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| ONR Assessment Report  Generic Design Assessment of the Rolls Royce SMR – Step 2 assessment of External Hazards |



ONR Assessment Report

**Project Name**: Generic Design Assessment of the Rolls-Royce SMR

**Report Title**: Step 2 assessment of External Hazards

**Authored by**: [Redacted]

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# Executive Summary

This report presents the outcomes of my external hazards assessment of the Rolls-Royce Small Modular Reactor (SMR) as part of Step 2 of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA). This assessment is based upon the information presented in version 2 of Rolls-Royce SMR Limited’s Environmental, Safety, Security and Safeguards (E3S) case chapters and supporting documentation.

ONR’s GDA process calls for a step-wise assessment, which increase in detail as the project progresses. The focus of my assessment in this step was towards the fundamental adequacy of the Rolls-Royce SMR design and safety case, and the suitability of the methodologies, approaches, codes, standards and philosophies which form the building blocks for the design and generic safety and security cases.

I targeted my assessment, in accordance with my assessment plan, at the content of most relevance to external hazards against the expectations of ONR’s Safety Assessment Principles (SAPs), Technical Assessment Guides (TAGs) and other guidance which ONR regards as relevant good practice.

I targeted the following aspects in my assessment of the Rolls-Royce SMR E3S case:

* The Generic Site Envelope.
* The beyond design basis and cliff edge methodology.
* The combined external hazards methodology and its application.
* The space weather hazards methodology.
* The analysis of background accidental aircraft crash frequency.
* The analysis of heat loadings from high extreme ambient temperatures and heatwaves within the Generic Site Envelope, including allowance for climate change.
* The analysis of seismic hazards within the Generic Site Envelope.
* The Requesting Party’s arrangements for information exchange.
* The Requesting Party’s approach to complying with the ALARP principle.

Based upon my assessment, I have concluded the following:

* The technical quality of the Requesting Party’s (RP’s) submissions that I have sampled has satisfied relevant regulatory expectations for this stage in the process, subject to some specific shortfalls that I identified. The RP has also been responsive and constructive in addressing my comments througout Step 2.
* The RP’s approach to external hazards analysis is based on relevant good practice, which has been adequately applied in the sample that I have assessed, apart from one exception that is identified in this report. I expect resolution of this exception to be achievable.
* I have identified a number of technical challenges that the RP will need to address during Step 3.

Overall, based on my assessment to date, and subject to the provision and assessment of suitable and sufficient supporting evidence, I have not identified any fundamental safety shortfalls that could prevent ONR permissioning the construction of a power station based on the generic Rolls-Royce SMR design.

# List of Abbreviations

AC Alternating Current

AFoE Annual Frequency of Exceedance

ALARP As Low As Reasonably Practicable

BDB Beyond Design Basis

CAE Claims, Arguments and Evidence

C&I Control and Instrumentation

CCF Common Cause Failures

CME Coronal Mass Ejection

CNS Civil Nuclear Security (ONR)

DAC Design Acceptance Confirmation

DB Design Basis

DG Diesel Generator

DRP3 Design Reference Point 3

E3S Environmental, Safety, Security and Safeguards (case)

EAT Extreme Ambient Temperatures

EUR European Utility Requirements

GB Great Britain

GDA Generic Design Assessment

GICs Geomagnetically Induced Currents

GLEs Ground Level Enhancements

GSD Generic Site Description

GSE Generic Site Envelope

HSE Health and Safety Executive

HVAC Heating Ventilation and Air Conditioning

IAEA International Atomic Energy Agency

LOOP Loss Of Offsite Power

LOOW Loss Of Offsite Water

LoS Loss of Service (for telecommunications systems)

LWR Light Water Reactor

NPP Nuclear Power Plant

NRW Natural Resources Wales

ONR Office for Nuclear Regulation

PGA Peak Ground Acceleration

PIE Postulated Initiating Event

PSA Probabilistic Safety Assessment

PWR Pressurised Water Reactor

RCP Representative Concentration Pathway

RFI Radio-Frequency Interference

RGP Relevant Good Practice

RP Requesting Party (Rolls-Royce SMR Limited)

RPV Reactor Pressure Vessel

SAA Severe Accident Analysis

SAP Safety Assessment Principle(s)

SEPs Solar Energetic Particles

SG Steam Generator

SMR Small Modular Reactor

SRBs Solar Radio Bursts

SSC Structure, System and Component

TAG Technical Assessment Guide(s) (ONR)

TSC Technical Support Contractor

UKCP18 UK Climate Projections 2018

WENRA Western European Nuclear Regulators Association

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# Introduction

1. This report presents the outcomes of my external hazards assessment of the Rolls-Royce Small Modular Reactor (SMR) as part of Step 2 of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA). This assessment is based upon the information presented in version 2 of Rolls-Royce SMR Limited’s Environmental, Safety, Security and Safeguards (E3S) case chapters (refs [1], [2], [3], [4] and [5]) and supporting documentation.
2. Assessment was undertaken in accordance with the requirements of the ONR Management System and follows ONR’s guidance on the mechanics of assessment, NS-TAST-GD-096 (ref. [6]). The ONR Safety Assessment Principles (SAPs) (ref. [7]), together with supporting Technical Assessment Guides (TAGs) (ref. [8]), have been used as the basis for this assessment.
3. This is a Major report (refer to NS-TAST-GD-108 (ref. [9])).
   1. Background
4. The ONR’s GDA process (ref. [10]) calls for a step-wise assessment of the Requesting Party's (RP) submissions with the assessments increasing in detail as the project progresses. Rolls-Royce SMR Limited is the RP for the GDA of the Rolls-Royce SMR design.
5. In April 2022 ONR, together with the Environment Agency and Natural Resources Wales (NRW), began Step 1 of the GDA for the generic Rolls-Royce SMR design. Step 1, which is the preparatory part of the design assessment process and mainly associated with initiation of the project and preparation for technical assessment in later steps, was successfully completed in 12 months.
6. Step 2 commenced in April 2023. This is the first substantive technical assessment step. The focus of ONR’s assessments in this step is towards the fundamental adequacy of the design and safety and security cases, and the suitability of the methodologies, approaches, codes, standards and philosophies which form the building blocks for the design and generic safety and security cases. The objective is to undertake an assessment of the design against regulatory expectations to identify any fundamental safety or security shortfalls that could prevent ONR permissioning the construction of a power station based on the design.
7. Prior to the start of Step 2, I prepared a detailed Assessment Plan for external hazards (ref. [11]). This has formed the basis of this assessment and was also shared with the RP to maximise openness and transparency.
8. This report is one of a series of assessments which support ONR’s overall judgements at the end of Step 2 which are recorded in the Step 2 Summary Report (ref. [12]).
   1. Scope
9. The assessment in this report is of the RP’s E3S case for the Rolls-Royce SMR as summarised in the E3S case chapters and supporting documentation.
10. The overall scope of the Rolls-Royce SMR GDA is described in (ref. [13]). Rolls-Royce SMR Limited has indicated that it intends to complete a three step GDA, with the objective of receiving a Design Acceptance Confirmation (DAC) from ONR and has aligned its GDA scope with this objective. The GDA scope defines the generic plant and layout and includes all Structures, Systems and Components (SSCs) that are identified as being important to safety, security and safeguards, all modes of operation, and all stages of the plant lifecycle.
11. However, given the step-wise assessment during GDA, information has not been submitted for all aspects within the GDA Scope during Step 2; for submissions due in Step 3 see (ref. [14]). The following aspects of the E3S case are therefore out of scope of this assessment:

* The completeness of the E3S case Claims, Arguments and Evidence (CAE) related to external hazards. This will be needed to demonstrate that the E3S case is coherent and complete with respect to external hazards.
* While the RP’s methodologies for space weather (ref. [15]) and Beyond Design Basis (BDB) and cliff edge for external hazards (ref. [16]) have been assessed, the outputs from the application of those methodologies are planned to be submitted in Step 3. Application of the methodologies is required to demonstrate the adequacy of the E3S case and the design.
* Combinations involving BDB external hazards are excluded from the current issue of the External Combined Hazards Report (ref. [17]). Analysis of these combinations is required to demonstrate the adequacy of the E3S case and the design.
* The methodology and outputs for external hazard – internal hazard combinations are planned to be submitted in Step 3. Analysis of these combinations is required to demonstrate the adequacy of the E3S case and the design.
* Detailed substantiation of the SSCs is planned to be submitted in Step 3 and is within the scope of engineering topic areas in ONR.
* The Generic Site Envelope (GSE) (ref. [18]) has selected conservative external hazard characterisations. Some of the parameters are based on a literature search of the values derived for previous GB GDAs, which omits a detailed understanding of how those values were derived. The RP may perform detailed external hazard characterisations once a site has been selected (ref. [19]). A design based on the current GSE values is likely to be adequate but, without the detailed derivations to support those values, the E3S case will be incomplete. In the GSE (ref. [18]) the RP has identified site-specific hazards that are outside the GDA scope and are therefore excluded from the scope of this assessment.
* For some external hazards, the SSCs that mitigate them will be site-specific, e.g. sea walls, so these are outside the GDA scope. However the RP has stated (ref. [20]) that commitments on the future dutyholder, such as analysing site-specific hazards, are being identified in the E3S Case Tier 1 chapters as the case develops. Identification of external hazard site-specific considerations will be developed in Step 3 of GDA and captured in the External Hazards Strategy.
* The RP is developing a global GSE in addition to the GB GSE. However, the global GSE is outside the scope of this GDA and this external hazards assessment, which will refer to the GB GSE (ref. [18]) accordingly.

