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

ONR Assessment Report

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

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

**Authored by**: [Redacted]

**Report Issue No**: 1

**Document ID**: ONRW-2126615823-3464

**Publication Date**: Jun-24

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# Executive Summary

This report presents the outcomes of my internal 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 internal 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:

* Adequacy of the RP’s arrangements to enable robust hazard identification and analysis.
* Adequacy of the RP’s claims, arguments, and evidence to demonstrate risks from internal hazards are ALARP.
* Adequacy of the design layout such that it is optimised to eliminate and/or mitigate hazard consequences.
* Any novel features that impact the internal hazards safety case.

Based upon my assessment I have concluded the following:

* Rolls-Royce SMR Limited, the Requesting Party (RP) has in place suitable methodologies to enable assessment of hazards to be undertaken. The adequacy and justification of the application of its methodologies remains to be demonstrated at Step 3.
* The RP has demonstrated that it is developing the design layout taking cognisance of internal hazards and the risks they present.
* The RP has in place a robust set of requirements to inform the siting and location of its hazard sources and hazard targets. If implemented adequately as the design layout develops, it is my opinion this should result in a design that is aligned to UK expectations this is to be demonstrated by the RP at Step 3.
* The RP’s E3S Chapters are consistent with its Tier 2 and 3 submissions. However, the RPs the current hazard analysis has not been based upon a complete and representative data set as the design layout is yet to mature. Notwithstanding this, I have been satisfied that the RP’s hazard analysis has highlighted key hazard sources and is informing the development of the design.
* I am satisfied that through Step 2 the RP has demonstrated it has taken steps to improve the design layout to be more resilient to hazards, when compared to the layout at the start of Step 2. Nevertheless, my assessment identified several areas where the management of hazard sources and their segregation has not yet been demonstrated. These areas include the interspace, main control room, fuelling block and containment. Additional work is required by the RP to demonstrate hazard tolerance and that the risk from internal hazards is ALARP. This is highly reliant on the design layout maturity that needs to be progressed at Step 3.
* The design layout at Step 2 continues to develop. As a result, the internal hazards E3S case does not yet provide a clear set of claims arguments and evidence that are sufficiently aligned to its hazard analysis as well as defining its safety measures. Notwithstanding this, I have been satisfied that the RP has in place adequate requirements to inform the design from a hazard perspective. I have seen adequate evidence that the RP is implementing these requirements as its design develops.

As highlighted above, a number of matters remain outstanding to be progressed at the GDA Step 3 detailed design assessment. Based on the evidence assessed to date through my sampling, at this point in Step 2, I am satisfied that the RP has made good progress in the identification of hazards, and potential bounding scenarios, but significant work remains to ensure the E3S internal hazards aspects are reflective of the reference design.

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

ALARP As low as is reasonably practicable

BDV Standby Generator

BLEVE Boiling Liquid Expanding Vapor Explosion

BSL Basic Safety level (in SAPs)

BSO Basic Safety Objective (in SAPs)

CAE Claims Arguments and Evidence

CFAST Consolidated Fire and Smoke Transport

CHS Conventional Health and Safety

CKoP Civil Kit of Parts

CLP Cask Loading Pit

CNS Civil Nuclear Security (ONR)

CoFT Control of Fuel Temperature

CV Containment Vessel

DAC Design Acceptance Certificate

DiD Defence in depth

DPS Diverse Protection System

DRP Design Reference Point

DR Design Review

DSA Deterministic Safety Assessment

EC&I Electrical, Controls and Instrumentation

ECC Emergency Core Cooling

ECCS Emergency Core Cooling System

EH External Hazards

EMI Electromagnetic Interference

ESWS Essential Service Water System

E3S Environment, Safety, Security and Safeguards

FDS Fire Dynamics Simulator

FDT Fire Dynamics Tools

FLACS Flame Acceleration Simulator

FMEA Failure Mode and Effect Analysis

FMECA Failure Mode Effects and Criticality Analysis

FoAK First of a Kind

FTC Fuel Transfer Channel

GDA Generic Design Assessment

HAZOP Hazard and Operability Studies

HEAF High Energy Arcing Fault

HEPF High energy pipe failure

HOW2 ONR’s Management System internal online portal

HSE Health and Safety Executive

HV High Voltage

HVAC Heating, Ventilation and Air conditioning

IAEA International Atomic Energy Agency

ICF Intact Circuit Faults

IEF Initiating Event Frequency

IH Internal Hazards

KBE Coolant Purification System

LAB Auxiliary Feed water lines

LBA Main steam system

LC Licence Condition

LDCS Lower Dome Concrete Structure

LFS Life Fire Safety

LOCA Loss of Coolant Accidents

LPIS Low Pressure Injection System

LUHS Local Ultimate Heatsink System

MCR Main Control Room

MFL Main Feedlines

MKoP Modularisation Kit of Parts

MOC Main Overhead Crane

MSL Main Steam Lines

MSIV Main Steam Isolation Valves

MWe Megawatt electric

MWth Megawatt thermal

NRW Natural Resources Wales

ONR Office for Nuclear Regulation

OPEX Operational Experience

PAMS Post accident management system

PCER Pre-construction Environnent Report

PCSR Pre-construction Safety Report

PDHR Passive Decay Heat Removal

PIE Postulated Initiating Events

PRZ Pressuriser

PSA Probabilistic Safety Assessment

PVB Pressure vessel burst

PWR Pressurised Water Reactor

RC Reinforced Concrete

RCP Reactor Coolant Pumps

RD Reference Design

RGP Relevant Good Practice

RI Reactor Island

RP Requesting Party

RPS Reactor Protection System

RPV Reactor Pressure Vessel

SAP Safety Assessment Principle(s)

SCC Steel-Concrete Composite

SCR Supplementary Control Room

SFAIRP So far as is reasonably practicable

SFP Spent Fuel Pool

SG Steam Generator

SMR Small Modular Reactor

SSC Structure, System and Component

TAG Technical Assessment Guide(s) (ONR)

TSC Technical Support Contractor

UP Upender Pit

VCE Vapour Cloud Explosion

VHR Very High Reliability

VTA Vehicle Transport Accidents

WENRA Western European Nuclear Regulators’ Association

Contents

[Executive Summary 3](#_Toc171584632)

[List of Abbreviations 5](#_Toc171584633)

[1. Introduction 9](#_Toc171584634)

[2. Assessment standards and interfaces 10](#_Toc171584635)

[3. Requesting party’s submission 14](#_Toc171584636)

[4. ONR assessment 23](#_Toc171584637)

[5. Conclusions 62](#_Toc171584638)

[References 64](#_Toc171584639)

[Appendix 1 – Relevant SAPs considered during the assessment 71](#_Toc171584640)

# Introduction

1. This report presents the outcomes of my internal 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]) 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. [2]). The ONR Safety Assessment Principles (SAPs) (ref. [3]), together with supporting Technical Assessment Guides (TAGs) (ref. [4]), have been used as the basis for this assessment.
3. This is a Major report (refer to NS-TAST-GD-108 (ref. [5])).

## Background

1. The ONR’s GDA process (ref. [6]) calls for a stepwise 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.
2. 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 associated with initiation of the project and preparation for technical assessment in later steps, was successfully completed in 12 months.
3. 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, safeguards 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.
4. Prior to the start of Step 2 I prepared a detailed Assessment Plan for internal hazards (ref. [7]). This has formed the basis of my assessment and was also shared with the RP to maximise openness and transparency.
5. 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. [8]).

## Scope

1. The assessment documented in this report is based upon the E3S case for the Rolls-Royce SMR as summarised in the E3S case chapters and supporting documentation.
2. The overall scope of the Rolls-Royce SMR GDA is described in its GDA scoping document (ref. [9]). Rolls-Royce SMR Limited has indicated that it intends to complete a three step GDA, with the objective of receiving a DAC from ONR and have aligned their GDA scope with this objective. The GDA scope defines the generic plant and layout and includes all systems, structures and components that are identified as being important to safety, security and safeguards, all modes of operation, and all stages of the plant lifecycle.
3. However, given the stepwise assessment during GDA, information has not been submitted for all aspects within the GDA Scope during Step 2. The following aspects of the E3S case are therefore out of scope of this assessment:

* Only mode 1 (power operation) is considered in scope for Step 2. I am satisfied that considering only mode 1 is adequate to provide the necessary fundamental design information required for a Step 2 hazards analysis as this relates to full power operation.
* All hazards that can impact class 3 and non-classified structures, systems, and components (SSCs) are excluded from the scope of my Step 2 assessment as this has not been addressed by the RP during Step 2. I am satisfied that focusing on the class 1 and class 2 systems within Step 2 is sufficient to provide a fundamental overview of the major hazards that could impact nuclear safety. This is because both class 1 and class 2 SSCs provide the principal means of fulfilling category A and B safety functions in line with ONR expectations for DBA analysis. (ref. [10]).

# 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 its 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.

## Standards

1. The ONR SAPs (ref. [3]) 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.
2. The International Atomic Energy Agency (IAEA) safety standards (ref. [11]) and nuclear security series (ref. [12]) 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.
3. Furthermore, ONR is a member of the Western European Nuclear Regulators Association (WENRA). WENRA has developed Reference Levels (ref. [13]), which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors (ref. [14]).
4. The relevant SAPs, IAEA standards and WENRA reference levels are embodied and expanded on in the TAGs (ref. [4]). The TAGs provide the principal means for assessing the internal hazards aspects in practice.

### Safety Assessment Principles (SAPs)

1. The key SAPs applied within my assessment are SC.4, EKP.3, ELO.4, ECS.2, EHA.1, EHA.2, EHA.3, EHA.6 and EHA.19. I consider these SAPs provide adequate coverage of the fundamental aspects of a hazard safety case including defence in depth, layout characteristics and internal hazard expectations.
2. A list of the SAPs used in this assessment is recorded in Appendix 1.

### Technical Assessment Guides (TAGs)

1. The following TAGs have been used as part of this assessment:

* NS-TAST-GD-096 - Guidance on Mechanics of Assessment (ref. [2]).
* NS-TAST-GD-014 – Internal hazards (ref. [15]).
* NS-TAST-GD-051 – The purpose, scope, and content of safety cases (ref. [16]).
* NS-TAST-GD-006 – Design basis analysis (ref. [17]).
* NS-TAST-GD-005 – Guidance on the demonstration of ALARP (As Low As Reasonably Practicable) (ref. [18]).

### 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 Analysis Report for Nuclear Power Plants, Specific Safety Guide No. SSG-61 (ref. [19]).
* IAEA, Safety of Nuclear Power Plants: Design, SSR-2/1 (ref. [20]).
* IAEA, Applicability of design safety requirements to small modular reactor technologies intended for near term deployment, IAEA-TECDOC-1936 (ref. [21]).
* IAEA, Protection against internal hazards in the design of nuclear power plants, SSG-64 (ref. [22]).
* IAEA, Protection against internal and external hazards in the operation of nuclear power plants, SSG-77 (ref. [23]).
* WENRA, Safety reference levels for existing reactors 2020 (ref. [13]).
* WENRA, Report: Applicability of the Safety Objectives to SMRs (ref. [24]).

1. The IAEA and WENRA documents have been considered together and define international safety case expectations regarding safety case structure and content, as well as providing specific internal hazards guidance. Guidance is also referenced that contextualises the application of international guidance for SMR assessment.

## Integration with other assessment topic

1. I worked closely with other topics as part of my internal 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 ONR’s assessment.
2. The key interactions with other topic areas were:

* Civil engineering – Design of barriers, associated codes and standards and the civil modular structures identified by the RP to provide segregation and protection against hazard loads.
* Mechanical engineering – Interfaces with Heating, Ventilation and Air conditioning (HVAC) requirements and dropped loads and lifting analysis.
* Nuclear site health and safety – Interface of hazard impact to Conventional, Health and Safety (CHS) aspects within modular structures and lifting aspects.
* Life fire safety – Substantiation of fire withstand claims of modular structures.

