating to evidence.
- I have identified some shortfalls against the SAPs that are highlighted in previous sections of my report. For example, the RP has not met the expectations of SAP EHA.18 in demonstrating the beyond design basis margins to failure of SSCs. However, I judge that these matters are best addressed during site-specific stages and design development, and do not undermine the generic safety case submissions that have been submitted for the generic UK HPR1000design.

■ TAGs:

- The RP's approach to external hazards has been cognisant of ONR's guidance in NS-TAST-GD-013 (Ref. 6).
- The RP's hazard combination identification and screening process is consistent with good practice identified by ONR.
- The RP's approach to BDBA is aligned with ONR's guidance including the adoption of a best estimate 1 x 10^{-5} / yr. event as the starting point for relevant hazards.
- Overall, I consider the RP's approach broadly aligned with NS-TAST-GD-013 and associated annexes.

■ ONR's GDA technical guidance (Ref. 10):

- The GDA technical guidance has influenced the RP's development of the GSE for external hazards, which I consider to be in accordance with this guidance.
- The RP has considered the reasonably foreseeable effects of climate change, over the lifetime of the facility, in the definition of the GSE values. The RP has used UKCP18, consistent with ONR's expectations (Ref. 100).
- The RP's malicious aircraft safety case is aligned with ONR's expectations.
- I have made efforts during Step 4 to ensure that the RP is aware of ONR's expectations in the technical guidance relating to beyond design basis flooding for GDA. This resulted in an improved safety evaluation for external flooding that is consistent with ONR's expectations.
- Overall, I judge the RP's safety case for the generic UK HPR1000 design to be aligned with ONR's GDA technical guidance.

■ National and International Guidance:

- The RP has used RGP in developing the external hazards safety case, including some of those listed in sub-section 2.4.3.
- Explicit links with RGP have been developed (Ref. 53, Ref. 54).
- The FCG3 reference design has principally applied US codes and standards. The RP has adopted European codes and standards, where appropriate, including the EUR seismic design spectra that replace RG1.60 design spectra.
- Overall, I consider the RP's external hazards safety case to be aligned with RGP.

637. Overall, I judge the RP's safety case has considered RGP and is generally aligned with ONR's expectations in the SAPs and guidance.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

638. This report presents the findings of my external hazards assessment of the generic UK HPR1000 design as part of the GDA process.

639. Based on my assessment, undertaken on a sampling basis, I have concluded the following:

- The RP has defined an adequate GSE within which the generic plant is designed to operate safely, including:
  - A suitable range of external hazards and hazard combinations are evaluated in GDA, with suitable justification provided for hazards that are screened out.
  - External hazard values for the GSE have been defined on a conservative basis as either the bounding value of the three candidate sites that inform the GSE or using best available data.
- The design philosophy for the UK HPR1000 is to select the bounding hazard value from either the FCG3 reference design or the GSE and to use this as the design input:
  - This approach provides confidence that the design will likely bound the characteristics of a UK site on which the technology might be deployed.
  - Demonstrable beyond design basis margin exists where the FCG3 reference design value for a hazard is selected as the UK HPR1000 design input and bounds the equivalent GSE value.
  - The impact on structures, systems and components is analysed where the GSE for a hazard is selected as the UK HPR1000 design input and bounds the equivalent FCG3 reference design value.
  - Any exceptions to this approach have been justified.
- The UK HPR1000 design is shown to be robust against external hazards, hazard combinations and associated effects through a combination of engineering, deterministic and probabilistic analysis approaches:
  - Measures are provided to protect against the effects of external hazards or items important to safety are qualified to withstand external hazard loadings.
  - External hazards do not adversely affect the functionality or reliability of systems important to safety and defence-in-depth is provided.
  - The design adopts good engineering practice, including redundancy, diversity and segregation of safety trains to mitigate CCF effects of external hazards.
  - Optioneering has been undertaken to address gaps identified by the safety evaluation, and modifications incorporated into the design to protect against relevant hazard effects.
  - Beyond design basis analysis demonstrates an absence of cliff-edge effects, although the margins to failure have not been identified.
  - The design implements lessons learned from the Fukushima Dai-ichi NPP accident, including the provision of additional cooling and power systems.
  - The design is aligned with RGP, including ONR’s SAPs for external hazards.

- Where my assessment has identified shortfalls against RGP, I am satisfied that these do not undermine the generic safety justification for UK HPR1000:
  - Shortfalls have been sentenced as either Assessment Findings or minor shortfalls based on ONR's guidance.
  - Assessment Findings will be addressed by a licensee post-GDA.
- The risks from external hazards for the generic UK HPR1000 design, at this stage of design development, have been reduced to ALARP.
- The generic UK HPR1000 design will be further developed post-GDA to account for the conditions and hazards at a site selected for deployment of the reactor technology. A final judgement on whether the detailed design reduces risks to be ALARP can only be made once these site-specific factors are addressed.
- If a licensee chooses to optimise the generic UK HPR1000 design during site-specific stages, then this would challenge the basis of the ONR external hazards assessment undertaken at GDA. Optimisation may involve additional safety analysis and / or plant redesign of those elements assessed at GDA.