1. My assessment has considered the following aspects (subject to the limitations highlighted above):

* The adequacy of the GSE, including the hazard screening methodology.
* The adequacy of the BDB & cliff edge methodology for external hazards.
* The adequacy of the combined external hazards methodology and its application.
* The adequacy of the analysis of background accidental aircraft crash frequency.
* The adequacy of the space weather hazards methodology.
* How hazards will impact on the proposed arrangements for layout strategy, the aseismic bearings, the hazard shield and Heating, Ventilation and Air Conditioning (HVAC) systems.
* The RP’s arrangements for information exchange between technical disciplines and for ensuring that there is consistency across its submissions and within the E3S case.
* The adequacy of the RP’s approach to RGP and the As Low As Reasonably Practicable (ALARP) principle.

# Assessment standards and interfaces

1. For ONR, the primary goal of the GDA Step 2 assessment is to reach an independent and informed judgment on the adequacy of a safety, security and safeguards case for the reactor technology being assessed.
2. ONR has a range of internal guidance to enable Inspectors to undertake a proportionate and consistent assessment of such cases. This section identifies the standards which have been considered in this assessment.
3. This section also identifies the key interfaces with other technical topic areas.
   1. Standards
4. The ONR Safety Assessment Principles (SAPs) (ref. [7]) constitute the regulatory principles against which the RP’s case is judged. Consequently, the SAPs are the basis for ONR’s assessment and have therefore been used for the Step 2 assessment of the Rolls-Royce SMR.
5. The International Atomic Energy Agency (IAEA) safety standards (ref. [21]) and nuclear security series (ref. [22]) are a cornerstone of the global nuclear safety and security regime. They provide a framework of fundamental principles, requirements and guidance. They are applicable, as relevant, throughout the entire lifetime of facilities and activities.
6. Furthermore, ONR is a member of the Western European Nuclear Regulators Association (WENRA). WENRA has developed Reference Levels (ref. [23]), which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors (ref. [24]).
7. The relevant SAPs, IAEA standards and WENRA reference levels are embodied and expanded on in the TAGs (ref. [8]). The TAGs provide the principal means for assessing the external hazards aspects in practice. The external hazards TAG (ref. [25]) was re-issued in October 2023 and is therefore broadly up to date with respect to IAEA standards and WENRA reference levels. IAEA SSG-89 (ref. [26]) was issued in February 2024, which was too late to be used for this Step 2 assessment.
   * 1. Safety Assessment Principles (SAPs)
8. The key SAPs applied within my assessment are SC.2, SC.4, SC.5, EDR.3, EHA.1, EHA.2, EHA.3, EHA.4, EHA.5, EHA.6, EHA.7, EHA.8, EHA.9, EHA.10, EHA.11, EHA.18, EHA.19, FA.2, FA.5 and FA.6.
9. A list of the SAPs used in this assessment is recorded in Appendix 1.
   * 1. Technical Assessment Guides (TAGs)
10. The following TAGs have been used as part of this assessment:

* NS-TAST-GD-005 – Regulating duties to reduce risks to ALARP (ref. [27]).
* NS-TAST-GD-013 – External Hazards (ref. [25]).
* NS-TAST-GD-051 – The purpose, scope and content of safety cases (ref. [28]).
* NS-TAST-GD-096 – Guidance on Mechanics of Assessment (ref. [6]).
* NS-TAST-GD-109 – Ageing and Degradation Management (ref. [29]).
  + 1. National and international standards and guidance

1. The following international standards and guidance have been used as part of this assessment:

* IAEA, Format and Content of the Safety Analsyis Report for Nuclear Power Plants, Specific Safety Guide No. SSG-61 (ref. [30]).
* IAEA, Protection Against Internal and External Hazards in the Operation of Nuclear Power Plants, Specific Safety Guide No. SSG-77 (ref. [31]).
* IAEA, External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Standard NS-G-1.5 (ref. [32]).
* IAEA, Design of Nuclear Installations Against External Events Excluding Earthquakes, Specific Safety Guide No. SSG-68 (ref. [33])
* WENRA, guidance on Safety of New Nuclear Power Plant (NPP) designs (ref. [34]).
* European Utility Requirements (EUR), Light Water Reactor (LWR) Nuclear Power Plants Volume 2 Generic Nuclear Island Requirements, Chapter 4: Design Basis (ref. [35]).

Note that IAEA, Evaluation of Seismic Safety for Nuclear Installations SSG-89 (ref. [26]) is also relevant but it was only issued in February 2024 (see paragraph ‎19).

* 1. Integration with other assessment topics

1. I worked closely with other topics (including the Environment Agency and NRW assessors) as part of my external hazards assessment. Similarly, other assessors sought input from my assessment. These interactions are key to the success of GDA to prevent or mitigate any gaps, duplications or inconsistencies in the regulators' assessments.
2. As outlined in the previous paragraph, the key interactions with other topic areas that have guided my Step 2 assessment were:

* Civil engineering, especially with respect to seismic and aircraft crash hazards, the aseismic bearings and the hazard shield.
* Control and Instrumentation (C&I), especially with respect to lightning and space weather.
* Electrical engineering, especially with respect to lightning and space weather.
* Internal hazards, especially with respect to seismic and aircraft crash hazards. Relevant combined and consequential hazards have been discussed in principle, although the RP’s analysis of these is not yet available (see paragraph ‎11).
* Mechanical engineering, especially with respect to high Extreme Ambient Temperatures (EAT) and HVAC systems.
  1. Use of technical support contractors

1. During Step 2 I have not engaged Technical Support Contractors (TSCs) to support my assessment of external hazards for the Rolls-Royce SMR. However, the ONR civil engineering assessor engaged a TSC and the scope of its work included a review the GSE. The TSC’s report (ref. [36]) is discussed in the GDA Step 2 assessment of civil engineering (ref. [37]), but I have also referred to it. It should be noted that all regulatory judgements have been made exclusively by ONR.

# Requesting party’s submission

1. Rolls-Royce SMR Limited submitted a series of E3S chapters, or summary reports, and other supporting references, which outline the E3S case for the generic Rolls-Royce SMR design. This section presents a summary of the RP’s safety case for external hazards. It also identifies the documents submitted by the RP which have formed the basis of my external hazards assessment of the Rolls-Royce SMR.
   1. Summary of the Rolls-Royce SMR design
2. The generic Rolls-Royce SMR design is a three loop Pressurised Water Reactor (PWR) with a target electrical power output of 470 MWe (from a thermal power of 1,358 MWth) and a design life of 60 years for non-replaceable components.
3. The Rolls-Royce SMR design has been developed by the RP based upon well-established PWR technology, in use all over the world. Innovation comes in the form of its modular approach to construction which would see the majority of the power station built in factory conditions and assembled on site.
4. The reactor itself is of a typical PWR design, including a steel Reactor Pressure Vessel (RPV) holding fuel assemblies, Steam Generators (SGs), reactor coolant pumps and piping, all held within a steel containment vessel. The reactor is equipped with a number of supporting systems for normal operations and a range of safety measures are present in the design to provide cooling, control criticality and contain radioactivity under fault conditions. Passive safety features are preferred to active components, reflecting the RP’s design philosophy.
5. From the RP’s submissions I would highlight the following aspects of the design as important from an external hazards perspective:

* A hazard shield, with various SSCs located within it, (ref. [38]) and (ref. [39]), formed from reinforced concrete walls and slabs, with the primary function to protect safety critical SSCs from external hazards including accidental and malicious aircraft impact.
* The hazard shield and reactor island rest on a basemat which is supported by a seismic isolation system (aseismic bearing and pedestals), (ref. [38]), (ref. [40]) and (ref. [41]). The function of the seismic isolation system is to reduce the seismic demand to the majority of reactor island superstructures, including the reactor and spent fuel pool. The design employs low damping rubber bearings and the proposals provide isolation in the horizontal direction only.
* High EAT have the potential to increase heat loadings on SSCs. HVAC and passive cooling systems have the function of protecting SSCs from excessive heating loadings, whether from internal or external sources. The detailed design for this falls to the mechanical engineering designers and is ongoing.
* Several external hazards, e.g. extreme winds, lightning and Geomagnetically Induced Currents (GICs), have the potential to cause Loss Of Offsite Power (LOOP) and may also cause faults in electrical and C&I SSCs. Backup electrical supplies will be provided, including diesel generators. Additional mitigations, such as diverse SSCs, may be provided but the detailed design for this is ongoing.
* Solar Energetic Particles (SEPs) have the potential to affect electrical and C&I SSCs. The hazard shield is expected to provide significant shielding to mitigate SEPs and local shielding may also be provided as necessary, but the detailed design of this has not been available during GDA Step 2.
* The modular construction and compact layout. The proximity and arrangement of SSCs affects the outcomes for various external hazards such as seismic events, aircraft crash and high EAT. Details of the layout are still being developed.
  1. E3S case approach and structure

1. Rolls-Royce SMR Limited has chosen to develop its cases in a holistic manner, as an Environment, Safety, Security and Safeguards (E3S) case. The overall objective for the E3S case is to demonstrate that the design will ‘protect people and the environment from harm’.
2. This means that, although the case made for each of the E3S purposes (i.e. environment, safety, security and safeguards) will inevitably be different at the top level, it will draw upon common evidence outputs (as well as other non-common outputs) to substantiate each of the purposes. This is claimed to offer benefits in terms of clarity, integration and understanding impacts from any changes to the case.
3. The E3S case is being developed using a three tier hierarchy and incorporating a Claim, Argument and Evidence (CAE) structure with the highest-level claims being derived from the RP’s own E3S principles. The highest level of the three tiers is the RP’s Tier 1 E3S chapters, with the lower tiers providing more detailed arguments and evidence. This is illustrated in Figure 1.