## Use of technical support contractors

1. During Step 2 I have not engaged Technical Support Contractors (TSCs) to support my assessment of the internal hazard aspects of the Rolls-Royce SMR.

# Requesting party’s submission

1. Rolls-Royce SMR Limited submitted a series of E3S chapters, summary reports, and other supporting references, which outline its E3S case for the generic Rolls-Royce SMR design. This section presents a summary of the RP’s E3S safety case for internal hazards. It also identifies the documents submitted by the RP which have formed the basis of my internal hazards assessment of the Rolls-Royce SMR.

## Summary of the Rolls-Royce SMR design

1. 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.
2. 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 the requesting party’s modular approach to construction which would see much of the power station built in factory conditions and assembled on site.
3. The reactor itself is of a typical PWR design, including a steel Reactor Pressure Vessel (RPV) holding fuel assemblies, Steam Generators (SG), Reactor Coolant Pumps (RCP) and piping, all held within a steel containment vessel. The reactor is equipped with several 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.
4. There are several novel aspects of this reactor design that I have considered relevant to my internal hazards assessment. These are:

* The compact layout as it can pose challenges to the internal hazards case.
* Deployment of internal supporting modular structures for safety systems and components.
* Deployment of a “kit of parts” to provide common engineered safety measure solutions (such as barriers) within the modular and civil structure.
* Implementation of aseismic bearings to absorb seismic energy.

## 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.

****

**Figure 1: Claim, Argument and Evidence (CAE) structure within the E3S hierarchy** (ref. [25])

1. The structure of the E3S case largely aligns with the IAEA guidance for safety cases, SSG-61 (ref. [19]), supplemented to include UK specific expectations and expanded to include the other E3S purposes.

## Summary of the requesting party’s E3S case for internal hazards

1. The principal E3S section for internal hazards is detailed within the safety analysis chapter 15 (ref. [1]). The chapter outlines the RP’s claims, arguments and evidence underpinning its reactor design from a safety analysis perspective. The fundamental claim for this chapter is:

“Claim 15: Safety analysis informs the design and demonstrates there is suitable and sufficient defence in depth to deliver the fundamental safety functions, and that nuclear safety risks to workers and the public are reduced ALARP.”

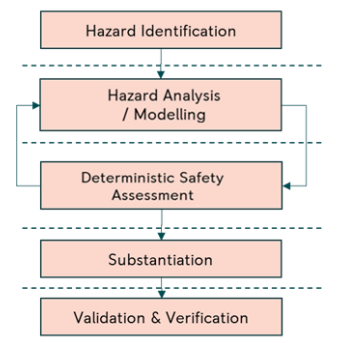
1. The underpinning internal hazard sub-claims supporting the top-level chapter 15 claim (detailed above) are presented within the RP’s safety case route map (ref. [26]). The route map states the following sub claims:

* Sub Claim level 1 – Design is tolerant to all internal hazards (including combined hazards).
  + Sub claim level 2 - The approach to ensure tolerance to internal hazards is based on RGP and OPEX.
  + Sub claim level 2 - The individual internal hazards and hazard combinations that can potentially cause initiating faults and thus affect nuclear safety are sufficiently identified.
  + Sub claim level 2 - The safety measures to mitigate the consequences of internal hazards are sufficiently identified and classified accordingly.
  + Sub claim level 2 - The layout is optimised to eliminate or minimise the risks of internal hazards (including combined hazards).
  + Sub claim level 2 - The modularisation approach is optimised to eliminate or minimise the risks of internal hazards (including combined hazards).
  + Sub claim level 2 - Analysis demonstrates that Reactor Island Within Hazard Shield is tolerant to Internal Hazards (including Combined Hazards).
  + Sub claim level 2 - Analysis demonstrates that Reactor Island outside Hazard Shield is tolerant to Internal Hazards (including Combined Hazards).
  + Sub claim level 2 - Internal Hazards Safety Measures are substantiated to achieve their Safety Categorised Functional Requirements.

1. Based on these safety case sub-claims the Rolls-Royce SMR safety case for internal hazards can be broadly grouped under the following headings which are summarised in turn below.

### Hazard methodologies

1. Chapter 15 of the E3S case (ref. [1]) states that the suitability and sufficiency of safety measures for internal hazards is considered both through deterministic safety assessment (DSA) and by meeting relevant good practice (RGP), that is defined within its internal hazard strategy (ref. [27]) and methodology reports (ref. [28]).
2. The RP’s internal hazards strategy (ref. [27]) sets out the approach to deliver these claims, including providing the scope of hazards considered individually and their combinations (ref. [29]). The hazards and their combinations are considered by the RP include fire, explosion, flooding, pressure part failure, missiles, blast, electromagnetic interference (EMI), dropped loads, hazardous materials, and vehicle transport accidents (VTA).
3. For each internal hazard, the RP’s hazards methodology (ref. [28]) provides a summary of the nature of the internal hazard, an overview of the analysis methodology, benchmarking against RGP and a summary of the analysis methods, inputs, assumptions and limitations to determine the magnitude of the hazard loads.
4. E3S chapter 15 (ref. [1]) states that the internal hazard assessment will determine the postulated initiating events (PIE) that occur due to hazards, and whether these hazards can damage claimed safety measures specific to that PIE. Each hazard sequence stated by the RP will be analysed to define the consequences (and may refer to initiating event frequencies (IEFs) defined in the DSA) all outputs are collated within the E3S hazard schedule (ref. [30]). The RP’s internal hazards strategy (ref. [27]) provides an overview of the RP’s hazards approach as shown in figure 2 below.



**Figure 2: Summary of the internal hazards approach** (ref. [27])

### Hazard identification

1. The internal hazards methodology (ref. [28]), outlines the RP’s approach to hazard identification. The RP states that the identification and characterisation of internal hazards will consider the initial conditions, the magnitude and likelihood of the hazards, the locations of the sources of the hazards, the resulting environmental conditions, and the possible impacts on SSC important to safety or on other SSCs.
2. The RP states that the basis of its hazard identification will be through area datasheets which are automatically updated using its requirements management database, currently IBM DOORs, (ref. [28]). The RP states the format of the area datasheets (ref. [31]) is such that all the required parameters are provided for every equipment item, making it possible to search the datasheets for the purpose of hazard identification.

### Hazard analysis

1. The RP’s internal hazards methodology (ref. [28]) states that its hazard analysis considers the unmitigated effects of hazards, i.e., not including hazard protection. The RP states that its hazard analysis determines the damage to SSCs that form the safety measures and whether those SSCs remain functional under the hazard conditions. The RP states that its focus for its internal hazard assessment is to determine whether multiple trains of a safety system can be failed by the hazard. It may also consider direct failure of containment of radiological material, and failure of Very High Reliability (VHR) components.

### Safety measures

1. For each internal hazard considered in the design, the RP states that safety measures should be implemented to control and to limit any nuclear safety consequences. The RP also states that suitability and sufficiency of safety measures for internal hazards is considered both through DSA and by meeting RGP as defined in its methodology for undertaking DSA (ref. [32]) and internal hazard strategy (ref. [27]). The RP states that defence in depth (DiD) is applied through provision of levels of safety measures (inherent features, equipment, and procedures) aimed at preventing faults in the first instance and ensuring appropriate protection or mitigation of accidents if prevention fails.
2. The RP states (ref. [27]) that its primary aim is to eliminate internal hazards from the design or to reduce the risks of hazards that cannot be eliminated. Where hazards cannot be eliminated, the RP states that safety measures are to be implemented. The RP states that the design of the safety measures will ensure that their functionality is based on the following design characteristics, with the most desirable being at the top of the list; Passive measures that do not rely on control, active or human intervention; Automatically initiated active engineered measures; Manually actuated active engineered measures; administration controls; and Mitigation measures (e.g. filtration or scrubbing).

### Optimisation of layout and modularisation

1. The approach to the optimisation of plant layout and implementation of modularisation is presented within the RP’s layout summary report (ref. [33]), modularisation strategy (ref. [34]), internal hazards strategy report (ref. [27]) and process cluster report (ref. [35]).
2. The RP states that protection against internal hazards is a key layout driver. The RP states that the relative positions of the internal blocks have been informed by internal hazards analysis (ref. [27, 36, 37]) and hazard design requirements (ref. [38]), which are largely derived from the use of spatial separation and civil concrete structures to protect SSCs against internal hazards. The RP states the following key layout features (ref. [33]):

* Four trains of Electrical, Controls and Instrumentation (EC&I) ranged around three sides of the outside of the Interspace. The trains are separated spatially and are in separate civil enclosures.
* Two trains of Safety Fluid Systems separated spatially and are on opposite sides of the Fuelling Block. This also facilitates segregation of pipe routing into Containment.
* Three trains of Low-Pressure Injection System (LPIS) accumulators separated spatially in three corners of the Interspace and enclosed in the civil corner buttress structures.
* Three trains of Local Ultimate Heatsink System (LUHS) tanks and Passive Steam Condensing System heat exchangers separated spatially in three corners of the Interspace and enclosed in the civil corner buttress structures.
* Spatially separated in-Containment routing and Containment penetrations for the steam and feed lines serving the three Steam Generators (SG).

1. In addition to the physical separation layout aspects the RP has adopted the use of steel modules to provide benefits in the construction of the plant (ref. [34]) called process clusters. These process clusters will be housed within a designated civil Block envelope, such as the fluids block, which are claimed as the principal hazard barriers. These civil Block envelope barriers are designated class 1 safety measures with the requirements to withstand multiple hazard loads (ref. [36]). Within the blocks themselves two types of internal barriers are proposed by the RP to protect against hazards.
2. The first type of internal barriers are inter-module barriers integrated within the cluster fames as part of the RP’s Modularisation kit of parts (MKoP). The RP’s intent is for these barriers to present generic hazard solutions for a range of hazards as per design requirements as defined in the MKoP design definition document (ref. [39]). The second barrier type are civil barriers required to provide a segregating wall between process clusters (ref. [35]).

### Substantiation of safety measures

1. The RP’s approach to design verification for internal hazards is outlined in the design verification report (ref. [40]). The report states that the design verification against hazards will be by demonstration of SSC withstands against IH loads and by justifying that the related hazard requirements are satisfied. Where applicable, the RP states it will undertake analysis of the SSCs withstand using proven codes and software. However, in cases where analytical means are not sufficient or constitute RGP, the RP state that it may conduct a physical test.

### Demonstration the risks are ALARP

1. The RP’s E3S chapter 24 (ref. [41]), summarises its claims and arguments that its design will reduce risks ALARP. The fundamental claim for the chapter is:

“Claim 24: The RR SMR design permits construction, commissioning, operation, maintenance and decommissioning with risks and exposures reduced to ALARP.”

1. Under this top-level claim are the following sub level claims relevant to internal hazards:

* The Rolls-Royce SMR design is developed to reduce risks to ALARP through the operational life.
* Safety analysis has informed the Rolls-Royce SMR design to reduce risks to ALARP.
* Internal Hazards assessment has informed the Rolls-Royce SMR design to reduce risks to ALARP.

1. To deliver these claims, chapter 24 (ref. [41]) provides the design principles to deliver the fundamental design requirements to reduce the risks from internal hazards. These principles can be summarised as follows:

* All the redundancies of the safety class 1 Control & Instrumentation (C&I) that support the Emergency Core Cooling System (ECCS) will be protected to ensure that no design basis internal hazard can defeat more than one of the safety class 1 C&I redundancies.
* Redundancy of the class 1 C&I systems will be in a separate fire zone, supported by its own independent class 1 support services.
* The safety class 1 C&I cables are separated between redundancies and shall be protected against design basis internal hazards.
* Hazard protection requirements toensure the Passive Decay Heat Removal (PDHR) is tolerant to internal and external hazards.
* Potential increase in magnitude from internal hazards (i.e. missiles from larger pressurised vessels) that require additional mitigation measures, such as, barriers and installation features will be identified.
* Internal hazards assessmentsconsider single random failures, as the internal hazards safety case should be tolerant to the potential for a single random failure.
* High integrity components need to be protected and different divisions or trains of safety systems need to be segregated; this will be achieved using hard boundaries, spatial separation, or a combination of the two, including segregated routing of pipework and cabling.