640. Overall, based on my sample assessment of the safety case for the generic UK HPR1000 design undertaken in accordance with ONR's procedures, I am satisfied that the case presented within the PCSR (Ref. 3, Ref. 4) and supporting documentation is adequate. On this basis, I am content that a DAC should be granted for the generic UK HPR1000 design from an external hazards perspective.

5.2 Recommendations

641. Based upon my assessment detailed in this report, I recommend that:

- **Recommendation 1**: From an external hazards perspective, ONR should grant a DAC for the generic UK HPR1000 design.
- **Recommendation 2:** The 10 Assessment Findings identified in this report should be resolved by the licensee for a site-specific application of the generic UK HPR1000 design.

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Annex 1

Relevant SAPs considered during the assessment

SAP No	SAP Title	Description
Engineering principles: external and internal hazards		
EHA.1	Identification and characterisation	An effective process should be applied to identify and characterise all external and internal hazards that could affect the safety of the facility.
EHA.2	Data sources	For each type of external hazard either site-specific or, if this is not appropriate, best available relevant data should be used to determine the relationship between event magnitudes and their frequencies.
EHA.3	Design basis events	For each internal or external hazard which cannot be excluded on the basis of either low frequency or insignificant consequence (see Principle EHA.19), a design basis event should be derived.
EHA.4	Frequency of initiating event	For natural external hazards, characterised by frequency of exceedance hazard curves and internal hazards, the design basis event for an internal or external hazard should be derived to have a predicted frequency of exceedance that accords with Fault Analysis Principle FA.5. The thresholds set in Principle FA.5 for design basis events are 1 in 10 000 years for external hazards and 1 in 100 000 years for man-made external hazards and all internal hazards (see also paragraph 629).
EHA.5	Design basis event operating states	Analysis of design basis events should assume the event occurs simultaneously with the facility's most adverse permitted operating state (see paragraph 631 c) and d)).
EHA.6	Analysis	The effects of internal and external hazards that could affect the safety of the facility should be analysed. The analysis should take into account hazard combinations, simultaneous effects, common cause failures, defence in depth and consequential effects.

SAP No	SAP Title	Description
EHA.7	cliff-edge effects	A small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences.
EHA.8	Aircraft crash	The total predicted frequency of aircraft crash, including helicopters and other airborne vehicles, on or near any facility housing structures, systems and components should be determined.
EHA.9	Earthquakes	The seismology and geology of the area around the site and the geology and hydrogeology of the site should be evaluated to derive a design basis earthquake (DBE).
EHA.10	Electromagnetic interference	The facility design should include preventative and/or protective measures against the effects of electromagnetic interference.
EHA.11	Weather conditions	Facilities should be shown to withstand weather conditions that meet design basis event criteria. Weather conditions beyond the design basis that have the potential to lead to a severe accident should also be analysed.
EHA.12	Flooding	Facilities should be shown to withstand flooding conditions up to and including the design basis event. Severe accidents involving flooding should also be analysed.
EHA.14	Fire, explosion, missiles, toxic gases etc – sources of harm	Sources that could give rise to fire, explosion, missiles, toxic gas release, collapsing or falling loads, pipe failure effects, or internal and external flooding should be identified, quantified and analysed within the safety case.
EHA.18	Beyond design basis events	Fault sequences initiated by internal and external hazards beyond the design basis should be analysed applying an appropriate combination of engineering, deterministic and probabilistic assessments
EHA.19	Screening	Hazards whose associated faults make no significant contribution to overall risks from the facility should be excluded from the fault analysis.
Engineering principles: key principles		

SAP No	SAP Title	Description
EKP.1	Inherent safety	The underpinning safety aim for any nuclear facility should be an inherently safe design, consistent with the operational purposes of the facility.
EKP.2	Fault tolerance	The sensitivity of the facility to potential faults should be minimised.
EKP.3	Defence in depth	Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.
Engineering principles: design for reliability		
EDR.2	Redundancy, diversity and segregation	Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components
EDR.3	Common cause failure	Common cause failure (CCF) should be addressed explicitly where a structure, system or component employs redundant or diverse components, measurements or actions to provide high reliability.
Engineering principles: safety systems		
ESS.18	Failure independence	No design basis event should disable a safety system
The regulatory assessment of safety cases		
SC.4	Safety case characteristics	A safety case should be accurate, objective and demonstrably complete for its intended purpose.
SC.5	Optimism, uncertainty and conservatism	Safety cases should identify areas of optimism and uncertainty, together with their significance, in addition to strengths and any claimed conservatism.
Fault analysis: assurance of validity of data and models		
AV.3	Use of data	The data used in the analysis of aspects of plant performance with safety significance should be shown to be valid for the circumstances by reference to established physical data, experiment or other appropriate means.