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**Figure 1: Claim, Argument and Evidence (CAE) structure within the E3S hierarchy** (ref. [1])

1. The structure of the E3S case largely aligns with the IAEA guidance for safety cases, SSG-61 (ref. [30]), supplemented to include UK specific expectations and expanded to include the other E3S purposes.
   1. Summary of the requesting party’s E3S case for External Hazards
2. The aspects covered by the Rolls-Royce SMR safety case in the area of external hazards can be broadly grouped under the headings listed below in this section. The E3S case claims relating to external hazards are detailed in E3S case chapters 2 (ref. [2]) and 15 (ref. [4]) the E3S case route map (ref. [42]). A summary of them is presented in Appendix A of (ref. [2]).
   * 1. Identification and screening of external hazards
3. The identification and screening of external hazards is presented in the GSE (ref. [18]). The GSE, including its identification and screening of external hazards, refers to both GB and international RGP, including ONR SAPs (ref. [7]), NS-TAST-GD-013 (ref. [25]) and IAEA Safety Standard NS-G-1.5 (ref. [32]).
4. The RP’s screening of external hazards is based on low frequency, low consequence or on the hazard being bounded by another hazard. Additionally some external hazards are deemed to be site-specific and therefore outside the GDA scope. However, for a number of these, e.g. seismic and flooding hazards, general comments providing reassurance on their assessment and mitigation, in addition to bounding values where practical have been provided.
   * 1. Identification and screening of combined external hazards
5. The RP submitted a methodology for identification and screening of combined external hazards (ref. [43]), which uses a 7 step process beginning with identification and initial screening of external hazards and ending with defining the magnitude / severity of external hazards acting in combination.
6. Subsequently a report that applied the methodology (ref. [17]) was submitted. The credible external hazard combinations generated by applying the methodology led to 8 screened in combined hazard scenarios (labelled scenarios A to H) and a further 9 hazard combinations not included in a scenario but included in the DB. The report also provides a provisional list of the PIEs that may arise from the generated hazard scenarios. The report also provides a summary of required updates, e.g., a future revision will need to consider BDB external hazards.
   * 1. Determination of DB external hazard values
7. The GSE (ref. [18]) presents DB external hazard values. These have mostly been derived by selecting the worst case bounding values generated by previous GDAs. The RP expects these values to provide a conservative DB for the GB EN-6 sites.
8. Unlike previous GDAs, the RP does not currently have any specific sites selected for deployment of the Rolls-Royce SMR and therefore intends to delay more detailed analysis of DB external hazards until a site has been selected. In terms of seismic hazards, the RP has specified a bounding Peak Ground Acceleration (PGA) and the ground stiffness types enveloped by the GSE (ref. [44]) but time histories are not yet included.
   * 1. Consideration of climate change in the GSE
9. The GSE (ref. [18]) presents a list of the hazards that are affected by climate change. The GSE has provided climate change adjustments to DB external hazard values where appropriate using the UK Climate Projections 2018 (UKCP18) (ref. [45]), derived by the Met Office. UKCP18 uses Representative Concentration Pathways (RCPs) with four radiative forcing scenarios; RCP2.6, RCP4.5, RCP6.0 and RCP8.5, e.g., RCP6.0 is equivalent to a radiative forcing of 6.0 W/m2. Where parameters are not covered by UKCP18, the best available data has been used.
10. The plant life is expected to extend into the 2100s. UKCP18 only provides data up to 2080 or 2100, depending on the hazard; however the RP may adopt the managed adaptive approach, i.e. the plant design may facilitate modification to adapt as climate change develops, RQ-01088 (ref. [19]). To provide an adequately conservative DB, the RP has selected RCP6.0 at the 90th percentile. RCP8.5 at 50th percentile has also been considered for parameters where UKCP18 does not provide values at RCP6.0.
    * 1. Adequacy of BDB and cliff edge margins
11. The RP has submitted a BDB and cliff-edge methodology for external hazards (ref. [16]). Its methodology for demonstrating that the installation can withstand severe BDB loads and that there is an absence of cliff-edges consists of four phases, where conservatisms in the design are removed until the cliff-edge and severe BDB cases are made. These phases apply equally to discrete and non-discrete hazards and are:

* Phase 1 – Conservatisms in the GB GSE compared to the site challenge.
* Phase 2 – Conservatisms in the use of the 84% confidence level compared to best estimate loads for non-discrete hazards and conservatisms in the design loads or hazards specification for discrete hazards.
* Phase 3 – Conservatisms in the design.
* Phase 4 – Other measures.
  + 1. ALARP by Design

1. The RP’s approach to demonstrating the external hazard risks are ALARP may be summarised as follows:

* Conservative values shall be used for DB hazards in accordance with RGP, see (ref. [18]).
* The BDB analysis will mainly be undertaken by the designers, rather than the RP’s external hazards team, see (ref. [16]). To ensure that requirements arising from external hazards are fully incorporated into the design, the RP has stated (ref. [20]) that work is progressing to develop the flow of hazard requirements through the RR SMR requirements management database. It is expected that high level requirements will be derived from the Fault Schedule which will then flow into the Hazards Protection Module and more detailed requirements will flow from this module, such as BDB requirements. Additionally, non-functional external hazard requirements will flow from the Transverse Requirement module. This process will be available for scrutiny during Step 3.
* External hazards and their combinations have been identified, and their magnitudes/loads have been quantified. The assessment has influenced in particular the design of civil structures. Generic methodologies have also been specified for a number of external hazard topics, which will be applied by designers during design development (ref. [4]).
  1. Basis of assessment: requesting party’s documentation

1. The principal documents that have formed the basis of my external hazards assessment of the E3S case are:

* GDA Scope and Step 2 Submission Plan for External Hazards (ref. [46]), which stated the submissions that the RP intended to deliver during Step 2 and therefore provides a measure of the RP’s progress against its programme.
* E3S Case Chapter 2: Generic Site Characteristics (ref. [2]). The GSE (ref. [18]) (see below) is a key input to this Tier 1 document. Along with E3S Case Chapter 15 (ref. [4]) (see below), this provides an overview of the scope, clarity and consistency of the safety case CAE for external hazards.
* E3S Case Chapter 15: Safety Analysis (ref. [4]). External hazards provide PIEs, which are a key input to this Tier 1 document.
* GB Generic Site Envelope (GSE) (ref. [18]), which presents the identification, screening and characterisation (frequency and severities) of DB external hazards. Appendix A (pages 55 to 95) in the GSE presents the external hazards screening for all of the identified external hazards. Table 1 (pages 9 to 12) in the GSE summarises the GB GSE DB values for all screened in external hazards, apart from those which have been designated “site-specific”, which are listed in the table but not evaluated. The related plant design values, with margins against the DB hazards, are not all available in Step 2 and they will be presented elsewhere in the RP’s E3S case.
* Analysis of Background Accidental Aircraft Crash Frequency (ref. [47]). This analysis derives relevant average GB aircraft crash frequencies for major categories of aircraft, along with basic data and methodologies that may be adapted and applied to specific sites.
* Space Weather Hazards Methodology Report (ref. [15]). This report derives relevant average GB space weather hazards data for the various categories of space weather (GICs, SEPs, etc) along with potential impacts on SSCs and basic data and methodologies that may be adapted and applied to specific sites.
* Combined External Hazards Methodology (ref. [43]), which presents methodologies for identifying, screening and characterising DB combinations of external hazards.
* External Combined Hazards Report (ref. [17]), which presents results derived by applying the Combined External Hazards Methodology (ref. [43]) (see above).
* BDB and Cliff Edge Methodology for External Hazards (ref. [16]), which presents methodologies for identifying, screening and analysing BDB external hazards with respect to design margins.
* External hazards are determined principally by location and they may be characterised independently of the reactor design. However potential interactions between the hazards and the design may affect the screening of external hazards and their consequences for the plant, so the high level design data available via the following submissions and the documents and SSCs to which they refer has provided useful background information for my external hazards assessment:
  + GB Generic Site Envelope (GSE) (ref. [18]) sections 1.2 and 5.
  + Reactor Island General Arrangement Plan (ref. [48]).
  + Layout and Modularisation Submission (ref. [49]).
  + GDA Design Reference Report (ref. [50]).
* Generic E3S Case Scope and Deliverable Document – External Hazards (ref. [14]), which states the external hazards related submissions that the RP intends to deliver during Step 3 and therefore provides an indication of the scope, adequacy and viability of the RP’s Step 3 programme, including how it will address ongoing Regulatory Queries (RQ) raised during Step 2.