1. In support of these claims, the RP’s ALARP summary report (ref. [42]), provides a summary of how the Rolls-Royce SMR has achieved and incorporated these ALARP principles within its Reference Design Seven (RD7) layout achieved in November 2023.
2. The RP states (ref. [42]), that the internal hazards analysis has provided confidence that the key claims for internal hazards are justified and that the plant is tolerant to internal hazards through provision of hazard prevention and protection, including optimisation of the plant layout and segregation (as described in sub section 3.3.5 above).
3. The ALARP report also highlights that the RP has captured future actions within its Internal Hazards Summary Reports (ref. [36, 37]) and the Internal Combined Hazards Methodology and Identification Report (ref. [29]). These relate to the need to perform analysis in the future and to conduct analysis on the RD7 layout, which has changed significantly compared to previous design iterations (RD6).

## Basis of assessment: requesting party’s documentation

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

* Rolls-Royce SMR Limited, E3S Chapter 15: Safety Analysis (ref. [1]).
* Internal Hazards Strategy (ref. [27]) - Outlines the approach to the identification of hazards and the assessment of their consequences.
* Internal Hazards Methodology (ref. [28]) - Outlines the analysis methods, codes, and standards that are to be applied for single hazard analysis.
* Internal Hazards Summary Report - Reactor Island Within Hazard Shield (ref. [36]) - Outlines the claims arguments and associated evidence of the hazards identified within the reactor island hazard shield (containment, interspace, safety system blocks, spent fuel pond). This includes definition of events based on the relevant datasheets and other relevant information.
* Combined Hazards Methodology and Identification (ref. [29]) - Outlines the methodologies, approach to the identification and screening of hazard combinations including external hazard initiators and their analysis to define relevant hazard loads.
* Hazards Schedule (ref. [30]) - Outlines the key hazards following the hazard identification and assessment process, including combined hazards, as well as the turbine island and balance of plant areas.
* Internal Hazards Summary Report - Outside Hazard Shield (ref. [37]) Outlines the hazards effecting the nuclear safety systems that support the reactor island and the hazard shield.
* Architectural & Layout Summary Report (ref. [33]) - Outlines the fundamental aspects of the Rolls-Royce SMR Limited design and how its general layout meets its E3S case requirements.
* Containment & Interspace Layout Report (ref. [43]) - Outlines the fundamental aspects of the containment and interspace design and how its layout meets the relevant E3S case requirements.
* Safety Fluid Systems Layout Report (ref. [44]) - Outlines the fundamental aspects of the fluid systems design and how its layout meets the relevant E3S case requirements.
* Safety EC&I Systems Layout Report (ref. [45]) - Outlines the fundamental aspects of the EC&I system design and how its layout meets the relevant E3S case requirements.
* Fuelling systems outside containment layout report (ref. [46]) – Outlines the fundamental aspects of the Fuelling Systems outside Containment (Fuelling Block) located within the Reactor Island (RI).

# ONR assessment

## Assessment strategy

1. The objective of my GDA Step 2 assessment is to reach an independent regulatory judgement on the fundamental aspects of the Rolls-Royce SMR design and safety case, relevant to internal hazards as described in sections 1 and 3 of this report.
2. To inform my judgment, consistent with my Step 2 assessment plan (ref. [7]) I considered the following:

* If the RP’s arrangements are adequate to facilitate a design that is robust to internal hazards.
* If the internal hazard methodologies are adequate to enable a systematic and robust internal hazard analysis in line with relevant good practice.
* If the provided RP documentation (via the safety case) adequately details its safety analysis, and, the RP’s safety demonstration is adequately articulated through its claims, arguments and evidence.
* If the RP has provided adequate demonstration that its analysis is based upon a robust data set.
* If the RP has provided adequate demonstration that its design layout is robust to internal hazards, including any specific novel features of the design.
* If there are any areas of regulatory concern to be taken forward in Step 3, and if there are any significant issues that may prevent ONR from issuing a DAC.

1. As described in section 2 of this report, I have considered both UK regulatory and international relevant good practice to inform my assessment and judgements.
2. Due to the wide scope of internal hazards, I adopted a sampling strategy informed by the RP’s safety case documentation. My sample areas had been informed by the RP’s Step 2 safety case submissions and my understanding of the design following my Step 1 engagement.
3. It should be noted that the assessment of the adequacy of the RP’s IBM DOORs requirement management tool is excluded from my assessment. This is a key aspect of the RP’s management of requirements, claims and source data to underpin its analysis and design. This tool will be assessed at the ONR project level and therefore I am satisfied that this aspect can be excluded from my assessment.

## Design Maturity

1. At the time of drafting this report the RP’s design reference point for Step 2 GDA has been defined within its GDA Design Reference Point report (DRP1) (ref. [47]). The design reference report presents the baseline design for GDA Step 2, outlining the physical system descriptions and requirements that form the design at that point in time. The layout recorded in the design reference report is the RP’s reference design 7 (RD7). However, the RP’s hazards analysis was undertaken against an earlier design layout configuration, reference design 6 (RD6) where the layout was fundamentally different.
2. It should also be noted that both RD6 and RD7 design layouts remain at concept definition (DR1) maturity (ref. [47]). DR1 is described by a series of criteria by the RP, which include but are not limited to the following RP’s statements (ref. [48]):

* Preliminary analysis and underpinning assessment are suitable to confirm the viability of the solution, but further underpinning assessment is needed to confirm the final concept and reaching DR3 level of maturity.
* Installation and layout are considered preliminary and at a contextual level to confirm feasibility only.
* It should be noted that SSC maturity indicated as DR1 status is still subject to some volatility and subject to change in the details, but the overall architecture should be stable.

1. I am satisfied that the RP had taken active steps to articulate and implement assumptions to mitigate the uncertainty of the design and layout information, as detailed in responses to my regulatory queries (RQ-1031) and their strategy report (ref. [49], [27]). The RP acknowledged that its analysis is not currently aligned to the Step 2 DRP (ref. [47]) and stated the following:

* The layout and design reference used to undertake the initial internal hazards identification process is considered sufficient to determine the bounding hazard loads. This is because the “areas” where class 1 and class 2 systems are to be located are considered stable although the exact locations of the SSCs and areas are not finalised.
* Area datasheets will identify changes from the reference design used to the Step 2 reference design. A change control process will be in place following establishing the Step 2 reference design point.

1. Notwithstanding the above, the data the RP is using as the basis for the current hazard analysis is lagging the Step 2 reference design layout and thus the conclusions drawn by the RP will remain subject to uncertainty. I consider this is acceptable at this stage of GDA as this can be addressed as part of Step 3. I am satisfied that the RP has provided sufficient oversight of the RD7 layout to facilitate my hazard assessment of the fundamental aspects of the SMR design, and that its E3S Chapters are consistent with its Tier 2 and 3 submissions that I have assessed during Step 2.
2. I have considered the impact of the design maturity on my assessment of the RP’s methodologies, design requirements and their application and judged it to be minimal. This is because I judge that the RP’s methodologies and design principles to be independent of the design’s maturity.
3. Given the considerations above, and, noting that detailed evidence and the application of methodologies will be expected in Step 3. I am satisfied that my Step 2 assessment aim, i.e. to judge the adequacy of the fundamental aspects of the RP’s hazard safety case, remains viable for the areas I have sampled.

## Assessment

### Adequacy of the internal hazard safety case

1. This section details my assessment findings of the fundamental aspects of the RP’s internal hazards safety case.

#### IH safety case structure and claims

1. I have assessed the RP’s safety case structure in line with the following relevant good practice guidance, ONR-TAST-GD-051 (ref. [16]), ONR SAPs (ref. [3]), IAEA SSG-61 (ref. [19]), IAEA SSG-64 (ref. [22]) and WENRA safety reference levels (ref. [13]). My Step 2 assessment focus was to determine the adequacy of the fundamental aspects of the RP’s safety case. This included assessment of the RP’s safety case claims, arguments and, where relevant, evidence to demonstrate that the internal hazards that pose a nuclear safety risk have been eliminated, minimised, and mitigated.
2. I have assessed the RP’s E3S case including the principal internal hazards chapter, chapter 15 (ref. [1]) and its safety case route map (ref. [26]). I am satisfied that the RP’s high-level safety claims (as presented in section 3 of this report) are sufficient (if adequately satisfied) to demonstrate that the plant is tolerant to internal hazards (RP’s top level hazard claim). I consider that the intent of the RP’s high level safety claims are adequately aligned to the intent of hazard analysis expectations defined in RGP (ref. [19], [20]). I am also satisfied that the RP safety case (ref. [1]) sets out an adequate scope to identify relevant internal hazards, which I judge to be in line with both UK regulatory expectations (ref. [15]) and international expectations (ref. [19], [13]), thus satisfying ONR SAPs FP.4 and EHA.1.
3. To assess the adequacy of the RP’s safety case structure, I sampled the following two hazard claims defined within the RP’s safety case route map (ref. [26]) to determine the adequacy of the claim, arguments and evidence auditability:

* Claim 1 - The approach to ensure tolerance to internal hazards is based on RGP and OPEX.
* Claim 2 - Where there are exceptions to segregation, safety measures are identified to ensure that sufficient SSCs are available, during and after an internal hazard, to deliver the safety functions.

1. From my assessment I found that each of the claims within the route map are not uniquely referenced making traceability challenging across the case. The route map (ref. [26]) specifically references document titles rather than providing a specific argument narrative. For claim 1, the internal hazards strategy (ref. [27]) is cited and for claim 2 the hazards schedule (ref. [30]). I sampled both documents to determine if adequate arguments and evidence were presented to demonstrate that the claims are satisfied. In both instances I did not find adequate traceability of the claim nor visibility of the relevant underpinning evidence to demonstrate that the claim is met.
2. Furthermore, my assessment of the various other chapters of the E3S case (ref. [25], [50], [51], [52], [53], [54], [55], [1], [56], [57]) highlighted additional claims (transverse requirements) that were relevant to hazards but not fully linked to the hazards case. Thus the claims, argument and evidence “golden thread” was not complete. Whilst I accept that the safety case is still in development as the design matures, it is my opinion that the RP needs to fully capture all relevant hazard claims that will form its E3S case. This should include the cross-cutting transverse requirements to ensure a golden thread can be established.
3. Overall, I am satisfied that the RP has in place suitable sufficient high-level claims to define an adequate hazards safety case scope. However, I consider that the totality of the RP’s E3S requirements and how these incorporate transverse (cross cutting) requirements from other parts of the E3S case need to be linked to form an auditable structure of claims, arguments and evidence. I consider this is a shortfall against ONR SAP SC.4 which I will follow up in Step 3 as a residual matter. The definition of a residual matter can be found in the guidance for requesting parties (ref. [6]).

#### Deterministic safety analysis approach

1. I have assessed the RP’s deterministic assessment approach for internal hazards. It is my expectation, in line with ONR SAPs ECS.2 and EHA.3 and EHA.5, that the safety significance of SSCs should be based primarily on deterministic methods through design basis analysis.
2. The RP’s approach for deterministic analysis is detailed within its internal hazard strategy (ref. [27]) and internal hazard methodology (ref. [28]). The strategy stated that the RP would undertake full deterministic analysis for hazards within the design basis and for those that result in a postulated initiating event (PIE) the following safety principles would be met:

* “A minimum of two lines of protection remains available after the hazard for frequent hazards (>1E-3/yr.). This will comprise at least one line of Category A protection and one line of diverse Category B protection.”
* “A minimum of one line of Category A protection remains available for infrequent hazards (1E-3 – 1E-5/yr.)”.