SAP No	SAP Title	Description
AV.4	Computer models	Computer models and datasets used in support of the safety analysis should be developed, maintained and applied in accordance with quality management procedures.
AV.5	Documentation	Documentation should be provided to facilitate review of the adequacy of the analytical models and data.
AV.6	Sensitivity studies	Studies should be carried out to determine the sensitivity of the analysis (and the conclusions drawn from it) to the assumptions made, the data used and the methods of calculation.
AV.7	Data collection	Data should be collected throughout the operating life of the facility to check or update the safety analysis.
AV.8	Update and review	The safety analysis should be updated where necessary, and reviewed periodically.
Fault analysis: design basis analysis		
FA.5	Initiating faults	The safety case should list all initiating faults that are included within the design basis analysis of the facility.
Numerical Targets: numerical targets and legal limits		
NT.2	Time at Risk	There should be sufficient control of radiological hazards at all times.

Annex 2

Assessment Findings

Number	Assessment Finding	Report Section / Sub Section
AF-UKHPR1000-0087	The licensee shall justify that risks from external flooding sources have been reduced as low as reasonably practicable for the site-specific design. This safety justification should give due consideration to: ■ Unprotected openings identified in the external walls of the fuel building and the extra cooling system and fire-fighting water production system building. ■ The elevation of the mobile equipment connection points, the independent mobile equipment storage building, batteries of the nuclear island 220V DC power supply and distribution system, and technical gallery ventilation shafts. ■ Potential for disruption both on and off-site. ■ Minimising the potential for common cause failure of the emergency diesel generators and station black out diesel generators.	4.9.1.2
AF-UKHPR1000-0088	The licensee shall demonstrate that the site-specific design provides protection against the wind-borne missiles hazard and that risks are reduced to be as low as reasonably practicable, including the implementation of modification options identified during GDA, where necessary.	4.10.1.3
AF-UKHPR1000-0089	The licensee shall substantiate the detailed design of the modified essential service water system and associated component cooling water system to demonstrate that the required safety functions are delivered in the presence of the minimum sea-water temperature hazard.	4.10.1.8
AF-UKHPR1000-0090	The licensee shall evaluate the potential effects of ice on unprotected structures, systems and components, taking into account site-specific characteristics and layout, to demonstrate that there are no adverse effects on the plant or loss of safety functions.	4.10.1.11

Number	Assessment Finding	Report Section / Sub Section
AF-UKHPR1000-0091	The licensee shall justify that the risks associated with the solar energetic particles hazard (and more generally space weather hazards) have been reduced as low as reasonably practicable by the site-specific design, and that the protection measures and mitigations developed during the UK HPR1000 GDA have been implemented for those susceptible systems and components.	4.11.1.1
AF-UKHPR1000-0121	The licensee shall demonstrate that the detailed civil structure design substantiates that the load-time functions for the selected malicious aircraft impact missiles (including cargoes and other modifications) are bounding of other credible missiles from this hazard.	4.12.1.3
AF-UKHPR1000-0092	The licensee shall justify the claims relating to aircraft impact on the Safeguard Building C below the +13.2m level giving consideration to the site-specific design and layout.	4.12.1.3
AF-UKHPR1000-0093	The licensee shall justify site-specific design features that are considered out of GDA scope against the malicious aircraft impact hazard, to demonstrate that the acceptance criteria are met, and risks are reduced as low as reasonably practicable.	4.12.1.3
AF-UKHPR1000-0094	The licensee shall substantiate the detailed design of fire barriers, including penetrations through the barriers, to demonstrate that the fire rating requirements are met by all relevant barriers, including the three safety fire cells in the reactor building and the fire barrier between safety fire cells A and B in the fuel building.	4.12.1.3
AF-UKHPR1000-0095	The licensee shall demonstrate that nuclear safety risks from falling cranes, resulting from an aircraft impact, are reduced as low as reasonably practicable by the detailed, site-specific design.	4.12.1.3

Annex 3

Step 3 areas for improvement and open points, and their status at the end of Step 4

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-1	It is not clear that the hazard identification, characterisation and screening process has produced a complete list of external hazard combinations for consideration during GDA. Further justification is needed to demonstrate the adequacy of the safety case for hazard combinations, and in particular the RP will need to justify that all credible hazard combinations are considered during GDA. This may necessitate additional analysis for those credible combinations omitted during Step 3.	Closed	The RP has revisited the hazard combinations identification and screening process during Step 4. I consider the process now meets the expectations of the SAPs and is based on RGP.	4.4
AFI-2	Credible hazard combinations with aircraft impact have not yet been analysed by the RP and this represents a gap in the safety case compared with SAPs EHA.6 and EHA.8. It is my expectation that these combinations will be consistent with the work being undertaken by the RP to address RO-UKHPR1000-0007. I will assess these combinations during Step 4 with the ONR Internal Hazards and Civil Engineering Inspector s.	Closed	The RP has submitted the aircraft crash safety case, which I have assessed and consider to be adequate. Hazard combinations with aircraft crash are presented in the 'Aircraft Crash Safety Evaluation Report' (Ref. 70).	4.12
AFI-3	The RP has categorised some external hazards as "basic hazards" and is proposing to define these on a 1×10^{-4} best estimate basis. This is inconsistent with the expectations of SAP EHA.4. I have raised RQ-UKHPR1000-0564 and will consider the RP's response in Step 4.	Closed	The RP has defined hazards on a basis commensurate with the expectations of SAP EHA.4.	4.6