# ONR assessment

* 1. Assessment strategy

1. As stated in paragraph ‎6 of this report, the objective is to undertake an assessment of the design against regulatory expectations to identify any fundamental safety or security shortfalls that could prevent ONR permissioning the construction of a power station based on the design. Hence, in accordance with my Step 2 assessment plan (ref. [11]), my targeting and sampling strategy has focused on hazards that are likely to result in the highest risks or uncertainties or that may give rise to novel challenges or complex assessment due to the plant design. On a sampling basis, I have therefore targeted the adequacy of:
   1. The GSE (ref. [18]), section ‎4.2.1.
   2. The BDB and cliff edge methodology (ref. [16]), section ‎4.2.2.
   3. The combined external hazards methodology and its application (ref. [43]) and (ref. [17]), section ‎4.2.3.
   4. The space weather hazards methodology (ref. [15]), section ‎4.2.4.
   5. The analysis of background accidental aircraft crash frequency (ref. [47]), section ‎4.2.5.
   6. The analysis of heat loadings from high EAT and heatwaves within the GSE (ref. [18]), section ‎4.2.6‎4.2.7‎4.2.8.
   7. The analysis of seismic hazards within the GSE (ref. [18]), section ‎4.2.7.
   8. The RP’s arrangements for information exchange, section ‎4.2.8.
   9. The RP’s approach to complying with the ALARP principle, section ‎4.2.9.
2. For each of the above topics, where applicable, I have assessed them against the following criteria:
   1. Are the methodologies, approaches, codes, standards and philosophies used consistent with Relevant Good Practice (RGP)?
   2. Are any deviations from RGP identified, explained and resolved or demonstrated to reduce risks to ALARP?
   3. Are relevant SAPs (Appendix 1) likely to be satisfied?
   4. Is the scope of planned deliverables adequate?
   5. Is the programme achievable and credible?
3. The RP’s submissions listed above in section ‎3.4 address the topics that I have identified for targeting and sampling in paragraphs ‎48 – ‎49, hence I have focused on assessing those documents for GDA Step 2.
   1. Assessment
      1. The GSE
4. The GB Generic Site Envelope (GSE) (ref. [18]), presents the identification, screening and characterisation (frequency and severities) of DB external hazards. The scope of the RP’s GDA external hazards analysis is primarily defined by the GSE. Appendix A of the GSE presents a list of external hazards based on RGP, including:

* IAEA Safety Standard NS-G-1.5 (ref. [32]).
* WENRA guidance on Safety of New Nuclear Power Plant (NPP) designs (ref. [34]).
* NS-TAST-GD-013 (ref. [25]).

1. For GB NPPs the external hazards that pose the highest risk are typically seismic events and external flooding. Heatwaves and high EAT, exacerbated by climate change, have the potential to increase heat loadings on plant and personnel which may lead to multiple Common Cause Failures (CCF). Additionally, accidental or malicious aircraft crash has the potential for high consequences, although the applicable frequencies for accidental aircraft crash are generally very low. The GSE has identified and discussed dominant external hazards such as these, along with a large number of hazards that are typically less challenging for GB NPPs, such as biofouling, volcanic ash, pandemics, mist and fog. I judge that the identification of external hazards in the GSE is sufficiently comprehensive such that it complies with ONR SAPs EHA.1 and FA.5, see (ref. [7]) and Appendix 1 in this report.
2. In accordance with RGP and SAP EHA.19 (Appendix 1), the initial comprehensive list of external hazards should be screened to eliminate hazards that make no significant contribution to overall risks from the facility. Such screening not only reduces the analysis workload, but also helps to ensure that nuclear safety resources are focused on the more significant hazards and that risks are addressed proportionately. As stated in paragraph ‎47, potential interactions between the hazards and the design may affect the screening of external hazards and their consequences for the plant, so the GSE (ref. [18]) includes a summary of relevant aspects of the design in sections 1.2 and 5. I did not find any discrepancies between the design as recorded in the GSE and the GDA Design Reference Report (ref. [50]).
3. Hazards that are judged to have low frequency, low consequence or are bounded by other hazards are screened out (GSE, section 4.3), which complies with SAP EHA.19. Additionally, the GSE categorises the screened in hazards, as follows:
4. Within scope of GDA.
5. Site-specific but reassurance can be provided during GDA.
6. Site-specific and only able to be treated as such in any detail.
7. I judge that this complies with the ONR GDA guidance given in (ref. [51]). Further, I judge that the categorisation of the hazards assigned to the first and third categories above is clearly justified. Ten hazards are assigned to the second category, including flooding, seismic, drought, industrial hazards, accidental aircraft crash and space weather and these merit some discussion, as follows.
8. All external hazards are site-specific, so designating a sub-set of external hazards as “site-specific” is somewhat arbitrary, although it is true that some are more variable between GB sites than others and characterising bounding values is simpler for some hazards than for others. Further it should be noted that, unlike previous GDAs performed by ONR, the Rolls-Royce SMR may be deployed on a wide range of sites, RQ-01062 (ref. [19]), and no specific site has yet been allocated for a Rolls-Royce SMR.
9. Although the “site-specific” external hazard screening applied by the RP is justified in principle, it also follows that those aspects of external hazards analysis that are deemed to be outside the GDA scope need to be clearly stated in the relevant submissions. The GSE (ref. [18]) provides such information, although some amendment to, and clarification of, the scope may be required as the GDA progresses. The GSE refers to ONR GDA guidance (ref. [51]) which states that the definition of the site envelope can be as broad or narrow as the RP wishes. This is correct but it is important to note that the GSE is a significant input to the NPP design, so omissions from the GSE might necessitate some re-design at the site licensing stage. Clear information on such omissions is therefore important for designers, investors and future dutyholders. That said, the RP has used bounding values for the majority of potential GB sites hence the extra work required could be limited.
10. I have highlighted this and the RP has stated (ref. [20]), also see paragraph ‎31, 7th bullet point, that commitments on the future dutyholder, such as analysing site-specific hazards, are being identified in the E3S Case Tier 1 chapters as the case develops. Further, identification of external hazard site-specific considerations will be developed in Step 3 of the GDA.
11. For external hazards that are not screened out, the DB event should be derived conservatively to take account of data and model uncertainties (SAPs EHA.3, EHA.4 and SAP paragraph 239). The GSE has selected conservative external hazard characterisations in part by a literature search for the worst case DB values derived for previous GB GDAs (see paragraph ‎11). This omits a detailed understanding of how those values were derived. I raised this point in RQ-01046 and RQ-01088 (ref. [19]). The RP may not conduct additional analysis based on a site within GDA timescales and this may be left as site specific work (ref. [19]). Given the conservatism applied in previous GDAs, a design based on the current GSE DB values is likely to be adequately conservative but, without the detailed derivations to support those values, the E3S case will be incomplete, see NS-TAST-GD-051 (ref. [28]). Viewed as a whole, I judge this approach to be adequate, but I note that it may defer a significant amount of safety case analysis until the site specific stageand it limits the scope of the GDA accordingly.
12. Note that, in accordance with my Step 2 assessment plan (ref. [11]), I have provided specific assessment related to space weather, accidental aircraft crash, heatwaves and seismic hazards respectively in sections ‎4.2.4, ‎4.2.5, ‎4.2.6 and ‎4.2.7 below.
13. In summary, I judge that the GSE (ref. [18]):

* Hazard identification complies with RGP (paragraph ‎51);
* Hazard screening complies with RGP. The RP has committed to provide clear information on characterisations for screened in hazards that are omitted or incomplete in the GSE in the E3S Case Tier 1 chapters as the case develops. I intend to sample this information during Step 3;
* DB hazard characterisations are likely to be conservative and provide an adequate basis for developing the design. However, ultimately further safety analysis will be required to support the DB values. This will be done when a site has been selected, but not necessarily within GDA timescales. This is a valid approach, but it imposes limits on the GDA scope accordingly.
  + 1. The BDB and cliff edge methodology

1. The RP’s BDB and cliff edge methodology (ref. [16]) presents methodologies for identifying, screening and analysing BDB external hazards with respect to design margins. Section 4.2 in the submission explains that the methodology consists of four phases, where conservatisms in the design are removed until the cliff-edge and severe BDB cases are made. These phases apply equally to discrete and non-discrete hazards and are:

* Phase 1 – Conservatisms in the GB GSE compared to the site challenge.
* Phase 2 – Conservatisms in the use of the 84th % confidence level compared to best estimate loads for non-discrete hazards and conservatisms in the design loads or hazards specification for discrete hazards.
* Phase 3 – Conservatisms in the design.
* Phase 4 – Other measures, e.g. the initiation of procedures to mitigate extreme weather based on weather forecasts.