1. In addition to these principles the RP has classified internal hazards as frequent or infrequent. The RP has designated fire and flooding as frequent hazards and all other internal hazards as infrequent. I queried this approach (RQ-1031) with the RP who stated that (ref. [49]) its assumptions for frequent and infrequent hazards would be confirmed within the internal hazard submissions. It also stated that the initiating event frequencies (IEFs) would be identified primarily using OPEX, which would also ensure that the list of PIEs is consistent with industry practice.
2. I am satisfied that the deterministic approach presented by the RP, including its intent to apply OPEX to underpin the frequencies, is in line with ONR’s expectations for design basis analysis as defined in ONR TAG-06 (ref. [17]) and international RGP (ref. [20]). Noting that the RP is yet to justify its hazard frequencies, it is my expectation that these frequencies are justified and appropriate protection measures are implemented, in line with ONR SAPs EHA.2, EHA.3, EHA.4 and FA.5 and international guidance (ref. [13]). I will consider the adequacy of the RP’s hazard frequency justification further in step 3 as a residual matter.

#### Adequacy of design principles

1. I have sampled the RP’s design requirements from an internal hazards perspective to gain confidence that the design, as it evolves, will adequately consider internal hazards. The RP’s internal hazards design requirements are captured within chapter 15 of the E3S case (ref. [1]) and through its transverse requirements report (ref. [38]).
2. Through my assessment of these submissions I have been satisfied that the requirements documented are aligned with RGP (ref. [15], [22] and [13]). The RP’s requirements highlight the need for segregation of safety trains, implementation of barriers, hazard reduction measures (such as reduction of combustible inventories), withstand demonstration and protection of high integrity components as well as the application of DiD. This provides me with sufficient confidence that as the design matures, the RP has in place sufficient requirements to inform its design choices that, in my view, should limit the severity of internal hazards. However, this needs to be demonstrated by the RP as the layout is established at Step 3 and I will follow it up as part of my Step 3 assessment.

### Adequacy of hazard methodologies

#### Hazard identification process

1. The RP’s hazard identification approach is detailed within its hazard identification strategy (ref. [58]). I have assessed the strategy to determine the adequacy of its approach. I have based my judgement on ONR and International RGP (ref. [22], [20]), with the expectation that a systematic identification of internal hazards and their combinations should be undertaken to determine their consequences and demonstrate that appropriate safety measures to eliminate/mitigate them have been identified.
2. The RP’s strategy (ref. [58]) recognises that its design is developing. I note that the RP had adopted different hazard identification processes dependent upon the maturity of the design. At the early design concept stages (commensurate with Step 2) the RP has applied “What If” and Hazard and Operability (HAZOP) studies, that I consider appropriate given the limited data and layout information. The RP stated it implemented guide words within its HAZOP process covering operational (including equipment, human factors, and handling), internal, external, environmental, security, safeguards, maintenance, commissioning, and decommissioning related hazards. As the design reaches a mature state and more detail is available, (at Step 3) the RP has identified three structured hazard identification techniques that will be utilised (HAZOP, Failure Mode and Effect Analysis (FMEA) and Failure Mode Effects and Criticality Analysis (FMECA)).
3. Following my assessment, I have been satisfied that the RP’s process for hazard identification is aligned to relevant good practice. I have also sampled across the hazard safety case, to assess evidence of the application of this process. I sampled Step 2 area data sheets (ref. [31]), hazard analysis (ref. [59]) and hazard summary reports (refs. [37] and [36]). Through my sampling I have seen sufficient evidence to provide me with confidence that the RP is adequately following their process which I consider is systematic and robust satisfying ONR SAP EHA.1.
4. At this stage, the outputs of the RP’s internal hazard analysis are not adequately aligned to the current layout design. I acknowledge that the RP has attempted to mitigate this through conservative assumptions. It is my view that in Step 3 the RP’s analysis needs to be reconciled with the design reference point layout, to have confidence that hazards are adequately identified, and assumptions and bounding hazard sources are well justified. I consider this is a shortfall against ONR SAPs AV.3, AV.7, EHA.2, EHA.19, as all data used to inform the hazard identification process and associated analysis should be representative of the GDA reference design. I will follow this aspect up in Step 3 as a residual matter.

#### Combined hazards methodology

1. The RP’s combined hazards methodology is presented within its combined hazards methodology and hazard identification report (ref. [29]). The report presents a 6-step approach to identify, screen, and analyse internal hazard combinations. As part of the screening criteria, the RP identifies several sources of guidance including IAEA-SSG 64 and ONR-TAG-014 (ref. [22, 15]). The RP establishes several high-level screening criteria that enables certain low frequency or low impact combination consequences to be screened out, which I consider is appropriate and is in line with ONR SAP EHA.19.
2. The RP’s methodology states that it considers three types of combined hazards: consequential, correlated, and unrelated (independent) hazards. I consider the RP’s approach is in line ONR SAPs EHA.1 and EHA.6, regarding identification and characterisation of internal hazards/hazard combinations and analysis of the consequential effects, and is in line with relevant good practice (ref. [15]). Three levels of hazard screening are applied by the RP to establish its hazard combinations. The RP describes this as generic screening based on rationalisation of consequences, area-specific based on systems within a block and layout-specific screening.
3. For consequential and correlated internal hazards, the RP applies further hazard identification and screening processes following the primary hazard event to determine whether a combined internal hazard is credible. For example, for a dropped load the RP would analyse the impacted area to determine if other SSCs such as a pressurised component could be impacted; if so, any hazards because of the SSC failure would be considered. It is my expectation that all assumptions used to screen in or out a hazard within an area needs adequate justification in line with ONR SAP EHA.19. At this stage, the RP has not yet undertaken its combined hazard analysis to demonstrate and justify its hazard combinations as well as the tolerance of the design against them. Notwithstanding this point, I judge the approach presented within the RP’s methodology adequate for the purposes of GDA.
4. My assessment identified that the RP does not consider a third consequential event (tertiary event), following an hazard initiator. This is because the RP had assumed the magnitude of the tertiary event is likely to be bounded by the single hazard assessment. I acknowledge that the RP’s hazard analysis for single hazards had considered bounding correlated hazards from the initial event that cannot be excluded, such as for high energy pipe failure (HEPF). However, I judge that the compact nature of the design could lead to a greater likelihood of domino effects within a given area. This could result in additional hazard loadings being generated. The exclusion of tertiary events, from its combined hazard analysis needs to be justified by the RP based on its reference design plant layout in Step 3 in line with ONR SAPs EHA.1 and EHA.2. I will follow this up during my assessment at Step 3 once the layout reaches sufficient maturity.
5. For independent hazards, the RP has applied a frequency screening approach that includes a recovery time. The approach assumes that the secondary hazard occurs after the first event, rather than “at the same time.” The RP stated that from application of its analysis only combinations of frequent hazards (i.e. flooding and fire) would fall within design basis, while all other independent combinations fall within beyond design basis analysis. The RP stated that this is out of scope for its Step 2 report.
6. Given the compact nature of the plant design, it is my expectation that the RP should consider and undertake sensitivity analysis (through PSA or otherwise) of the potential combined hazard consequential effects close to the cut off frequencies (10-7 per annum), specifically to demonstrate that the above assumption stands and that there are no cliff-edge effects which are not otherwise captured in the safety case to satisfy ONR SAPs EHA.1, EHA.7 and EHA.18. I note the RP has also recognised this aspect and have captured it as a forward action, which will be progressed at Step 3.
7. The RP’s methodology identifies that a key hazard combination is that initiated by an external hazard. Both ONR (ref. [15]) and IAEA (ref. [22]) guidance expects that combined internal and external hazard combinations are adequately identified and analysed. It is highlighted by the RP that at this stage the identification of external hazards (EH) and internal hazards combinations have not yet been undertaken, but is planned to be addressed at Step 3. I consider this a shortfall in its current Step 2 safety case against ONR SAPs EHA.1 and EHA.14, however, I acknowledge that the RP has captured this as a forward action which I will follow up in my assessment at Step 3 as a residual matter.
8. As acknowledged by the RP (ref. [29]), the combined hazards analysis has been undertaken using area data sheets with significant gaps. In addition, the analysis has been undertaken on the RD6 plant layout that is fundamentally different to the RD7 layout. Therefore, layout specific analysis has not yet been undertaken. While this is an ongoing project risk, I consider it acceptable at this stage of GDA as the RP has already noted the design and safety case gaps and committed to address them during Step 3. I will follow up the outputs of its updated analysis as a residual matter in Step 3. Overall, I am satisfied that the RP’s high-level approach to combined hazards analysis is adequate.

#### Hazard analysis methods

##### Fire

1. I assessed the RP’s internal fire methodology (ref. [28]). The methodology sets out to define methods for fire hazard identification/categorisation and fire hazard analysis.
2. The RP stated that its hazard identification consists of identifying fire hazards from its area datasheets and categorising them as Solid Combustible, Flammable Liquid or Flammable Gas (ref. [28]). This is in line with the expectations in the internal hazards TAG that the safety case should provide reference to surveys or studies of combustible substances, which should be systematic and demonstrably complete (ref. [15]).
3. The RP methodology (ref. [28]) stated that it intends to characterise fire effects separately for local and global hazards and then compare these effects with failure thresholds. Consideration of both global and local fire hazards meets my expectations as informed by the ONR internal hazards TAG (ref. [15]).
4. My assessment noted that no specific methodology was presented for the assessment of fire-generated effects, such as localised radiative effects on structures, or for assessment of VHR components against fire. In response to my queries (RQ-1096), the RP stated (ref. [49]) that its approach for assessing fire-generated effects in the context of its design involves establishing requirements for SSCs based on global fire effects via indicative loads calculated using the Consolidated Fire and Smoke Transport (CFAST) modelling tool and supplemented by local fire modelling where required. The RP also stated that fire challenges to VHR components would be addressed by locating fire sources away from them and using local protection/barriers where required in addition to inherent withstand claims (ref. [49]). I am content that these approaches should provide an adequate baseline for the RP to develop its design in Step 3.
5. In line with RGP (ref. [15]), it is my expectation that safety cases demonstrate that suitable fire consequence analysis methods and models have been applied to estimate the severity of fire hazards (SAPs EHA.1, EHA.5, EHA.6) and that the outputs from fire and ignition source identification have been taken forward for analysis. The RP’s methodology indicates that fire effects and severity will be completed as part of its analysis process (ref. [28]). In the methodology, the RP sets out its validation and verification sources for proposed modelling tools CFAST, Fire Dynamics Tools (FDT), Phast and Fire Dynamics Simulator (FDS) (ref. [28]), which are predominantly based on the NUREG-1824-S1 (ref. [60]) validation methodology. The non-dimensional validation ranges from table 7-1 of NUREG-1824-S1 are referred to by the RP and a method for adjusting the fire diameter to bring the Froude number into validation range is presented in line with NUREG-2178-V1 (refs. [60], [61]).
6. I am content that the validation and verification approach proposed by the RP is in line with the intent of the ONR SAPs AV series. The RP’s approach is underpinned by RGP (refs. [60], [61]) which includes US regulatory guidance specific to the proposed use of these analysis codes, and I judge to be of relevance for this design.
7. The RP presented a process for identification of its bounding cases for fire (ref. [28]). However, through my assessment I have identified several shortfalls with its presented methodology. It is my view that the RP does not make it clear how modelling variables necessary to represent the scenario are to be defined and characterised. I also note that the methodology does not make clear how potential bounding rooms are selected, how conservatism is ensured or what assumptions are made.
8. In response to my queries (RQ-1096) on this matter, the RP stated (ref. [49]) that its process will be made clearer in future revisions of the methodology. The RP provided additional information on the bounding case parameters and process (ref. [49]). Based on the additional information, I am content that the methodology presented, when considered with this extra detail, provides the basis for an adequate bounding case selection. The RP’s methodology also identifies a process for fire modelling tool selection and applicability assessment (ref. [28]). I consider the approach presented by the RP is aligned to RGP (ref. [15]) but I note that it does not yet present its approach to determine how the RP will assess fire effects and their associated consequences to SSCs (refs. [28]. [15]). I will follow this aspect up as a residual matter in Step 3, including assessment of the implementation of the RP’s improved methodology.
9. My assessment identified that the RP frequently references the US NRC NUREG documents, including NUREG-1934 (ref. [62]). Whilst I am content that this represents RGP for the proposed tools and methods, I note that some process stages from this document, especially relating to uncertainty and sensitivity analysis and comparison to goals/objectives are not fully included within the RP’s methodology. In the response to my queries on this exclusion, the RP stated (ref. [49]) that uncertainties are to be addressed by taking a conservative approach when input information is selected and making conservative modelling assumptions and that sensitivity analysis will inform this approach. I am satisfied that this proposed approach can meet my expectations as informed by ONR SAPs AV.6 and SC.5. Overall, I am satisfied that the RP’s approach should provide a sound basis for its Step 3 fire analysis, which I will follow up as part of my Step 3 assessment.