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-4	The GSE wind speed value has been revised during Step 3, but it is not clear why this has resulted in a lower value given a 3-second gust would typically be expected to exceed the 10 minute average wind speed previously calculated. I have raised RQ-UKHPR1000-0558 and will consider the RP's response during Step 4, noting that there appears to be considerable margin to the design basis of 80 m/s.	Closed	The RP has addressed inconsistencies in relevant reports and redefined the GSE three-second gust as 41.66 m/s (43.66 m/s with climate change). 10 minute mean values not reported, as these are not used in the generic UK HPR1000 design, but can be calculated from the three-second gust using applicable codes and standards.	4.10.1.2
AFI-5	The RP has analysed the effects of climate change using UKCP09. UKCP18 was published in 2018 and I consider this RGP. I expect the RP to adopt UKCP18 during Step 4 and evaluate the impact for those hazards affected by climate change. The RP will need to also substantiate SSCs against any relevant revised hazard values as a result of adopting UKCP18.	Closed	UKCP18 used by the RP where data is available.	4.5.1.1
AFI-6	There is no clear link from the RP's hazard analyses into the civil engineering documentation including the Basis of Safety Case's safety functional requirements schedules in terms of the performance requirements for claimed protection measures. Further detail is also needed to clarify whether the loads are applicable to the whole structure, system or specific components. The RP has committed to providing suitably detailed examples to demonstrate the linkages and completeness of the safety case during Step 4. I will also consider the links between the hazard schedule and other engineering schedules.	Closed	The External Hazards Schedule (Ref. 79) and hazard protection requirement code provide the traceability of requirements from the external hazards safety case into the engineering documentation. Based on my sampling I consider the RP to have addressed this matter.	4.15

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-7	I consider that the safety evaluation reports need further justification of their completeness with regards to the SSCs identified for inclusion in the analysis, and to ensure that all relevant SSCs are considered. This should include: • A discussion of relevant deterministic analysis performed for the reference design against external hazards. • For the earthquake safety evaluation reports, the selection of non-classified SSCs should be justified to ensure that the analysis considers all relevant SSCs. • For the tornado, external explosion and aircraft crash hazards, I expect the RP to give due consideration to non-classified penetrations in the civil structures and unprotected components of the emergency diesel generator systems, and identify where the performance requirements for these SSCs will be recorded. I expect the RP to provide a comprehensive justification that the analysis remains adequate following application of the UK categorisation and classification scheme, including for: • those non-classified SSCs identified by the earthquake safety evaluation reports; and • non-classified penetrations on the nuclear auxiliary and radioactive waste management buildings (BNX and BWX respectively).	Closed	I have sampled, in detail, the RP's analysis for tornadic missiles and aircraft crash. I consider the RP's analysis adequate. The RP has submitted further evidence for the substantiation of the generic UK HPR1000 design against consequential internal hazards initiated by earthquake in response to RO-UKHPR1000-0055. I note that RO-UKHPR1000-0055 has been closed by the ONR Internal Hazards Inspector during Step 4.	4.10.1.3 4.12.1.2 & 4.12.1.3 4.8.1.2 & 4.18.1.6

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-8	I do not consider the RP's flooding analysis to meet the expectations of SAP EHA.12. In particular the RP's analysis does not provide sufficient understanding of the beyond design basis sequence of failure of SSCs and any cliff-edges that apply. I have raised a RQ for the RP to address this gap, and will consider the response during Step 4. In responding to this RQ I expect the RP to consider those vulnerabilities identified during Step 3 (unsealed penetrations on BEJ and BFX structures) and identify any reasonably practicable steps that could be taken to enhance the resilience of the design against the flooding hazard.	Closed	The RP has revisited the flooding analysis during GDA Step 4. I have assessed this, and consider the analysis adequate. I have interfaced with the ONR SAA Inspector to understand the design's defence-in-depth against beyond design basis flooding. I consider the RP has considered relevant lessons from the Fukushima Dai-ichi NPP accident and this is reflected in the design.	4.9.1.2
AFI-9	The RP commissioned a study to characterise the lightning hazard for the GSE, resulting in an increased peak current of 300 kA. I have raised a RQ for the RP to submit a copy of the lightning hazard derivation report to clarify the annual probability of exceedance for the hazard and whether this represent a maximum credible event for the UK.	Closed	The RP has defined the GSE lightning peak current as 300 kA. I judge this acceptable for GDA. I note that the RP considers this a maximum credible event for the purposes of GDA.	4.10.1.12
AFI-10	The RP's deterministic analysis of the design against external hazards has identified vulnerabilities, including for the lightning, tornado, external explosion and air temperature hazards. The RP is currently considering options to address these vulnerabilities and protect against the hazards. I expect the RP to provide a robust optioneering, justification and substantiation of the proposed modifications against the hazards. Modifications will be submitted during Step 4. I will sample the modifications to form a judgement on the adequacy of the RP's design modification process and proposed modifications with relevant ONR specialist inspectors.	Closed	Shortfalls against lightning and space weather hazard effects have been identified and mitigation / optioneering presented by the RP. HVAC concerns addressed by resolution of RO-UKHPR1000-0002 and RO-UKHPR1000-0039.	4.10.1.12, 4.11 and 4.18