1. The RP’s BDB analysis seeks to remove justifiable conservatisms from the DB plant response model to give an indication of the installation’s ‘best estimate’ reaction to the level of hazard applied and to show adequate margin above the DB.
2. In summary, NS-TAST-GD-013 (ref. [25]) states that greater uncertainties in the BDB analysis may be off-set by greater margins against BDB events in the SSCs. RPs and dutyholders are free to decide exactly where to put the emphasis in this respect so long as the overall justification is clear and robust. Given that the SAPs define the DB as conservatively estimated, the conservatisms are part of the DB, not the first part of a best estimate BDB analysis. A direct comparison between the DB event and the best estimate 10-5 event (ref. [25]) may reveal conservatism but the RP’s Phase 2 methodology does not. At best, “Phase 2” provides a qualitative, defence in depth claim that is insufficient on its own. A better approach would be to omit the current “Phase 2” from this process and re-number the other Phases accordingly. The RP’s methodology would then comply with RGP and would be likely to satisfy SAPs EHA.7 and EHA.18 (Appendix 1) provided it was applied consistently, rigorously and comprehensively. Hence, I have identified a shortfall in this respect in the RP’s current BDB and cliff edge methodology (ref. [16]). As the RP has not yet developed its BDB case this shortfall does not indicate any shortcoming in the design, but the BDB case needs underpinning by an adequate process.
3. In this context (ref. [52]), designers should also have a strategy for addressing ageing and degradation of SSCs, NS-TAST-GD-109 (ref. [29]), especially how to demonstrate ongoing compliance of degraded SSCs against the safety functional requirements in the safety case. This can be particularly challenging for passive SSCs, e.g. large concrete or steel structures, which it may not be practicable to repair or replace during the plant’s operating life and adequate examination and analysis of degraded SSCs may also be difficult. For new designs it is good practice, and consistent with the ALARP Principle (ref. [27]), to address this issue where practicable in the design, e.g. to facilitate access to SSCs for examination and to provide safety margins that allow for predictable levels of degradation over the plant’s design life. Section 8 in (ref. [16]) addresses erosion of design margins at a high level, including the effects of climate change over the plant lifetime. This is consistent with RGP (NS-TAST-GD-013), although the detailed application of it in the Rolls-Royce SMR design has yet to be demonstrated.
4. Sections 3.1 – 3.4 in (ref. [16]) present useful summaries of the BDB and cliff-edge analyses performed for four previous GDAs. However the heading for this section describes it as, “Relevant Good Practice”, which is misleading. Although previous GDAs should have complied with RGP, they do not constitute RGP for several reasons, e.g.,

* RGP for one NPP design may not be directly applicable to a different NPP design.
* Previous GDAs included site-specific elements, which may not cover all of the sites applicable to the Rolls Royce SMR.
* The designs covered by previous GDAs may not have complied with RGP in every respect.
* Some aspects of RGP may have changed since the previous GDAs were completed.

1. Despite this reservation, the conclusion stated above in paragraph ‎64 remains valid, as the proposed methodology (paragraphs ‎62 - ‎63) is not based on the data from previous GDAs.
2. Sections 4.1 and 4.2 in (ref. [16]) indicate that application of the BDB and cliff edge methodology will mainly be done by the designers, rather than the RP’s external hazards team. There is no problem with that in principle, but I suggested (ref. [20]) that it would be useful if the external hazards team provide some oversight and co-ordination on this topic to ensure that all of the relevant disciplines are engaged, different hazards and SSCs are covered in a consistent manner, all of the BDB analysis conclusions are collated in a coherent manner and the BDB requirements are adequately addressed in the E3S case CAE. The RP is free to decide how to manage this, but I asked for clarification on how it will be managed.
3. The RP responded (ref. [20]) that work is progressing to develop the flow of hazard requirements through the RR SMR requirements management database. It is expected that high level requirements will be derived from the Fault Schedule which will then flow into the Hazards Protection Module and more detailed requirements will flow from this module, such as BDB requirements. Additionally, non-functional External Hazard requirements will flow from the Transverse Requirement module. I intend to examine this in more detail in Step 3.
4. In summary, for the BDB and cliff edge methodology (ref. [16]), I judge that:

* There is a shortfall in the RP’s current BDB and cliff edge methodology (ref. [16]), see paragraph ‎64;
* Subject to resolving the above shortfall, the methodology is likely to satisfy SAPs EHA.7 and EHA.18 (Appendix 1) provided it is applied consistently, rigorously and comprehensively;
* Includes a high level strategy for demonstrating ongoing compliance of ageing and degraded SSCs (NS-TAST-GD-109 and SAPs EAD.2, EAD.3 and EAD.4) against the safety functional requirements in the safety case, including consideration of climate change (paragraph ‎65).

1. The detailed application of the BDB and cliff edge methodology in the Rolls-Royce SMR design has yet to be demonstrated, RQ-01062 (ref. [19]) and para ‎11, and I intend to sample this during Step 3. Also note NS-TAST-GD-096 (ref. [6]) on the need to substantiate documented claims.
   * 1. The combined external hazards methodology and its application
2. The RP has submitted:

* A combined external hazards methodology (ref. [43]). This presents methodologies for identifying, screening and characterising DB combinations of external hazards. In this section I have referred to this as, “the methodology”.
* An external combined hazards report (ref. [17]), which applies the methodology presented in (ref. [43]). In this section I have referred to the external combined hazards report as, “the report”.

1. I commented on both documents and the RP responded to my comments (ref. [20]). The methodology (section 2.1) consists of seven steps, which may be summarised as follows:

* Establish and contextualise external hazards of concern:
  + Step 1: identify and undertake initial screening of external hazards.
  + Step 2: obtain hazard information.
* Determine hazard combination pairs:
  + Step 3: generate a hazard pair matrix and classify paired hazard combinations.
* Understand further hazard combinations beyond pairings:
  + Step 4: construct external hazards scenarios.
  + Step 5: consider consequential external hazards resulting from scenarios.
  + Step 6: screen the external hazards combinations.
* Produce a grouping matrix and understand how the combined external hazards will impact the plant:
  + Step 7: define the magnitude / severity of external hazards acting in combination.

1. The output of this methodology in the report is a series of credible external hazard combinations, given in three distinct sets:

* Individual Hazards, e.g., Flooding (coastal and fluvial) included as a combination with external flooding, high tides, storm surge, waves, wind generated waves, extreme rainfall, river level, flash flood, groundwater, and snow melt.
* Combined Hazard Scenarios, e.g., Scenario B, which is a DB scenario combining multiple hazards associated with heatwaves, such as high dry bulb air temperature, humidity, drought, lightning and rain (including pluvial flooding).
* Credible Hazard Combinations, e.g., Seismic activity and hail / snow / ice can place a vertical load on buildings. This hazard combination considers the possibility that snow could fall and remain present during seismic activity. If this event occurred, buildings would have an increased loading placed on them during seismic activity. Snow load should be considered at operating basis. This hazard pair could form superimposed loads.

1. Section 7 of the report also derives conservative magnitudes / severities for the hazards in the screened in combinations.
2. ONR SAP EHA.6 (Appendix 1) explicitly refers to analysing hazard combinations but the principles stated in the following SAPs are also applicable to hazard combinations: SC.4, EHA.1, EHA.3, EHA.4, EHA.19, FA.2, FA.5 and FA.6. Further, SAP EHA.5 states that analysis of design basis events should assume the event occurs simultaneously with the facility’s most adverse permitted operating state. Typically NPP operation at full power provides the most adverse permitted operating state; however for combined hazards that are not simultaneous it is conceivable that the first hazard to occur may initiate plant shutdown. Subsequent hazards may then apply to other plant operating states.
3. Combined hazards is a complex topic and there is not a unique approach to it. IAEA SSG-77 (ref. [31]) seeks, “a systematic process to identify and categorise hazard combinations”. NS-TAST-GD-013 (ref. [25]), section 5.6.8, addresses combinations of external hazards and states that there should be a systematic process to identify and categorise hazard combinations and then screen those hazards on the basis of plant effects and occurrence frequency. It then provides guidance on identification, categorisation and screening of hazard combinations. The methodology refers to NS-TAST-GD-013 and to various IAEA guidance, including SSG-68 (ref. [33]), which provides guidance on analysing hazard combinations.
4. With reference to NS-TAST-GD-013, the methodology (sections 2.8.4 – 2.8.6) outlines an approach to analysing two levels of BDB events. However, combinations involving BDB external hazards are excluded from the current issue of the report (see para ‎11). These are due to be included in Step 3, RQ-01088 (ref. [19]). Analysis of these combinations is required to demonstrate the adequacy of the E3S case and the design.
5. Section 9 of the report outlines future work on hazard combinations, e.g. on external – internal hazard combinations, as well as combinations involving BDB external hazards. I judge that the high level scope of future work outlined in the report is adequate. Although further work is required on hazard combinations, my review (ref. [20]) of the methodology and the report concluded that they lay a solid foundation for future work. Issue 2 of the report is due on 28/02/2025 (ref. [14]), although detailed analysis of combinations involving BDB external hazards is likely to be covered in several submissions and combined external – internal hazards will be covered in separate submissions (ref. [14]).
6. In summary, I judge that the methodology (ref. [43]) and the report (ref. [17]):

* Comply with RGP, e.g. (ref. [25]) and (ref. [33]), see paragraphs ‎77 - ‎79;
* Are likely to satisfy relevant SAPs, such as EHA.6 (Appendix 1), subject to the inclusion of BDB events.