##### Explosion

1. I have assessed the methodology presented by the RP for its internal explosion analysis (ref. [28]). It is my expectation that the safety case systematically identifies all explosion sources in accordance with SAPs EHA.1 and EHA.16, alongside clear descriptions of inventories, flammability / explosivity properties, storage and operating conditions (pressure, temperature), locations etc in line with the internal hazards TAG (ref. [15]).
2. Through assessment I am satisfied that the RP’s methodology (ref. [28]) considers the common explosion scenarios that I would expect to see within such a plant. The sources identified included flammable gas explosions (explosions within buildings), High Energy Arcing Fault (HEAF), Vapour Cloud Explosion (VCE) (explosions external to buildings) and oil mist release. Aligned to my observation in the fire methodology section above, I note that the RP does not address SSC response, substantiation, or qualification (ref. [28]). I consider this a shortfall in the RP’s methodology against SAPs ESS.2 and ECS.3, and I will follow this up as a residual matter in Step 3.
3. For the analysis of flammable gas explosion it is my expectation that the RP’s analysis is based on unmitigated worst-case scenarios (for example, a stoichiometric concentration of the flammable substance is assumed, ventilation is unavailable to disperse the flammable mix and so on) (ref. [15]). It is my view that the RP’s methodology sets out an approach for assessment of flammable cloud size that is consistent with this expectation (ref. [28]). For example, for voids, the total affected void volume, assumed to be at stoichiometric concentration, and the stoichiometric equivalent volume of the flammable gas in the free jet are summated to determine the flammable cloud size (ref. [28]).
4. It is my expectation that chronic accumulation of gases / vapours / stable mists reaching flammable concentrations at the release point or elsewhere in or outside process are considered (ref. [15]). From my assessment of the RP’s methodology, I am satisfied it meets this expectation by specifically identifying both leak and accumulation scenarios for flammable gases (ref. [28]).
5. The RP’s HEAF method requires identification of voltage, fault current, arc time, arc energy and TNT equivalent weight, which are in line with my expectations (refs. [15], [28]). I am satisfied that the RP references adequate RGP including IEEE 1584 as well as its own methodologies (refs. [28], [63]). For vapour cloud explosion, the RP’s approach assuming full release of tank inventory is in line with my expectations as per the internal hazards TAG (ref. [15]).
6. The RP stated that oil mist hazards will be identified with a suitable screening approach including all pressure systems which contain oil and systems at atmospheric pressure which could contain oil above their flashpoint (ref. [28]). Methods for droplet size distribution and percentage of leak converted to mist are outlined based on RGP and recognised methods, such as that outlined in the recent HSE oil mists industry project (ref. [64]). Appropriate tools are identified by the RP to evaluate explosion overpressure such as Flame Acceleration Simulator (FLACS), but no detail is presented on how this tool will be applied. It is my judgement that the RP outlines an adequate method for assessing oil mists.
7. Overall, I am content that the RP has developed an adequate approach for the assessment of explosion hazards in line with UK expectations as informed by the SAPs and internal hazards TAG (ref. [15]). I will seek evidence demonstrating the suitable application of this methodology in Step 3.

##### Pressure part failure

1. I assessed the RP’s pressure part failure methodology (ref. [28]). The methodology presents multiple methods to address the specific consequential hazards following a pressure part boundary failure. The RP’s methodology is split into two different hazard categories, Pressure vessel burst (PVB) and High energy pipe failure (HEPF). I am satisfied that the RP has implemented appropriate thresholds for the classification of high energy pipes, based on temperature (above ≥ 95ºC), pressure (≥ 1.9MPa(g)) and gas held above atmospheric pressure and aligned to RGP (ref. [15]).
2. For PVB, various methods are presented by the RP to quantify the its hazard loadings from missiles, blast (This includes Boiling liquid, expanding vapour explosions (BLEVE) for high pressure systems operating ≥ 200ºC, as stated in response to my query RQ-1102, (ref. [49])), and steam release effects. I note that internal missiles are further categorised into single fragments / end cap and rocket missiles. HEPF hazard effects are grouped into hazards that result in global effects and those that generate localised effects. For global effects steam release and flooding are considered. For local effects missiles, blast, and pipe whip and jet impingement as well as the associated reaction forces are considered.
3. Following my assessment of the RP’s methods, and the RP’s responses to my queries (RQ-1102, ref. [49]), I am satisfied that the PVB and HEPF methodologies are adequate, for the purposes of GDA, to quantify the key hazards related to pressurised component failures as defined in both ONR and IAEA guidance (ref. [15], [22]). The RP’s analysis assumes that vessels catastrophically fail and assumes double ended guillotine failure of pipes. I have noted several gaps regarding blast analysis (such as confined reflection of blast waves) and analysis of medium energy pipes as the RP does not currently provide a methodology to address these. The RP has committed (ref. [49]) to include these aspects in its update of the methodology as part of Step 3, as it currently remains a gap within its methodology against ONR SAP EHA.14.
4. At this stage, I consider that RP’s hazards analysis methodology for pressure part failure needs to be updated, and its application and methodology justified for identified hazard analysis scenarios, (such as, vessel break up and justification of worst-case missile impact energies). This includes the need to justify the methods to be applied to substantiate claimed SSCs withstand (such as civil barriers) to individual and combined hazard loads, which have not yet been presented at this time. I will follow this up in Step 3 as a residual matter.

##### Missiles

1. I assessed the RP’s Internal Missile Hazard (Rotating Plant) methodology (ref. [28]) taking account of the RP’s responses to my queries (RQ-1101, ref. [49]). The methodology highlighted the need to identify all internal missile sources, including rotating equipment. I note that it is conservatively assumed by the RP’s methodology that missile fragments are not contained within its casing thus provides an unmitigated analysis. However, the application of the methods will need to be justified including the missile directions and physical description of the missiles themselves.
2. I also acknowledge that the RP had considered turbine missiles. Although out of scope of GDA, the disintegration of the main steam turbines are acknowledged by the RP as a major hazard and the RP has adopted the strategy/requirement to ensure that all buildings with class 1 and 2 SSCs sit outside the low trajectory missile cone. I consider that this is aligned with RGP (ref. [15], [22]) and is a fundamental design consideration. I also note that the RP acknowledges the need to consider high trajectory turbine missiles. This is an area to be progressed at Step 3 as the design layout and SSC locations (including rotational machinery) are yet to be finalised and I will seek further information in Step 3. In summary, following my assessment of the RP’s internal missile hazard methodology, I am content that the proposed approach is adequate and aligned to RGP (ref. [15], [22]).

##### Flooding

1. I assessed the RP’s flooding methodology (ref. [28]) and its responses to my queries (RQ-1100, ref. [49]). The RP clarified (ref. [49]) that its flooding analysis will be based upon unmitigated fluid release considering the full inventory of the flood source connected to the release point, such as a full tank volume or, full systems potential flooding inventory. The RP’s intent is to implement flooding zones consistent with segregation of trains. The RP has stated that its flooding modelling will assume that the floodwater remains within a designated flooding zone, considering drainage from the upper levels to lower levels. It is my view that the assumptions will need to be justified as the RP considers flood and other internal hazards during different operational modes and worst-case plant status, in line with ONR SAPs EKP.2 and EKP.3, to ensure adequate defence in depth is maintained.
2. I am satisfied that the fundamental aspects of the RP’s flooding methodology considering the flood source, duration including flow rate (Torricelli equation) and its determination of flood depth satisfies RGP (ref. [22, 15]). I note that the application of these methods will need to be justified including the volume taken up by equipment for each flooding scenario identified (case by case). I will seek further information in Step 3 as this is an area to be progressed as the design layout (including vessel and pipe routing) and SSC locations are yet to be finalised. Following my assessment of the RP’s flooding methodology I am satisfied that the approach proposed is adequate.

##### Dropped loads

1. I assessed the RP’s dropped load hazard methodology (ref. [28]) and response to my queries (RQ-1094, ref. [49]). The RP’s methodology stated dropped loads will include direct drops, swings loads and collapsed loads and its analysis will consider what structures could be impacted. The RP also stated that vibration effects will be assessed, albeit separately.
2. The RP’s methodology stated that following a dropped load it assumed the load will topple, increasing the potential impact area. I consider this to be a conservative basis for its analysis. However, other load parameters such as the treatment of the maximum drop height and the maximum loading of a lifting device are not defined by the RP and I consider this a gap in its current methodology. The details of how these parameters are to be established and utilised within the methodology will need to be provided at Step 3 to confirm a conservative basis for its analysis and I will follow this up in Step 3 as a residual matter.
3. I queried the identification process of the RP’s dropped load sources (ref. [49]) noting my expectation that all sources should be systematically identified i.e. not just limiting the hazard identification to lifting devices which directly lift SSCs. The RP stated (ref. [49]) that its initial hazard identification work would be reported within the reactor island mechanical handling design summary report (ref. [65]) drafted by the RP’s mechanical handling team.
4. I assessed the mechanical handling summary report (ref. [65]) and I noted that whilst its mechanical handling equipment is identified, it is primarily from the point of view of mechanical handling tasks to be completed e.g. RCP replacement, lifting of heavy plant equipment. I note that the document (ref. [65]) acknowledges the requirement to consider internal hazards, including the need to eliminate handling operations and minimising lift heights where possible. However, insufficient information is provided on the application of these specific considerations. I consider the limited information to be a shortfall. It is my expectation, in line with RGP (ref. [15]) that the RP justifies the routing of its lifting activities such that risk to SSCs from the hazards of dropped, toppled or collapsed loads is reduced to ALARP.
5. Overall, I am satisfied that the RP’s quantitative analysis approach described in its methodology report (ref. [28]) is adequate at this stage of GDA. It is important to note that the overall methodology relies on information and approaches developed by the RP’s mechanical engineering team and it is my expectation that these considerations are well integrated in the internal hazards case. It is my view that the RP has not yet adequately articulated the detail of its dropped loads hazard identification and assessment process including a complete set of assumptions and sources of information. I consider this is a shortfall against UK relevant good practice (ref. [15]) and I will follow this up in Step 3 as a residual matter.