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-11	I expect the RP to provide a robust substantiation that the BEX and BPX to support their current non-classified status. This should demonstrate the structures do not impact the delivery of safety functions by SSCs within the nuclear island and are not subject to cliff-edge effects as a result of external hazards loadings.	Closed	The RP has provided a bounding cliff-edge assessment for the BEX that shows a small increase of seismic demand beyond the design basis does not lead to failure or significant increase of pounding on other structures. The RP's analysis demonstrates that the BEX does not impact on the delivery of safety functions by other SSCs within the nuclear island.	4.15
AFI-12	The RP needs to clarify in its safety case the approach to beyond design basis analysis to demonstrate the margins to failure and that cliff-edge effects do not exist for external hazards.	Closed	The RP has submitted its 'Beyond Design Basis External Hazards Evaluation Methodology' (Ref. 61). Cliff edge and beyond design basis analyses are provided in relevant safety evaluation reports. I have interfaced with the ONR Civil Engineering Inspector in relation to seismic beyond design basis analysis, which is demonstrably bounding of other natural hazards, and we are content that the RP has demonstrated an absence of cliff-edge effects for the generic UK HPR1000 design.	4.16

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-13	The RP needs to clarify and justify the air temperature requirements on the HVAC systems and other SSCs, such as the emergency diesel generators, that could be affected by the hazards. The RP needs to provide a comprehensive justification and substantiation of the reference design SSCs including HVAC systems to show that they remain suitable and sufficient to withstand the UK air temperature hazards. Furthermore, the RP will need to demonstrate that closure of the explosion and pressure-wave dampers does not compromise the performance of those SSCs that they are protecting.	Closed	The RP has substantiated a sample of HVAC systems against the high-air temperature hazard via RO-UKHPR1000-0002 and RO-UKHPR1000-0039.	4.18
AFI-14	The RP needs to justify the decision to not characterise the solar energetic particle hazard in GDA. I also expect the RP to provide a comprehensive justification of the proposed protection measures for C&I systems against space weather hazards. The RP will also need to demonstrate that common cause failure has been considered in the design, and that the C&I architecture includes adequate diversity and independence of systems.	Closed	The RP has undertaken a vulnerability analysis of the design against the solar energetic particles hazard. The RP has identified a number of SSCs potentially vulnerable to the hazard and suggested potential design improvements that require supplier feedback at the site-specific phase. I consider this appropriate for GDA.	4.11
AFI-15	Agreement needs to be reached with the RP on the analysis methodology for the medium commercial turbojet (MCT) category. This analysis is expected to demonstrate the MCT is bounded by other categories, but this will require substantiation by the RP's analysis.	Closed	The RP has presented its approach for the MCT in 'Development of Aircraft Impact Force-Time Functions for UK-HPR1000' (Ref. 297). I consider this approach adequate.	4.12.1.3 & 4.18.1.2

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-16	The scope of the proposed documentation to address RO-UKHPR1000-0007 will not provide a complete safety case for the aircraft crash hazard. The safety case needs further development to clarify and justify the acceptance criteria, the protection strategy and extent of protection including articulating any safety claims relating to defence-in-depth and shielding / shadowing of SSCs. The RP should identify where this information will be documented in the safety case and, if necessary, identify any further documentation need to provide a full safety case for the aircraft crash hazard. In developing the safety case the RP should also: • Clarify the version of NEI 07-13 used. It is my expectation that the latest version will be utilised for GDA. • Consider the effects of an aircraft crash occurring during shutdown including an evaluation of the potential damage and articulate any safety claims / arguments. The results of a footprint analysis review to address **AFI-17**	Closed	The RP has revised and enhanced the existing documentation to include the expected information. I have assessed the safety case submitted by the RP in response to RO-UKHPR1000-0007 and consider the RP has addressed the concerns raised therein. I have therefore closed RO-UKHPR1000-0007.	4.12.1.3 & 4.18.1.2
AFI-17	The RP should formally demonstrate at the earliest opportunity the extent of the aircraft impact protection with an appropriate justification for each building. This should include a review the footprint analysis for the civil structures against the aircraft crash hazard, giving consideration to areas/penetrations vulnerable to fire/explosion and, if necessary, reconsider the claims relating to consequential internal fire/explosion. It is my expectation that the withstand of protection measures if claimed against malicious aircraft impact will also be substantiated (e.g. inverse-L structures, EPW dampers etc.).	Closed	The RP has revised and enhanced the existing documentation to include the expected information. The design has been substantiated against the hazard in the 'Design Substantiation for Aircraft Impact' (Ref. 365). I consider the RP has addressed my concerns raised via RO-UKHPR1000-0007. I have closed RO-UKHPR1000-0007.	4.12.1.3 & 4.18.1.2