1. Note that hazard combinations are also relevant to sections ‎4.2.4 - ‎4.2.9 below. I intend to assess this topic further during Step 3.
   * 1. The space weather hazards methodology
2. Consideration of space weather hazards is an expectation given in Annex 5 of NS-TAST-GD-013 (ref. [25]) and the RP has recognised this. Without adequate protection or qualification, a significant proportion of electrical and C&I systems may be vulnerable to CCF in a severe space weather event, with potentially serious effects on NPP safety. Coronal Mass Ejections (CMEs) from the Sun colliding with Earth’s magnetosphere may generate geomagnetic storms leading to Geomagnetically Induced Currents (GICs). These could lead to widespread electrical disruptions, blackouts, and damage due to extended outages of the electrical power grid, i.e. LOOP. Progress is being made on estimating DB and BDB space weather events, although there are significant uncertainties at present.
3. Section 4.20 in the GSE (ref. [18]) presents a useful high level discussion on space weather hazards.
4. Besides CMEs and the associated GICs, space weather also includes SEPs (showers of neutrons reaching ground level) and Solar Radio Bursts (SRBs). SEPs produce Ground Level Enhancements (GLEs), which can interfere with the performance of C&I and electrical equipment. SRBs are radio-frequency emissions at natural plasma frequencies which drop through the frequency spectrum from flares and CMEs. As the frequency of emission passes through bands used for different telecommunications systems, the resulting Radio-Frequency Interference (RFI) may disrupt those services, causing reduced performance or complete Loss of Service (LoS). The effects of a space weather event on earth vary with location. NS-TAST-GD-013 Annex 5 also discusses the potential effects of GICs on transformers, which may depend on the event duration. The GSE (ref. [18]) categorises space weather as a site-specific hazard for which general comments giving reassurance on its assessment and mitigation, in addition to bounding values where practical, have been provided, see paragraph ‎54.
5. Like other external hazards, space weather is likely to have a site-wide impact and it may lead to multiple CCF which requires analysis and mitigation in accordance with SAP EDR.3 (Appendix 1). My RQ-01045 (ref. [19]) raised the issue of CCF due to space weather. The RP’s response cited diversity and segregation of power supplies, including the ability to bring in mobile plant if appropriate to provide confidence against CCF. However, I note that, as space weather events are likely to affect a whole site, segregation may be of limited value, unless it incorporates mitigation such as shielding and surge protection. The RP expects to claim some mitigation of space weather by the Rolls-Royce SMR hazard shield, which may comply with SAP EHA.10, although this has yet to be quantified, see RQ-01046 and RQ-01088 (ref. [19]).
6. The RP has submitted a space weather hazards methodology report (ref. [15]), which I reviewed (ref. [53]). The report derives relevant average GB space weather hazards data for the various hazard types (GICs, GLEs, etc) along with potential impacts on SSCs and basic data and methodologies that may be adapted and applied to specific sites.
7. A combined hazard scenario (see paragraph ‎74, 2nd bullet point) has been identified for space weather; Scenario E in (ref. [17]), which includes LOOP and Loss Of Offsite Water (LOOW).
8. In summary, based on my review (ref. [53]) of the RP’s space weather methodology (ref. [15]) I judge that it is clear and comprehensive, especially as space weather is still a developing field. I raised a few points for clarification. Given that space weather effects are location dependent, the RP has deferred detailed responses until a site has been identified. This is a valid approach, but this may be a challenge during GDA timescales and it also imposes limits on the GDA scope (see paragraphs ‎59 and ‎61, 3rd bullet point). As for other external hazards, most of the SAPs listed in Appendix 1 are applicable to space weather. Rigorous application of the RP’s methodology should achieve compliance with these SAPs. I judge that the RP’s space weather methodology (ref. [15]) addresses key RGP expectations from NS-TAST-GD-013 (ref. [25]), in principle. Important details are yet to be addressed by applying the methodology to the Rolls-Royce SMR design (see para ‎11) and I intend to sample this during Step 3, including combined hazard Scenario E in (ref. [17]).
   * 1. The analysis of background accidental aircraft crash frequency
9. Accidental aircraft crash is addressed in section 4.18 of the GSE (ref. [18]). The aircraft crash hazard has several aspects. A crash may be accidental, in which case its likely frequency and consequences may be assessed as for many other external hazards. Frequencies are not estimated for malicious crashes, where the analysis focuses on consequences and their mitigation. The main consequences of aircraft crashes are typically divided into impact damage and aircraft fuel fires. Work for the Health and Safety Executive (HSE) by Byrne (ref. [54]) divided aircraft crashes into five categories, namely:

* Light.
* Helicopter.
* Small transport.
* Large transport.
* Military combat and jet trainer.

1. Hence, frequencies and worst case consequences may be estimated for each of these categories and then summed to obtain overall aircraft crash risks. The calculations may distinguish between UK average data and more localised data which allows for the proximity of flight paths, airfields and airports. Annex 4 of NS-TAST-GD-013 (ref. [25]) identifies the above categorisation of aircraft crashes based on Byrne’s work as RGP.
2. Mitigation for aircraft crashes typically includes civil structures capable of withstanding crashes, at least for certain aircraft categories, and / or segregation / spatial separation of redundant or diverse SSCs such that a crash is unlikely to affect all of the SSCs performing a given safety function.
3. For this GDA accidental aircraft crash frequencies and aircraft fuel fires are being covered by ONR’s and the RP’s external hazards specialists. Aircraft crash consequences and their mitigation are primarily being covered by ONR’s and the RP’s civil engineering specialists (ref. [37]), with some support from and feedback to the external hazards specialists. The Rolls-Royce SMR hazard shield is intended to provide aircraft impact protection for the SSCs inside it. ONR has discussed expectations for the analysis of malicious aircraft impact with the RP (ref. [55], [56], [57]), and much of this is also applicable to the consequences of accidental impacts. The case for malicious aircraft crash will need to be further developed in Step 3.
4. As explained above, crash consequences are not primarily covered by this external hazards report, but in RQ-01046 and RQ-01088 (ref. [19]) I highlighted that some SSCs, such as electrical systems connected by electrical cables, are likely to be only partially protected from aircraft crashes by the Rolls-Royce SMR hazard shield. The RP’s response stated that SSCs will be designed and verified to deliver functions during and after a DB aircraft impact. For the standby Alternating Current (AC) Diesel Generators (DGs), there is an overall concept that they are separated either side of the reactor island to minimise the probability of an aircraft impact, malicious or accidental, on both at the same time, with the hazard shield in the middle. The electrical systems use redundancy, diversity and segregation to provide the required function as necessary. The design details are still being developed but I judge that this approach complies with SAP EDR.3 (Appendix 1) and with RGP such as NS-TAST-GD-013 (ref. [25]).
5. The RP has submitted and analysis of background accidental aircraft crash frequency (ref. [47]), which I have reviewed (ref. [58]). The RP’s analysis uses the Byrne method (ref. [54]), with updates to the methodology and data, such as more recent aircraft crash data. It calculates a UK background accidental aircraft crash rate assuming that the generic location of the site is more than five miles from an aerodrome and not in the vicinity of a published air route or extended flightpath associated with an aerodrome.
6. The analysis aims to calculate a mean accidental aircraft crash rate onto the critical area of a Rolls-Royce SMR site that is conservative, but not excessively conservative, and the calculated result is a frequency of less than 1.2 x 10-6 per year. Additional site-specific work will be necessary when a site has been selected. The additional work will, as necessary, amend assumptions made in the calculation of this generic background accidental aircraft crash rate for the selected site.
7. My review (ref. [58]) of the RP’s submission (ref. [47]) noted that, when assessing the potential consequences of aircraft crashes, in addition to the five Byrne aircraft categories, the data and assumptions stated in appendix F of the submission to calculate the effective target area will be significant. I have communicated this to ONR’s civil engineering assessor (ref. [59]).
8. My review concluded that the objective of selecting accident rates that are conservative, but not excessively conservative, has been adequately demonstrated for each of the five Byrne aircraft categories. Hence the overall background accidental aircraft crash frequency is also conservative, but not excessively conservative.
9. In summary, I judge that the RP’s submission (ref. [47]) is a comprehensive report, which achieves its objective in accordance with RGP, e.g. NS-TAST-GD-013 (ref. [25]), and complies with all of the relevant SAPs (Appendix 1) including: SC.4, SC.5, EDR.3, EHA.1, EHA.2, EHA.3, EHA.4, EHA.6, EHA.8, EHA.19, FA.2 and FA.5. The RP has identified additional site-specific work that will be necessary when a site has been selected, but for the purpose of the GDA, the analysis of background accidental aircraft crash frequency (ref. [47]) is adequate, suitably comprehensive and complete.
10. There is one caveat to the previous paragraph, which was raised by ONR’s civil engineering assessor, as follows. There are a few Beluga XLs in service (ref. [59]), which has a 60m wingspan, but is not included in category E or F in section 13.7.2 in the RP’s submission (ref. [47]). Currently the only category F planes in the report are the Airbus A380 and the Boeing 747-8. Given the low accidental crash rates for large aircraft I judge that this omission is unlikely to significantly affect the estimated background accidental aircraft crash frequency. However, this omission should be reconsidered for site-specific analysis of accidental aircraft crash frequency and for analysing aircraft crash consequences in Step 3. I will consider the consequences of aircraft crash further in Step 3 in collaboration with ONR’s civil engineering assessor, including the aforementioned omission of Beluga XLs.
    * 1. The analysis of heat loadings from high EAT and heatwaves
11. High EAT and heatwaves have the potential to contribute to overheating and CCF of SSCs, including electrical and C&I systems. HVAC systems to control temperature will be part of the RP’s design, but high EAT and heatwaves also have the potential to cause HVAC failures and the DB for safety related HVAC systems needs to allow for high EAT and heatwaves. The compact layout of the Rolls-Royce SMR, with a relatively high density of heat generating plant, also has the potential to exacerbate heat loadings within the facility.
12. Annex 2 of NS-TAST-GD-013 (ref. [25]) addresses high EAT and heatwaves. For meteorological hazards such as these, ONR expects dutyholders and RPs to take into account the reasonably foreseeable effects of climate change over the facility’s lifetime (ONR SAPs paragraph 259). NS-TAST-GD-013 references UKCP18 (ref. [45]) as RGP and UKCP18 uses RCPs to develop climate change projections (see paragraphs ‎43 - ‎44). ONR does not prescribe the RCP values to be used to define a DB event. However, ONR expects that the RCP values selected are adequately conservative in line with the ONR SAPs and that additional sensitivity studies are carried out. EHA.11 in the ONR SAPs states that facilities should be shown to withstand weather conditions that meet DB event criteria. Weather conditions beyond the DB that have the potential to lead to a severe accident should also be analysed.
13. Significant uncertainties exist in estimating the effects of climate change and to allow for this it is acceptable, and sometimes necessary, to use the managed adaptive approach and the RP may use this where appropriate (see paragraph ‎44). Allowing sufficient space for additional HVAC systems that may be required as a managed adaptive response is not necessarily straightforward and I will consider this as the design develops in collaboration with other relevant ONR assessors, such as the mechanical engineering assessor. However, this topic also depends on the claims that are made on HVAC in the E3S case. The mitigation of high EAT and heatwaves may rely on other measures, so a holistic approach incorporating all relevant factors is needed and this may require some complex analysis, e.g. of heat flows within the facility buildings. I have not identified any fundamental shortfalls in the RP’s approach to high EAT and heatwaves from an external hazards perspective. In this respect, I have considered the RP’s use of RGP for hazard identification, screening and characterisation, with due allowance for climate change. I have also examined the RP’s intention to mitigate this hazard in the design including adequate safety margins. However the design is currently immature in this respect and there are potentially several viable options from which a solution that reduces risks to ALARP needs to be selected. This falls within the remit of other ONR disciplines and I will engage further on this with stakeholders in Step 3.
14. Air temperature, including heatwaves, is addressed in section 4.6 of the GSE (ref. [18]). The GSE selects a bounding maximum dry bulb air temperature of 42˚C by reviewing the sources (where available) listed below for Hinkley Point, Sizewell, Bradwell, Wylfa and Oldbury:

* Eurocode, hourly at 10-4 Annual Frequency of Exceedance (AFoE).
* EU post-Fukushima stress tests.
* Previous GDA submissions at 10-4 AFoE.

1. South eastern England is generally the hottest part of the UK. Sizewell and Bradwell are both located in this region, so data for those sites are likely to be suitably conservative. I judge that the results derived from the above review are likely to be bounding for UK EN-6 sites.
2. To allow for climate change, the GSE also uses RCP6.0 emissions scenario for a 90% probability level corresponding to a value of +7˚C to the year 2100. This value is bounding of RCP8.5 at the 50th percentile and is therefore considered to be conservative by the RP.
3. The resulting value for maximum hourly air temperature for a 10-4 AFoE including climate change to 2100 is thus 42˚C + 7˚C = 49.0˚C. I judge that this is an adequately conservative estimate, especially if it is combined with the managed adaptive approach for safety critical SSCs. However, as explained in paragraph ‎59, further analysis is required in the E3S case to support DB values derived in this way. Alternatively the RP may be able to claim that the design provides substantial margins, or diverse / segregated / passive SSCs to mitigate high EAT. In principle there is more than one way to address this hazard. Once a Licensee and site has been selected, the RP will work with the Licensee to understand the scope of services. This might involve the RP carrying out the relevant site-specific studies to determine site specific external hazard parameters, to define the site challenge for the reasonably foreseeable future, i.e. within the limits of UKCP18, see the response to RQ-01043 (ref. [19]). Also, combined internal / external hazards submissions are planned in Step 3 (ref. [14]), which should address this topic.
4. As well as estimating peak temperatures, it is necessary to analyse prolonged periods of high temperature, i.e. heatwaves. At present the GB GSE design basis allows for three consecutive days with a maximum hourly temperature of 49˚C (corresponding to a wet bulb temperature of 32.3˚C). The RP considers this to be conservative and that the maximum temperature is very unlikely to reach this peak for 3 consecutive days. Heatwave temperatures will be explored further during GDA. EUR guidance on heatwaves (ref. [35]) states that the plant should be able to manage a temperature of 41˚C for 7 consecutive days. The GSE (ref. [18]) states that design will bound this requirement.
5. In summary:

* The RP’s analysis of climate change in the GSE (ref. [18]) utilises RGP, i.e. UKCP18 (ref. [45]), and a managed adaptive approach is being considered as necessary. This is valid in principle, but space constraints may pose challenges for the managed adaptive approach in practice.
* The results derived for high EAT and heatwaves in the GSE are likely to be adequately conservative for developing the design but, as explained in paragraph ‎59, further analysis is required in the E3S case to support the derivation of the DB values.
* As for other external hazards, most of the SAPs listed in Appendix 1 are relevant to this topic. To demonstrate compliance with the SAPs complex analysis of heat loadings in the plant may be necessary but several possible approaches exist for addressing high EAT and heatwaves in the design. Further work on this topic will be considered when a site is selected and in Step 3. Completing this work may challenge the RP’s GDA programme and it also imposes limits on the GDA scope (see paragraphs ‎59 and ‎61, 3rd bullet point).
  + 1. The analysis of seismic hazards

1. SAP EHA.9 (Appendix 1) states that the seismology and geology of the area around the site and the geology and hydrogeology of the site should be evaluated to derive a DB earthquake. Hence, by its nature, this is site-specific. Seismic hazards are addressed in sections 4.16, 4.17, 5.5, 7.2, Appendix A and Appendix B of the GSE (ref. [18]), which correctly states that the seismic hazard is site-specific and should be confirmed at the site-specific stage.
2. However the GSE also provides parameters that are intended to bound UK seismicity. Appendix B in the GSE proposes DB earthquake spectra for horizontal and vertical accelerations based on EUR spectra (ref. [35]) enhanced for the vertical spectrum at certain frequencies and (ref. [60]). The EUR spectra are referred to as RGP in Annex 1 of NS-TAST-GD-013 (ref. [25]).
3. Similar to the approach for high EAT (paragraph ‎103), the GSE selects a bounding PGA by reviewing the sources listed below for four EN-6 sites, namely, Hinkley Point, Sizewell, Bradwell and Wylfa:

* EU post-Fukushima stress tests at 10-4 AFoE.
* Previous GDA submissions at 10-4 AFoE.

1. The bounding PGA of 0.3 g is from the Bradwell GDA submission and this also bounds the EUR reference DB earthquake of 0.25 g. GSE section 4.17 states that the currently assumed shear wave velocity range is between 400-1700 m/s. This is applicable to soft, medium and hard rock sites and Appendix B in the GSE presents 0.3 g spectra for soft, medium and hard rock sites.
2. However, the RP notes that the recommended shear wave velocity for very hard rock sites is 3,000 m/s (ref. [44]), well above the 1700 m/s limit in Appendix B. Further, the TSC review the GSE (ref. [36]) (see paragraph ‎26 above), highlights design response spectra for very hard rock sites where the peak of the spectra extends to frequencies up to 35 Hz, considerably higher than the comparable frequency of 15 Hz for EUR’s hard spectrum. Moreover ground investigation results for Wylfa may reclassify the site from hard to very hard. Hence, additional consideration will be required if Wylfa, or any very hard rock site, is chosen for deployment of the Rolls-Royce SMR design.
3. My RQ-01045 (ref. [19]) noted that, like other external hazards, seismic events can cause LOOP and CCF. The RP’s response stated that diversity and segregation of power supplies including the ability to bring in mobile plant if appropriate should give confidence against CCF. I intend to liaise with other ONR specialist assessors during Step 3 to ensure that this is adequately addressed in the detailed design.
4. The Rolls-Royce SMR design includes a basemat supported by aseismic bearings, see (ref. [41]) and paragraph ‎31, 2nd bullet point, which are intended to mitigate the effects of seismic events on the plant. However the aseismic bearings also introduce some complications, including:

* Detailed analysis of the plant motions in a seismic event will be more complex with the inclusion of the aseismic bearings.
* For items supported on the bearings, seismic accelerations will be reduced but the associated relative displacements will increase, with an increased potential for impacts between adjacent structures, potentially exacerbated by the compact layout.
* Some SSCs, such as pipes and electric cables, are likely to be located partially on the basemat and partially off it, which is likely to cause some additional stresses in those SSCs during a seismic event.

1. In RQ-01046 (ref. [19]) I clarified with the RP that the above bullet points will be addressed within future E3S submissions. I will follow these up in Step 3. The above complications should not be insurmountable, but they may challenge the RP’s GDA programme.
2. ONR’s civil engineering assessor raised RQ-01195 (ref. [19]), which asked about assumptions (e.g., platform height) related to tsunami when setting the site envelope. The RP’s response stated, “…none of the known UK sites are deemed subject to tsunami hazards.” I noted that the combined external hazards report (ref. [17]) screens in a number of combinations involving tsunamis. In 1607 severe flooding occurred around the river Severn. This was probably a storm surge event, although the consequences were quite similar to a tsunami and it had a severe impact on nearby people and agricultural land. So events similar to a tsunami are possible in GB. Added to that is the “Storegga Slide” (possibly caused by an undersea earthquake and landslide), which occurred off the coast of Norway about 8,000 years ago and caused a tsunami that affected the coasts of eastern Scotland and NE England (ref. [61]).
3. Hence, the RP’s response to this RQ was inconsistent based on its own combined external hazards report (ref. [17]). This highlights the importance of effective information exchange between disciplines by the RP. I have highlighted this general point about consistency across the E3S case to the RP on several occasions, e.g. (ref. [20]), and I will continue to monitor it during Step 3. Some aspects of the tsunami hazard will be site-specific, but I will seek assurance in Step 3 that the RP has addressed this adequately in its generic design.
4. In summary:

* The RP’s generic analysis of seismic hazards is conservative and complies with RGP, e.g. paragraph ‎110.
* Although the aseismic bearings are intended to mitigate against the effects of the seismic hazard, they also introduce a number of complications that may challenge the RP’s GDA programme, see paragraphs ‎115 - ‎116 above.
* As for other external hazards, most of the SAPs listed in Appendix 1 are relevant to this topic and further demonstration of compliance with these SAPs will be required in Step 3, e.g. SAP FA.6 is relevant for the preceding bullet point.
* A specific shortfall was identified in the RP’s information exchange between disciplines, see paragraphs ‎117 - ‎118 above, and I will continue to monitor this during Step 3.
* Additional consideration will be required if Wylfa, or any very hard rock site, is chosen for deployment of the Rolls-Royce SMR design, see paragraph ‎113.
  + 1. The RP’s arrangements for information exchange

1. The RP’s arrangements for information exchange have been mentioned previously, e.g. paragraph ‎119, 4th bullet point. However, I have included this as a separate short section because I judge that it is a challenging topic for the RP and it is important for complying with ONR SAP SC.2. Due to the facility wide nature of external hazards, with the potential to cause multiple CCF, it is important that PIEs arising from external hazards are adequately communicated to all relevant stakeholders. In particular, the design needs to be specified and qualified against external hazard loads which will bound the DB events of GB sites.
2. Similarly, combined external hazards and combined external – internal hazards (see section ‎4.2.3) can generate complex fault sequences that affect multiple disciplines and require effective communication between them.
3. A further area that requires effective communication is the “site-specific” external hazard screening applied by the RP and those aspects of external hazards analysis that are deemed to be outside the GDA scope need to be clearly stated in the relevant submissions. The GSE (ref. [18]) provides such information, although some amendment to, and clarification of, the scope may be required as the GDA progresses, e.g. see paragraphs ‎56 - ‎58.
4. The RP has given me a high level outline of how the flow of hazard requirements is being developed, (ref. [20]), see paragraph ‎46, 3rd bullet point, and stated that this process will be available for scrutiny during Step 3. Also note paragraph ‎11, 1st bullet point. The process appears to be adequate in principle but I intend to sample its application in Step 3, especially for the CAE summarised in Table 1 below. NS-TAST-GD-051 (ref. [28]) and SAPs SC.4 and FA.6 (Appendix 1) are applicable to this process.
5. For Step 2, I have sampled relevant Tier 1 E3S Chapters, (refs [1], [2], [3], [4] and [5]), and I can confirm that they are consistent with the Tier 2 and 3 submissions, (refs [18], [16], [43], [17], [15], [47]), that I have assessed.

**Table 1: Mapping of Claims to E3S Chapter Sections** (refs [2] and [42])

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| --- | --- | --- |
| Sub-Claim Level 1 | Sub-Claim Level 2 or 3  [I have added explanation in square parentheses. Other text is quoted from the RP’s documentation.] | Section of E3S case containing Arguments / Evidence summary |
| The Great Britain generic site envelope is bounding for suitable locations  (E3S case chapter 2) | All credible external hazards are identified and screened in a systematic manner using RGP. | 2.2.1, 2.2.2 |
| Combined external hazards are identified and screened in a systematic manner using RGP. | 2.2.19 |
| Design Basis (DB) external hazard values are determined using codes and RGP. [Note that “DB external hazard values” are equivalent to “DB events” (see SAP EHA.3) in this context.] | 2.2.5 – 2.2.18, 2.3 |
| The generic site envelope considers climate change for the expected life of the Rolls-Royce SMR. | 2.2.3 |
| Design is tolerant to all External Hazards (including Combined Hazards) | BDB and cliff edge margins are adequate and ensure robustness of hazards protection. [The sub-claims in this row are stated in E3S case chapter 15, but the arguments and evidence may be presented in other chapters, e.g. chapter 8 for electrical SSCs.] | Various |
| Design is tolerant to all Internal Hazards (including Combined Hazards) | [The sub-claim in this row is stated in E3S case chapter 15, but the arguments and evidence may be presented in other chapters. Note: there is currently no sub-claim that explicitly mentions combined external-internal hazards but they are mentioned once in the commentary column of the E3S case route map (ref. [42]) and a Tier 3 submission on this topic is planned in GDA Step 3 (ref. [14]).] | Various |

* + 1. ALARP

1. ONR SAPs paragraphs 14 – 15 state, “The starting point for demonstrating that risks are ALARP and safety is adequate is that the normal requirements of good practice in engineering, operation and safety management are met. This is a fundamental expectation for safety cases… The development of standards defining relevant good practice often includes ALARP considerations, so in many cases meeting these standards will be sufficient to demonstrate that legal requirements have been satisfied.” Also see NS-TAST-GD-005 (ref. [27]).
2. The RP’s external hazards submissions during GDA Step 2 (see section ‎3.4) refer to RGP (see section ‎2.1 and paragraphs ‎35 and ‎37) as the basis for its approach. The RP has applied RGP in specific instances that I have sampled, see e.g. paragraphs ‎51, ‎88, ‎93 and ‎108. However, I have identified a specific shortfall against RGP in paragraphs ‎62 - ‎64, although it should be straightforward to rectify this.
3. The RP’s approach to design includes incorporating resilience against external hazards as outlined in paragraph ‎46. The designs being developed for the seismic isolation system, the hazard shield and the HVAC systems are of particular significance for external hazards. I judge that the RP’s approach complies with NS-TAST-GD-005 (ref. [27]) and the ALARP principle.
4. While significant work remains to be done in Step 3, I am satisfied that the RP’s overall approach complies with RGP and is consistent with delivering an E3S case which demonstrates that the external hazards risks associated with the Rolls-Royce SMR are ALARP.

# Conclusions

* 1. Conclusions

1. This report presents the Step 2 external hazards assessment for the GDA of the Rolls-Royce SMR design. The focus of my assessment in this Step was towards the fundamental adequacy of the design and safety case. I have assessed the Tier 1 E3S chapters and relevant supporting documentation (see section ‎3.4) provided by Rolls-Royce SMR Limited to form my judgements. I targeted my assessment, in accordance with my assessment plan (ref. [11]), at the content of most relevance to external hazards against the expectations of ONR’s SAPs, TAGs and other guidance which ONR regards as relevant good practice. My assessment of the RP’s Step 2 external hazards submissions did not find any discrepancies between the design as recorded in the GDA Design Reference Report (ref. [50]) and those submissions, e.g., see paragraph ‎53. I have sampled Tier 1 E3S Chapters, (refs [1], [2], [3], [4] and [5]), and I can confirm that they are consistent with the Tier 2 and 3 submissions, (refs [18], [16], [43], [17], [15], [47]), that I have assessed (see paragraph ‎124).
2. Based upon my assessment, I have concluded the following:

* The technical quality of the RP’s submissions that I have sampled has been to a suitable standard, e.g. (ref. [58]), subject to some specific shortfalls that I identified, e.g. paragraph ‎70, 1st bullet point. The RP has also been responsive and constructive in addressing my comments througout Step 2, e.g. (ref. [20]).
* The RP’s approach to external hazards analysis is based on RGP, which has been adequately applied in the sample that I have assessed (paragraph ‎126), although paragraphs ‎62 - ‎64 identify an exception to this.
* I have identified a number of challenges that the RP will need to address during Step 3, including:
  + Further analysis is required in the E3S case to support the DB values identified in the GSE, paragraph ‎61, 3rd bullet point.
  + The substantiation of claims made on the hazard shield, e.g. paragraph ‎85.
  + The potential inclusion of the Beluga XL in category E or F in section 13.7.2 in the RP’s analysis of accidental aircraft crash frequency (ref. [47]), at least in any site-specific analysis. This should also be considered in Step 3 when analysing the consequences of aircraft crash. See paragraph ‎99.
  + The analysis of high EAT and heatwaves, paragraph ‎108, including possible application of the managed adaptive approach to HVAC, paragraph ‎102.
  + The analysis of seismic hazards, including effects related to the aseismic bearings, paragraph ‎119.
  + The analysis of external hazard – internal hazard combinations, with adequate inclusion of BDB events, paragraphs ‎78 and ‎79.
  + The RP’s arrangements for information exchange, section ‎4.2.8.

1. Overall, based on my assessment to date, and subject to the provision and assessment of suitable and sufficient supporting evidence, I have not identified any fundamental safety shortfalls that could prevent ONR permissioning the construction of a power station based on the generic Rolls-Royce SMR design with respect to the analysis of external hazards.
   1. Recommendations
2. My recommendation is as follows:

* Recommendation 1: ONR should consider the outcomes from my assessment as part of the decision to progress to Step 3 of GDA for the generic Rolls-Royce SMR design.

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# Appendix 1 – Relevant SAPs considered during the assessment

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| --- | --- |
| SAP No. | SAP Title |
| SC.2 | Safety case process outputs |
| SC.4 | Safety case characteristics |
| SC.5 | Optimism, uncertainty and conservatism |
| EAD.2 | Lifetime margins |
| EAD.3 | Periodic measurement of material properties |
| EAD.4 | Periodic measurement of parameters |
| EDR.3 | Common cause failure |
| EHA.1 | Identification and characterisation |
| EHA.2 | Data sources |
| EHA.3 | Design basis events |
| EHA.4 | Frequency of initiating event |
| EHA.5 | Design basis event operating states |
| EHA.6 | Analysis |
| EHA.7 | ‘Cliff-edge’ effects |
| EHA.8 | Aircraft crash |
| EHA.9 | Earthquakes |
| EHA.10 | Electromagnetic interference |
| EHA.11 | Weather conditions |
| EHA.18 | BDB events |
| EHA.19 | Screening |
| FA.2 | Identification of initiating faults |
| FA.5 | Initiating faults |
| FA.6 | Fault sequences |