##### Other hazards

1. I have assessed the RP’s hazard methodologies for vehicular transport accident, hazardous chemicals and electro-magnetic impulse (EMI) (ref. [28]). The RP’s methodology presents the approaches to identification and quantification of these specific hazards. I raised queries for each of these hazards (RQ-1098, RQ-1097 and RQ-1095, ref. [49]) to seek clarification on the RP’s scope to which its methods are to be applied. The RP responded to each my queries (ref. [49]) and I have assessed both the methodology and RP responses for each of hazard areas which are detailed below.
2. Following my assessment of the RP vehicular transport accident methodology and hazardous chemicals methods (ref. [28], [49]), I am satisfied that the information presented by the RP is adequate for the purposes of GDA to quantify the associated hazards. I note that the RP’s analysis (ref. [59], [66]) highlighted that the size of the bounding transport vehicles and the transport routes, as well as specific chemicals and the quantities held on site will not be confirmed until Step 3. I consider this is acceptable at this stage and will be an area to be progressed at Step 3 once more detailed information is available.
3. I have assessed the RP’s EMI methodologies (ref. [28], [49]). I am satisfied that the RP recognises that the most significant hazard presented by an EMI event would be as a result of its impact on the control and instrumentation systems, that could result in spurious operation. I queried (RQ-1095) the scope of the EMI sources to be considered by the RP as this was not well defined in its methodology. In response to my query (RQ-1095, ref. [49]) the RP stated that it intends to address the following sources of an EMI:

* Natural Sources
  + Lightning surge (note that lightning is categorised as one of the external EMI sources)
  + Electrostatic discharge (ESD), from a charged person or object
* Man-made sources
  + Intentional sources caused by
    - Portable communication devices
    - Mobile phones, Radio transceivers,
    - Portable electronic devices and computers, etc
    - Wireless Local Area Network (WLAN)
  + Unintentional sources
    - Electrical equipment e.g. Electric motors, Generators, Transformers, Power cables and Arc welding equipment, etc. Resulting in low frequency magnetic or electric fields or higher frequency electromagnetic fields.
    - Power system switching transients (under both normal and fault conditions) caused by Circuit breakers, Inverters, Thyristors, Relays, etc. Resulting in supply voltage interruptions, dips, surges and fluctuations and transient over-voltages on supply, signal and control lines.

1. It is my view that the RP has provided sufficient information on its EMI coverage that is consistent with relevant good practice (ref. [15]). This, in my opinion, should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence in this area. Given that EMI crosses multiple specialist areas, I will be seeking advice from ONR Electrical and C&I specialists during Step 3 to determine the extent to which the electrical equipment proposed by the RP could produce an EMI and the vulnerability of the C&I system to an EMI. I consider this a residual matter to follow up at Step 3.

### Layout Fundamental Characteristics (RD7)

1. This section provides my assessment of the fundamental aspects of the RP’s Step 2 reference design. In line with IAEA guidance (ref. [22, 21]) and WENRA safety reference levels (ref. [13, 24]), ONR expects a ‘defence-in-depth’ approach to be applied to internal hazards, as well as a demonstration that the layout is optimised to eliminate and/or mitigate the impact of hazard conditions on nuclear safety SSCs.

#### Barriers

1. I have sampled the RP’s approach to the implementation and substantiation of barriers. Barriers that segregate defined areas and nuclear safety trains are fundamental to the RP’s layout and design, as well as to satisfy its E3S claim that the design is tolerant to internal hazards (ref. [1]). The RP has identified two types of barrier: inter-module barriers that are integrated within the cluster fames as part its MKoP, and passive civil barriers as part of its civil kit of parts (CKoP) to provide a segregation between process clusters and block envelopes (ref. [35]).
2. Demonstration of barrier withstands against individual and combined hazards is a key requirement of the RP’s deterministic analysis to demonstrate that the plant has at least one safety train available for any design basis accident. The RP’s approach to barrier implementation and substantiation is detailed within its structural design methods statement (ref. [67]), design basis for reactor island structures (ref. [68]), design description document for reactor Island process clusters (ref. [35]) and modularisation kit of parts barrier design definition (ref. [39]).
3. I have assessed these documents and consulted with the ONR civil engineering lead on aspects of adequacy of the codes proposed. From my assessment I have been satisfied that from an internal hazards perspective the RP has recognised the need to analyse hazard loads and substantiate barriers against them. These requirements are captured as civil functional requirements detailed within the design basis for reactor island structures report (ref. [68]). The RP’s requirements state that the civil structure shall be designed against individual and combined hazards load cases. The RP’s structural design methods statement (ref. [67]) underpins these requirements with proposed methodologies, however, the exact methodology to be adopted for a specific barrier had not been finalised by the RP at this stage. The RP itself acknowledges this point and its method statement (ref. [67]) stated the methodologies for hazard substantiation of its barriers is still being developed and captured as a forward action (FAP-SDMS-ALL-004) to be addressed by the RP during Step 3.
4. The modularisation kit of parts barrier design definition report (ref. [39]) also considers the need to withstand internal hazards. I note that the strategy does not consider design against the following hazards: explosion, pipe whip, EMI, and blast from arc flash. The assumption made by the RP (ref. [39]) is that these hazards will be mitigated through design, by adopting an intrinsically safe design methodology and from the civil boundaries and separation. It is also assumed by the RP that internal barriers do not have to protect against pipe whip, as the RP stated the extent of whipping can be reduced or eliminated by appropriate restraint design, which should be substantiated against the forces exerted. The strategy also highlighted that more detailed zonal requirements for each area is required to be progressed for internal hazards (both individual and combined), to help mature the MKoP scope for barriers design.
5. I am satisfied that the fundamental principles for the implementation of barriers to provide segregation of nuclear safety trains are adequate. I am content that there are sufficient requirements in place to drive the future substantiation of nuclear safety barriers for both individual and combined hazards, noting that the methodologies for barrier substantiation are yet to be finalised.
6. Further work is required by the RP during Step 3 to define its safety measure claims, its barrier segregation claims (both for modular and civil structures) and justify the methods it intends to adopt to substantiate them. I also consider that a key aspect of this is for the RP to identify all its safety measures, including all its implicit claims. RP claims on restraints etc need to be understood by the RP as their fixing requirements (to a structure/wall) and space requirements will impact the current space constraints within the module structures and potentially result is challenges for layout optimisation. I consider that at this stage, the lack of layout information for the implementation of suitable restraints to protect its nuclear barriers from hazard loads is a potential shortfall. This will need to be addressed in Step 3 by the RP to demonstrate compliance against relevant good practice (ref. [15], [22]) which I will follow up in Step 3 as residual matter.

#### Safety fluid system block

1. I sampled the following aspects of the RP’s safety fluid systems layout (ref. [44]) as I consider these to be significant contributors to a fundamental assessment of the generic design at GDA Step 2.

* Divisional segregation of class 2 SSCs, as no claimed class 1 systems are currently identified in these blocks.
* Layout and hazard impacts on non-segregated safety systems.
* Location and treatment of significant hazard sources.

1. The safety fluid systems block consist of two divisions referred to as trains 1 & 2 which are located north and south of the fuelling block. Each train is housed within the Reactor Island (RI) Hazard Shield.
2. The safety fluid systems block report highlighted (ref. [44]) that in the RD7 design the EC&I safety systems block is no longer situated on top of the safety fluid systems block. This therefore means that the proposed ice stores for local cooling of the EC&I block will no longer present a flooding risk to the safety fluid systems trains. This move has also resulted in the safety classification of the safety fluid systems trains MKoP structure to class 2 from class 1. I also noted that the RD7 design has relocated the boron storage tank to the fuelling block. Pipework from the boron storage tank will still run into the safety fluid systems block, and hence will still represent a flooding risk, however, a complete tank rupture would not impact this block.
3. My assessment identified that the RD7 layout locates the two trains of the class 2 fluid systems in segregated blocks which are spatially separated (ref. [44]). These blocks are now located to either side of the fuelling block segregated by internal civil structures. The internal hazards summary report (ref. [36]), which is aligned to an earlier layout (RD6), placed a class 1 segregation requirement on the barriers separating these trains. This has moved from being a MKoP requirement to a concrete solution at RD7 which I see as a positive change, reducing barrier substantiation risk.
4. The Safety Fluid Systems Block includes the following class 2 and class 3 Systems:

* Fuel Pool Cooling System.
* Emergency Boron Injection System.
* Cold Shutdown Cooling System.
* High Pressure Injection System.
* Component Cooling System.
* Level and Volume Control System.
* Chemistry Control System.
* Auxiliary Sampling System.

1. These safety systems are present in both safety fluid blocks which are physically segregated and spatially separated blocks. I consider that this delivers a high level of segregation and eliminates the vulnerability which may have been present in the RD6 layout. With respect to the equipment and systems within the blocks, I am satisfied from the evidence assessed that the RP’s provision of separated and segregated blocks meets ONR expectations in SAP ELO.4 and RGP (ref. [41], [22] and [20]) and that limiting the consequences of hazards is ensured by good plant layout principles, and by protecting the plant from the hazard loadings through the provision of robust passive civil barriers.
2. However, I note that cross connections from both safety fluid blocks pass through the interspace block and at this stage of the design there is no detailed information as to how these connections will be segregated. I will seek further information in Step 3 (See interspace block section for more detail). In addition, there are also several cross connections between the two blocks located within the fuelling block that could also challenge the adequacy of some of the safety fluid blocks independence claims, this is detailed further in sub-section 4.3.3.4 of this report.
3. The RP assumes “that the divisional boundary of a system can be contained through the use of MKoP barriers”. However, the withstand of divisional barriers had not been assessed in the Step 2 internal hazard analysis report (ref. [59]) and it is my observations that no internal MKoP barriers currently have formal safety claims made against them (see sub section 4.3.3.1 of this report). I also note that the claimed EC&I MKoP barriers in the RD6 design are now stated to be concrete barriers in the latest RD7 design. It is my opinion that further development of this area is required and I will seek further information in Step 3. It is my expectation that the RP comprehensively identifies and documents its safety claims on barriers and undertakes sufficient substantiation to demonstrate that the claims are satisfied.
4. Overall, I am satisfied that the general Safety Fluids System Block layout information that has been submitted is consistent with UK relevant good practice (ref. [15]). This should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence. However, insufficient detail has been presented to form a judgement on the adequacy of the barrier solutions and segregation of the connections from the Safety fluid blocks as they pass through the Interspace block and fuelling block which I will follow up in Step 3 as a residual matter.

#### EC&I system block

1. I sampled the following aspects of the RP’s EC&I safety systems layout as I consider these to be the most significant contributors to a fundamental assessment of the generic design at GDA Step 2.

* Divisional segregation of class 1 and class 2 EC&I SSCs.
* Layout and hazard impacts on non-segregated safety cabling.
* Location and treatment of significant hazard sources within the EC&I blocks.
* Location of Main Control Room (MCR) and resulting internal hazard considerations.