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
AFI-18	The RP should capture via its processes the assumed position and extent of buildings that are claimed to provide shielding and shadowing of the SSCs needed to deliver fundamental safety functions against the aircraft crash hazard. Should the location of these buildings change at the site-specific phase, a licensee will need to analyse the consequences for the design.	Closed	The RP has revised and enhanced the existing documentation to include the expected information. I consider the RP has addressed my concerns raised via RO-UKHPR1000-0007. I have closed RO-UKHPR1000-0007.	4.12.1.3 & 4.18.1.2
OP-1	On-going dialogue with the ONR Civil Engineering Inspector during Step 4 with regards to the withstand of the civil structures against individual hazards and hazard combinations.	Closed	I have interfaced with the ONR Civil Engineering Inspector in relation to: • Translation of site-wide hazard values into local loadings for structures using RGP. • Substantiation of civil structures claimed in the external hazards safety case. • Substantiation and adequacy of the aircraft impact safety case. • Beyond design basis withstand of the civil structures against seismic hazards. • Requirements traceability from the external hazards safety case into the civil engineering design. • Regulatory observations: RO-UKHPR1000-0002, 0007 & 0009.	4.10.1.2, 4.10.1.10, 4.12.1.3, 4.14, 4.15, 4.16, 4.17 & 4.18

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
OP-2	On-going dialogue with the ONR Internal Hazards inspector during Step 4 to ensure that all relevant hazard combinations for GDA are identified, screened and an appropriate analysis is provided of the design's withstand against the hazard combination.	Closed	I have interfaced with the ONR Internal Hazards Inspector in relation to: • Hazard combination (consequential) identification and screening. • Substantiation of the seismic (earthquake) safety case for consequential internal hazards. • Regulatory observation RO-UKHPR1000-0055.	4.4, 4.8 & 4.18
OP-3	On-going dialogue with the ONR PSA Inspector during Step 4 to ensure that external hazards and hazard combinations are considered in the PSA, and to understand the potential implications for the design.	Closed	I have interfaced with the ONR PSA Inspector in relation to: • Risk associated with external hazards. • External flooding safety case.	4.7 & 4.9
OP-4	I will assess any further changes to the Generic Site Envelope values proposed by the Requesting Party during Step 4, and I will sample the evidential basis for some hazard values to form a judgement on their adequacy.	Closed	During Step 4 some GSE values were modified to include climate change allowances from UKCP18. I have assessed the adequacy of the GSE and consider it adequate.	4.5

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
OP-5	I will consider the adequacy of the Requesting Party’s categorisation and classification of protection measures during Step 4 by liaising with the relevant ONR specialist inspectors.	Closed	The RP’s modification process was assessed by ONR MSQA Inspector and found to be adequate, and has been used across the GDA programme. I have assessed several modifications during Step 4, found these to be adequate and accepted these into GDA.	4.5.1.1
OP-6	I will continue liaising with the Civil Engineering Inspector with respect to the seismic analysis of the civil structures against the seismic (vibratory) hazard during Step 4.	Closed	See OP-2.	-
OP-7	I will liaise with the C&I and Internal Hazards Inspectors to ensure that the protection against the lightning hazard and electromagnetic interference is adequate.	Closed	I have engaged with the relevant ONR inspectors and they have confirmed that the design is adequate against these hazards.	4.10.1.12 & 4.10.1.13
OP-8	I will assess the adequacy of the design’s protection against fault conditions that can arise from external hazards in more detail during Step 4 including: • Consideration of generic hazards associated with loss of heat sink. • Liaising with the Electrical Engineering Inspector with regards to the adequacy of the design against LOOP	Closed	I have assessed the design’s robustness against LUHS and consider it adequate for GDA. I have also engaged with the ONR Electrical Engineering Inspector and their assessment considers the design is robust against LOOP.	4.13
OP-9	I will consider the hazard derivation and protection measures proposed for the Geomagnetically Induced Current Hazard with the ONR Electrical Engineering Inspector during Step 4.	Closed	I have engaged with the ONR Electrical Engineering Inspector and consider that the proposed strategy for mitigating against the effects of GIC is adequate, noting the need for further design development post-GDA.	4.11.1.2

Step 3 Matter	Description	Status	Justification for Status	Report Section / Sub section
OP-10	I expect the RP to clarify during Step 4 if any claim is intended to be made on administrative measures taken in response to weather warnings for design basis meteorological external hazards.	Closed	I have assessed the external hazards schedule and the RP has recognised administrative arrangements as defence-in-depth. The RP has also identified relevant human-based safety claims on operators relevant to the external hazards safety case. I am content with this approach for GDA, recognising operational processes and procedures will be developed post-GDA.	4.15
OP-11	I will undertake a more detailed assessment of the malicious aircraft impact load time functions developed by the RP for the agreed hazard definitions. My detailed assessment of the adequacy of the load time functions in Step 4 will be supported by the civil engineering TSC.	Closed	I have assessed the RP’s methodology for development of load-time functions, and I consider this to be adequate.	4.12.1.3

Annex 4

External hazards parameters for the FCG3 reference design, GSE and UK HPR1000 design input

Hazard Group	Hazard	FCG3 Reference Design Value	UK Generic Site Envelope Value	UK HPR1000 Design Input Value	Margin between UK HPR1000 design input value and UK Generic Site Envelope value?	Notes
Seismic	Peak ground acceleration	0.3g	0.3g	0.3g	No	
	Response spectra	RG1.60 spectra	EUR soft and medium spectra	EUR soft and medium spectra	-	Considered in RO-UKHPR1000-0009
	Shear wave velocity	1100-3000 m/s	150-1100 m/s	150-1100 m/s	No	Considered in RO-UKHPR1000-0009
Hydrological	Flooding	-	Site specific	Not defined	-	Beyond design basis only
Man-made	Accidental aircraft crash – light aircraft	-	1.76 km^{-2} / yr. / 10^{-5}	6.25 x 10^{-7}	-	GSE based on UK background crash rates
	Accidental aircraft crash – helicopters	-	0.97 km^{-2} / yr. / 10^{-5}	3.13 x 10^{-7}	-	GSE based on UK background crash rates
	Accidental aircraft crash – small transport aircraft	-	0.06 km^{-2} / yr. / 10^{-5}	0.21 x 10^{-7}	-	GSE based on UK background crash rates

Hazard Group	Hazard	FCG3 Reference Design Value	UK Generic Site Envelope Value	UK HPR1000 Design Input Value	Margin between UK HPR1000 design input value and UK Generic Site Envelope value?	Notes
	Accidental aircraft crash – large transport aircraft	-	0.08 km^{-2} / yr. / 10^{-5}	0.28 x 10^{-7}	-	GSE based on UK background crash rates
	Accidental aircraft crash – military combat aircraft	-	0.28 km^{-2} / yr. / 10^{-5}	0.99 x 10^{-7}	-	GSE based on UK background crash rates
	Total	Light aircraft considered	3.19 km^{-2} / yr. / 10^{-5}	10.86 x 10^{-7} Light aircraft considered	Yes	GSE based on UK background crash rates
	External explosion	10 kPa 20 kPa (including reflections)	Site specific	20 kPa (including reflections)	N/A	Considered on a generic basis -
Meteorological	Wind speed 3 second gust	80 m/s	41.66 m/s (Present) 43.66 m/s (2100)	80 m/s	Yes	
	Tornado speed	89 m/s	65 m/s	89 m/s	Yes	
	Tornado pressure drop	6.3 kPa	2.6 kPa	6.3 kPa	Yes	

Hazard Group	Hazard	FCG3 Reference Design Value	UK Generic Site Envelope Value	UK HPR1000 Design Input Value	Margin between UK HPR1000 design input value and UK Generic Site Envelope value?	Notes
	Tornado pressure drop rate	2.5 kPa/s	0.75 kPa/s	2.5 kPa/s	Yes	
	Tornadic missiles	Schedule 40 pipe at 34 m/s	Schedule 40 pipe at 24 m/s	Schedule 40 pipe at 34 m/s	Yes	
		1810 kg automobile at 34 m/s	1178 kg automobile at 24 m/s	1810 kg automobile at 34 m/s	Yes	
		Solid steel sphere of 0.0254m diameter at 7 m/s	Solid steel sphere of 0.0254m diameter at 6 m/s	Solid steel sphere of 0.0254m diameter at 7 m/s	Yes	
	Extreme high-air temperature	37.9°C	48.5 °C	48.5 °C	No	
	Extreme low-air temperature	6 °C	-22 °C	-22 °C	No	
	Humidity maximum	100 %	100 %	100 %	No	
	Humidity minimum	8 %	12 %	8 %	Yes	
	Maximum hourly enthalpy	103 kJ/kg (coincident enthalpy	78.4 kJ/kg (Present) 90.5 kJ/kg (2080)	90.5 kJ/kg (2080)	No	GSE value used as UK HPR1000