1. My assessment identified that the RD7 layout locates trains of the class 1 Diverse Protection System (DPS) in spatially separated blocks (as described by the RP in the EC&I layout report (ref. [45])). These blocks are located within four separate segregated areas. The internal hazards summary report (ref. [36]), which is aligned to an earlier layout (RD6), placed a class 1 segregation requirement on the barriers separating these trains. This has again moved from being a MKoP to a concrete solution at RD7 which I see as a positive change reducing barrier substantiation risk.
2. The class 2 Reactor Protection System (RPS) and Post Accident Management System (PAMS) system panels are similarly distributed across these physically segregated and spatially separated blocks. The class 1 and 2 endurance cooling delivered by the low temperature chilled water system is presented by the RP as a series of divisional sub-systems, each located within the same divisional compartment as the system it is serving. The RP states (ref. [45]) that this delivers a high level of segregation and eliminates vulnerability to hazards that running ductwork out of the blocks would introduce. This arrangement also places the ice stores, identified by the RP as the dominant flooding hazard source, at the bottom of each segregated block. The RP claimed that this eliminates significant consequences from flooding due to the limited ice volume compared to the available flood volume (ref. [36]).
3. I am satisfied from the evidence assessed that the RP’s provision of separated and segregated divisional blocks meets ONR expectations in SAP ELO.4 and the IH TAG (ref. [15]) and that limiting the consequences of hazards is ensured by good plant layout principles, and by protecting the plant from the hazard loadings through the provision of robust passive barriers.
4. In the internal hazards summary report (ref. [36]), the RP identified RPS and DPS cross-connections between trains as ‘having a negative effect on segregation’ in the RD6 design. In the RD7 design the RP illustrates some DPS and RPS cable routing at a high level. This makes use of access corridors to run cables, with cables passing through divisions to which they do not belong. This remains to be demonstrated as the layout matures in Step 3.
5. The RP also assumes “that the divisional boundary of a system can be contained through the use of MKoP barriers”. However, substantiation of the withstand of divisional barriers has not yet been undertaken, as further development of the layout is required and thus is not part of the Step 2 internal hazard analysis report (ref. [59]). However, It is my observation that no internal MKoP barriers currently have formal safety claims made against them (see sub section 4.3.3.1 of this report). I also note that the claimed EC&I MKoP barriers at RD6, are now stated to be concrete barriers in the latest RD7 design, but this option remains to be confirmed in Step 3. It is my opinion that further development of this area is required by the RP to enable judgements on the adequacy of MKoP solutions to be made and I will consequently seek further information in Step 3.
6. The RP states that the MCR is housed within the fourth cluster of the EC&I block (ref. [45]). The MCR is not specifically considered in the Internal Hazards Summary report (ref. [36]). However, in the SMR Control Facilities Description (ref. [69]) the RP states that the MCR shall be both operable and habitable following the full range of internal hazards considered by the RP. This is consistent with RGP such as IAEA SSG-64 and BS EN IEC 60964 (refs. [22], [70]).
7. In the EC&I layout report, the RP describes how the MCR is separated from the main corridor and division 4 of the DPS by MKoP barriers (ref. [45]). There is no clear nuclear safety claim on these barriers at this stage, although this is implied by the requirement to protect the MCR from hazards. As above, I expect the RP to develop the treatment of barrier requirements and claims in Step 3.
8. The MCR is adjacent to the main steam line compartment above the class 3 cluster 5. This has the potential to pose a significant hazard to the MCR. This is yet to be considered in the RP’s internal hazards analysis. The MCR is on Level 2 which is the top of a six-module stack and therefore the supporting modules must meet hazard resilience requirements. I raised an joint query the ONR Civil Engineering inspector (RQ-1128, ref. [49]) on whether any claims would be made on the aseismic bearings performance to reduce impact of seismic induced internal hazards, which could impact the MCR (such as fire). It was clarified by the RP (ref. [49]) that the assessment of external hazards-internal hazards combinations and the claims placed on the bearings will be presented in the Combined Internal/External Hazards assessment report in Step 3.
9. The RP stated (ref. [49]) that whilst the provision of aseismic bearings protects against seismic load effects, it acknowledged it did not terminate the fault and therefore withstand of equipment against secondary response spectra is still required. The secondary response spectra still needs to be assessed by the RP as an initiating event for potential seismic induced internal hazards, which the RP stated will be progressed during GDA Step 3. I have liaised with the ONR civil engineering inspector regarding the position of the MCR and they confirmed that substantiation of the seismic withstand of the MCR is a focus for their Step 3 assessment.
10. At this stage it is my view that there is insufficient evidence for me to make a judgement on the adequacy of the MCR location. For Step 3 I expect the RP to demonstrate that the risks to the MCR from internal hazards are ALARP. I have discussed the habitability of the MCR in the event of fire with the ONR life fire safety assessor who confirmed that no justification for extended operator presence in the MCR post fire has been provided at Step 2.
11. Overall, I am satisfied that the general EC&I block layout information that has been submitted is consistent with UK relevant good practice and should enable the RP to further develop the generic Rolls-Royce SMR design and associated E3S case evidence. However, given the lack of maturity of the RP’s safety case, I am unable to form a judgement on the adequacy of the barrier solutions, cable routings and the MCR location. I will follow up these topics in Step 3 as a residual matter.

#### Fuelling block

1. I sampled the following aspects of the RP’s fuelling layout as I consider these to be the most significant in a fundamental assessment of the generic design at GDA Step 2.

* Divisional segregation of class 1 and class 2 SSCs.
* Layout and hazard impacts on non-segregated SSCs.
* Location and treatment of significant hazard sources within the fuel block area.
* Location of fuel pond.

1. The fuelling block is located on the west side of containment building between safety fluid systems blocks 1 and 2 and has a direct interface with the auxiliary block to enable new fuel to enter the fuelling block. The fuelling block layout report (ref. [46]) highlighted that the block houses several class 1 and 2 systems that support the blocks primary function to facilitate the receipt, handling and storage of new/spent fuel.
2. My assessment identified that the dominant structures within the fuelling block are the Spent Fuel Pool (SFP), Cask Loading Pit (CLP) and Upender Pit (UP). These are located centrally within the block with all other areas being located around them. From a general layout perspective, I am satisfied that the pools are adequately segregated from other safety blocks, via civil structures and physical separation (ref. [71]). The UP is also directly connected to the fuel transfer channel (FTC) that allows the transport of fuel to and from containment. The FTC outside the Containment Vessel is encased within an inspection chamber surrounded by 1.8m of concrete (ref. [46]), which provides shielding to minimise dose rates to operators as well as protection form hazard sources.
3. I have assessed the fuelling block layout aspects within the hazards summary report (ref. [36]) and the layout report (ref. [46]). The hazards assessment was based on the previous layout (RD6) which in my view has fundamentally changed. I do consider that the changes implemented by the RP have been positive from a hazards perspective. This includes the movement of the Local Ultimate Heat sink (LUHS) tanks out of the block as well as the coolant purification system removing pressure part failure and flooding sources from within the block, which I consider satisfies RGP (ref. [15], [22]) with respect to elimination of hazards through design.
4. Although some improvements have been made by the RP in the block design, my assessment has identified the following points:

* The RP’s segregation of electrical cables and cabinets serving mechanical handling systems and Boron storage tank (four class 1 cables) is yet to be finalised. Given that there is limited equipment, the RP needs to demonstrate that they are appropriately protected from hazards to prevent common cause failures in line with ONR SAP FA.6.
* Layout of the mechanical lifting devices remains at low maturity (ref. [46]). I note that there is a potential that the RPs proposed operating envelope for the mechanical handling devices could impact multiple nuclear safety systems (such as feed lines for the CLP, UP and Fuel Pool Cooling System (FAK) isolation valves) either from collision or dropped loads. I consider this a potential risk which the RP needs to address as part of its design development, including to identify and manage its risks related to its lifting activities in line with ONR SAPs EHA.1, EHA.14.
* The current layout has a region located behind the spent fuel pool and pits that contains various cross-connects (via floors 2 to 5). This provides a distribution route for cross-connects between the safety fluid systems trains between the eastern structure and the interspace hazard shield wall. This region serves connections between the Fuel Pool Cooling System , Emergency Boron Injection System, Cold Shutdown Cooling System and the Component Cooling System. I note that the RP highlighted (ref. [46]) that its segregation solution is dependent on the hazards present in the Fuelling Block. A complete assessment of these is to be progressed as the layout develops. This is also captured in the fluids layout report (ref. [44]) which highlights the current solution is a design risk. I consider that the current layout may have an fundamental impact on the RP’s independence claims of the fluid block, and is a potential shortfall against ONR SAP ELO.4 and FA.6 which needs to be progressed by the RP at Step 3.
* The design contains a single boron tank to provide the alternative shut down function (ASF) in fault or hazard conditions. The system is class 2, which under frequent faults is expected to be available. The RP highlighted (ref. [46]) that the boron tank is subject to further design review. The tank is also located in the cross-connection region, which adds further layout concerns, especially as the spent fuel overhead crane could present a dropped load hazard in this region. Further information is required to ascertain the adequacy of the boron tank location. I expect justification of how the boron tank is optimised to provide resilience against internal hazards and/or minimise its potential as a hazard source itself, in line with ONR SAP ELO.4. This needs to be progressed by the RP at Step 3.
* I note that the CLP Gate (designation FAB PT542) is to be a class 1 structure as it provides part of the boundary when the spent fuel pool and cask loading pits are fully flooded. Failure of this gate would lead to loss of the fluid containment, and it would fill the New Fuel Receipt and Inspection Area. This flooding scenario is discounted in the hazard's summary report (ref. [36]) as it stated by the RP that it is not considered feasible for both the CLP gate and the UP gate to be open at the same time. However, in the refuelling report it remains unclear if the failure of one gate could still result in a flood. It is my expectation that all associated internal hazards should be considered, as well as understanding the unmitigated consequences of failure, to ensure adequate safety measures are in place in line with RGP (ref. [15]).

1. In summary, I am satisfied that the general layout of the fuelling building is consistent with UK relevant good practice as the positioning of the fuel pool within the RI is segregated from other blocks. However, there remains uncertainty due to design decisions particularly on the physical layout of systems. I have identified several areas within the current layout which, as highlighted above, pose challenges to the RP’s fundamental claims on segregation including for the fluid safety systems block. I consider that at this stage the RP has not yet demonstrated that the layout is optimised for internal hazards. This is a potential shortfall against ONR SAPs ELO.4 and FA.6 which I will follow up in Step 3 as a residual matter.

#### Interspace block

1. I sampled the following aspects of the Rolls-Royce SMR interspace block. I consider these to be the most significant contributors to a fundamental assessment of the generic design at GDA Step 2.

* Divisional segregation of class 1 and class 2 SSCs.
* Layout and hazard impacts on non-segregated safety systems and cabling.
* Location and optimisation of significant hazard sources within the interspace block.

1. The interspace block is an area that surrounds the reactor containment vessel, and is described in the RP’s containment and interspace layout summary report (ref. [43]). My assessment identified that many of the systems required for the safe operation, shutdown, and control of the reactor such as the main steam system and both the main and auxiliary feed water lines pass through this area. The area also contains other systems and components important to safety including the Main steam isolation valves (MSIV), ECC pipework and PDHR pipework. The LUHS tanks are also located within the buttress spaces of this area, as well as key EC&I cables.
2. The layout report (ref. [43]) highlighted the RD7 changes within the interspace as compared to the RD6 layout, which the hazards analysis (ref. [36]) was based. These RD7 changes include:

* 90-degree rotation of containment, thus all access and services penetrations to the interspace have been repositioned.
* The Fuelling Systems block has been moved from south of Containment to the west thus pipe routing changed.
* Safety Fluids Systems block has been split into two blocks having a significant impact on the routing of safety systems pipework between the interspace and containment.
* Three local ultimate heat sink (LUHS) tanks are now located within the northwest, southwest and southeast buttresses of the Interspace.
* The EC&I clusters are distributed around the north, east and south of the Interspace, changing the cable routings from these areas via the Interspace to Containment for each electrical train.