Hazard Group	Hazard	FCG3 Reference Design Value	UK Generic Site Envelope Value	UK HPR1000 Design Input Value	Margin between UK HPR1000 design input value and UK Generic Site Envelope value?	Notes
	Maximum enthalpy 6 hour mean	with high-air temperature)*	78.4 kJ/kg (Present) 90.5 kJ/kg (2080)			design input. However, cooling coils are specified to be the same as the reference design (i.e. 103 kJ/kg)
	Maximum enthalpy 12 hour mean		78.1 kJ/kg (Present) 90.2 kJ/kg (2080)			
	Rainfall 1 hour	226.6 mm	163 mm (Present) 216 mm (2100)	216 mm	Yes	
	Rainfall 24 hours	871.1 mm	228 mm (Present) 302 mm (2100)	302 mm	No	GSE used as design basis, not reference design
	Seawater temperature maximum	38°C	28 °C (Present) 33.5 °C (2100)	33.5 °C (2100)	No	GSE value used as UK HPR1000 design input. However, cooling coils are specified to be the same as the reference design (i.e. 38 °C)
	Seawater temperature minimum	8.9°C	-1.8 °C	-2 °C	Yes	

Hazard Group	Hazard	FCG3 Reference Design Value	UK Generic Site Envelope Value	UK HPR1000 Design Input Value	Margin between UK HPR1000 design input value and UK Generic Site Envelope value?	Notes
	Snow load	Not considered	1.5 kPa	1.5 kPa	No	
	Clear ice thickness	Not considered	117 mm	117 mm	No	
	Clear ice density	Not considered	9 kN/m^3	9 kN/m^3	No	
	Lightning peak current	200 kA	300 kA	300 kA	No	
	Lightning mean flash frequency	Not considered	1.3 flashes / km^2 / yr.	1.3 flashes / km^2 / yr.	No	
	Thunderstorm days	Not considered	13 days / yr.	13 days / yr.	No	
Space weather	Geomagnetically induced current	Not considered	6,080 nT/min	6,080 nT/min	No	
	Solar energetic particles	Not considered	Not defined	Not defined	-	Susceptibility analysis undertaken
Design basis conditions	Loss of off-site power	-	24 hours	24 hours		
		-	48 hours	48 hours		
		-	168 hours	168 hours		

Hazard Group	Hazard	FCG3 Reference Design Value	UK Generic Site Envelope Value	UK HPR1000 Design Input Value	Margin between UK HPR1000 design input value and UK Generic Site Envelope value?	Notes
	Loss of ultimate heat sink	-	Site specific	Not defined	Considered on a generic basis	

Annex 5

External hazards and site characteristics screened-out of GDA for characterisation during site-specific stages

Hazard Group	Hazards
Seismic	Extended period ground motion
Hydrological	Dam failure, Instability of the coastal area, Storm surge, Wind generated waves, Changes in river channel or obstruction of river channel, Bore, Snow melt, Water course containment failure, Tidal effects, Tsunami, Sea level, Seiche
Biological	Biological fouling, Seaweed, Fish, Jellyfish, Marine growth, Infestation, Airborne swarms, Crustacean or mollusc growth, Biological flotsam, Microbiological corrosion, Water debris
Man made	Impacts from adjacent sites, Gas clouds, Liquid release, Fires, Explosions, Structural failure, Transport, Pipelines, Vibrations, Malicious activity, Industrial plants, Military facilities, Transport of nuclear material, Forest fire, Ship collision, Unexploded ordnance, Hydrocarbon pollution
Meteorological	Extremes of ground temperature, Sandstorms, Air pressure, Low groundwater, Low sea water level, Waterspout, Surface ice on lake or sea, Mist, Fog, Freezing fog, Salt storm
Geological	Contaminated land, Landslides (slope instability), Radon / Methane, Groundwater flooding
Landscape change	Windblown sand and dune movement, Coastal erosion, Longshore drift, Shingle mounding, Sediment deposition, Water course erosion, Water course path change, Water table movements, Changes in land use and water use
Site characteristics (seismic)	Local site effects, Soil structure interaction, Liquefaction, Surface faulting / ground rupture, Dynamic compaction, Permanent ground displacement
Site characteristics (geological)	Settlement, Ground heave, Groundwater, Leeching, Unstable soils, Properties of sub-strata, Characteristics of subsurface material, soil erosion

External hazards and site characteristics screened-out of consideration

Hazard Group	Hazards
Meteorological	Meteorite (the annual probability of exceedance for a meteorite to strike a NPP site is considered to be less than 1 x 10^{-7} / yr.), Solar flare (bounded by space weather)
Geological	Volcanoes (The UK does not have volcanoes. The effects of volcanic ash and dust have been screened-out for consideration during site licensing)
Site characteristics (geological)	Mining, Caverns, Sinkholes (none of the EN-6 sites are underlain by these geological features)