1. Notwithstanding the changes above, key decisions on the layout of pipe work remain to be made (ref. [33]). These include main steam and feedwater pipe routes; central containment layout including pressuriser, steam generators, LUHS configuration and locations; routing of safety fluid systems, all of which I consider will have a significant impact on the layout within the interspace and its hazard profile. I acknowledge that the RP’s hazard analysis work (ref. [36, 59]) has identified bounding loads to inform the design. Given that further design developments are expected, it is my view that further justification is required by the RP to demonstrate that the bounding loads will remain bounding.
2. My assessment of the current interspace layout arrangement has identified that this area is very congested. The main volume of the interspace is taken up by the steel containment vessel. In general, congested areas present significant challenges to internal hazard management. Previous GDA projects (ref. [72]) have shown that measures such as barriers and seismic restraints, when required to mitigate risks from high energy components, need significant space to be installed. If this is not allocated at design conception it is challenging to retrofit solutions. It is my expectation that as the RP progresses the layout and design within this area, it should consider the space constraints, safety measure requirements and general congestion when optimising its layout for hazards. I will focus on these aspects, including the justification of safety train segregation in my Step 3 assessment.
3. In summary, I have assessed the fundamental layout aspects of the interspace block from an internal hazard perspective. It is my view that the RP needs to undertake further hazards analysis of this area based on the finalised layout of SSCs that will form the Step 3 design reference point. The RP’s analysis will need to ensure that its safety train segregation claims are robust taking account of the layout and hazard conditions (local and global). This should then enable the RP to demonstrate through appropriate deterministic methods that the risks from hazards in this region are ALARP.

#### Containment block

1. The containment block contains the most significant SSCs, including the reactor pressure vessel (RPV). I have sampled the following fundamental aspects that I consider most relevant for the containment block with respect to internal hazards:

* Segregation of very high reliability (VHR) components, class 1 and class 2 SSCs.
* Layout and hazard impacts on non-segregated safety systems.
* Location and optimisation of significant hazard sources.

1. The containment block boundary described in the containment layout report (ref. [43]) is defined by the containment vessel (CV) steel walls which houses all its SSCs. Located at the base of the CV is a reinforced concrete infill called the lower dome concrete structure (LDCS). The LDCS provides support for the RPV cavity, Main Containment Sumps, and base of the Refuelling Pool. The upper surface of the LDCS also provides the ground floor for Containment, at Site Level 02 (+5.6m). The CV houses the three-loop reactor coolant system comprising of; pressuriser (PRZ), steam generators (SGs), primary circuit piping and reactor coolant pump (RCP). In addition, it also houses the main steam lines (MSL), main feedlines (MFL) and other associated in-containment pipework and services supporting the containment area.
2. The RPV, primary circuit piping, SGs, PRZ, MSL and RCP are all currently identified by the RP as candidate VHR components (ref. [36]). On this basis I am content that their failure can be discounted from design basis analysis as the RP intent is to demonstrate that the reliability of the components is equal to or less than 10-7yr, and therefore will be subject to ONR Structural integrity assessment. However, it is my expectation in line with ONR SAPs EMC.1, EMC.2 and EMC.3 that these components are adequately protected from internal hazards so that the VHR components integrity claims are not challenged.
3. Located above the LDCS sit the three SGs and PRZ as well as associated pipes (MFL & MSL). The layout has two enclosures that segregate the two SGs from the remaining SG and PRZ. I note that the RP’s enclosure material is steel-concrete composite (SCC) blocks. The RP highlighted the primary purpose of the enclosure walls is to provide radiation shielding from the source terms associated with the RPV and primary circuit (ref. [43]). The RP stated (ref. [43]) it expects that enclosures could also provide a degree of physical protection to the SGs and PRZ from internal hazards outside of the enclosure. I note that the RP acknowledges that the detailed internal hazards analysis has not been undertaken as it requires the layout to mature, thus substantiation of the SCC blocks cannot yet be undertaken at this stage.
4. The RP also highlighted (ref. [43]) that while the SCC enclosures house the primary components and the Refuelling Pool and Cavity, the remaining structures in containment are proposed to be steel frames. These steel frame structures are to house the main safety and safety-related support systems, in addition to supporting the Main Overhead Crane (MOC) rails and housing main access ways. The RP’s layout report (ref. [43]) highlighted that it considered there were limited changes within the containment from the RD6 layout on which the RP’s hazard analysis was based. I have identified that some significant changes have been implemented by the RP as detailed in the interspace section of my report sub-section 4.3.3.5. I consider that these design changes can have a significant impact on the pipework layout within the containment and therefore its hazards profile, which I will follow up as part of my Step 3 hazards assessment.
5. I have assessed the RP’s hazard analysis (ref. [36]) related to containment. The RP’s analysis identified multiple internal hazards including combined hazards (ref. [29]) within the CV such as; fire, pipe whip and blast (from pressure part failures), missiles and dropped loads including those from structural failures. I note that due to the current level of layout maturity further work is required by the RP to ensure the most relevant design information is taken into account within the RP’s hazard analysis. Although bounding loads have been identified, it is my view that these need to be justified along with any claimed safety measures, in particular any claims on internal barriers and mitigation measures such as restraints. It is my opinion that such claims need to be established by the RP early on in Step 3 to ensure that containment space allocation is defined for them, and layout is adequately optimised, and sufficient analysis is undertaken to demonstrate that the safety claims are satisfied.
6. I also noted from the RP’s layout report (ref. [43]) that it highlighted further work is required to ascertain the fixing requirements for both the SGs and the CV during a seismic event as well as substantiation of the seismic isolation system of which it is dependent (see section 4.3.4.2 of this report). I have discussed this with the ONR Civil engineering lead and this will be followed up during Step 3. In addition, the CV also contains various internal steel structures and mechanical handling equipment which, if not adequately substantiated against seismic induced hazards (such as fires, pipe whip etc.), could result in hazard challenges to the VHR components. During Step 3, it is my view that the RP will need to demonstrate its VHR components are adequately protected within the confined space of the CV, either via segregation or otherwise, from internal hazards both individual and combined covering localised and global effects.
7. In summary, I have assessed the fundamental layout aspects of the containment block from an internal hazard perspective. I judge that further hazards analysis of this area is needed taking due account of the layout of its SSCs that will form the Step 3 design reference point. The RPs analysis will need to ensure that its segregation claims are robust and the optimisation of its layout justified, to demonstrate that the risks from hazards in this region are ALARP. At this stage, it is my view that sufficient detail is not yet available to form a judgement on the adequacy of the revised containment layout from a hazards perspective. I consider this a potential shortfall against ONR SAPs ELO.4 and EKP.3, which I will follow up in Step 3 as a residual matter.

#### Areas outside the hazard shield

1. I sampled the following aspects of the RP’s systems layout for the areas outside of the main hazard shield. I consider these to be the most significant contributors to a fundamental assessment of the generic design at GDA Step 2.

* Segregation of class 1 and class 2 SSCs located outside of the hazard shield.
* Layout and hazard impacts on non-segregated safety systems.
* Location of significant penetrations and services which pass through the hazard shield.
* Location and treatment of significant hazard sources.

1. The RP described the general layout of the reactor island including areas inside and outside the hazard shield within the reactor island architectural layout report (ref. [33]). The RP stated that its hazard shield is a safety class 1 Reinforced Concrete (RC) structure which includes a RC roof slab and steel trusses. The RP stated that the location of its safety systems either inside or outside the hazard shield has been driven by several factors including the system safety classification, the systems vulnerability to single point failure as well as functional and operational drivers. The RP claims that vulnerability to internal hazards has also been considered in the layout of the areas outside the hazard shield and I have sampled this rationale through the following submissions:

* Internal Hazards Summary Report – Outside Hazard Shield (ref. [37]).
* Internal Hazards Analysis Report – Outside Hazard Shield (ref. [66]).

1. Within the RP’s RD7 design (ref. [33]) the following blocks are noted as being located outside the hazard shield but within the reactor island:

* Auxiliary block.
* Waste processing block.
* Outage block.
* Support/access block.

1. The auxiliary block is the only block outside of the hazard shield which is placed on the Aseismic Bearing. The RP stated that this layout is based on the current design iteration and is subject to potential change. The RP stated that for safety class 1 or class 2 systems which are located outside the hazard shield full segregation or separation is provided.
2. The only systems identified by the RP that meet this criteria are the 11kV boards and main standby generators for trains 1 and 2 (High Voltage (HV) essential Alternating Current (AC) Standby Generation System – BDV System) as well as components for the Essential Service Water System (ESWS) (ref. [33]). I also note that the auxiliary block contains several systems required for spent fuel pool and radwaste management including components for the spent fuel coolant purification system, the coolant purification system and the storage system for wet & solid radwaste. These are not currently identified by the RP as safety class 1 or class 2 systems.
3. The RP identified internal hazards that originate outside the hazard shield both within the RD7 layout (ref. [37]) and RD6 layout (ref. [36]) as the Auxiliary Block was previously enclosed in the hazard shield at RD6. The reports identify all areas that are included within GDA scope but sit outside of the hazard shield. These include the above reactor island areas as well as the turbine island, balance of plant and cooling water island. Each of the class 1 or class 2 systems identified in these areas are noted as being located outside of the potential impact zone of a turbine missile. I consider that the approach of limiting the number of class 1 or class 2 systems which are located outside the hazard shield, whilst ensuring their vulnerability from known site hazards (within the generic design) is minimised, to be aligned with SAP ELO.4.
4. In addition to the systems noted above, the RP stated that the Supplementary Control Room (SCR) will be located within the support/access block and will be supported by a safety class 1 system, the low temperature chilled water system. The design of this system is not yet mature, however, this may require additional hazard protection and layout optimisation which will need to be progressed at Step 3.
5. My assessment has identified that the RD7 layout locates trains of the class 2 BDV system in the north and south sections of the reactor island i.e. they are separated by the hazard shield. They are therefore separated by at least two class 1 RC barriers. I judge that this layout is aligned with examples given in IAEA SSG-64 (ref. [22]) and with SAP ELO.4. Similarly, the ESWS is also separated into two divisions located to the north and south of the hazard shield.
6. The RP provides further information on the planned layout of the ESWS in its safety fluid report (ref. [44]). The report (ref. [44]) identifies that the connection point for each train of the ESWS is within the safety fluid systems block trains 1 and 2 such that the two trains are segregated by additional barriers. In addition to the above systems the other significant targets outside the hazard shield are the barrier surrounding the Auxiliary Block (assumed to be class 1 by the RP) and the barrier forming the hazard shield.
7. I note that the RP’s hazard analysis (ref. [66]) provides some information on location of significant hazard sources and potential impact on SSCs. The report (ref. [66]) nevertheless acknowledged that information on equipment outside the hazard shield is not yet incorporated into its Area Data Sheets (ADS). I consider this a shortfall against ONR SAPs EHA.2 and AV.3 that needs to be progressed at Step 3.
8. The RP’s analysis (ref. [66]) focused on three key hazard sources, the diesel inventory for the back-up generators, sources of hazardous materials relevant to MCR tenability and other site storage hazards. I consider these are relevant hazard sources that provide an indication of hazard challenges outside the hazard shield.
9. The RP stated (ref. [66]) that the diesel generator (BDV system) tank locations are approximately 50m away from the hazard shield and greater than 50m away from the auxiliary block boundary. I am satisfied that these distances provide a significant separation from the hazard source to the potential hazard targets as well as to the other train of the BDV system. I note that the potential impact on the ESWS system or the SCR is not discussed by the RP. This will be followed up as part of Step 3 however, I judge that the significant separation distance provides confidence that this presents a low risk.
10. I note that the RP’s analysis of hazardous materials (ref. [66]) focusses on the location of the main air intakes for the MCR and SCR. The RP highlighted that the air intakes for these rooms are expected to be routed such that they are via an opening in the shell roof and that the intake structure will be located on top of the hazard shield above the EC&I block.
11. It is my opinion that this arrangement may lead to a complicated HVAC arrangement with air being routed through a significant distance before reaching the MCR as well as passing through the boundary of the reactor island and hazard shield. It is my view that such aspects will need to be explored within Step 3 alongside ONR mechanical engineering and other interfacing specialisms as highlighted in section 4.3.4.6 of this report.
12. I am satisfied based on my assessment of the initial analysis performed by the RP of the potential extent of hazardous substances release that the risks to the tenability of the MCR are likely to be acceptable (ref. [66]). This is based primarily on my view of the assumed height of the MCR intake and the associated predicted concentrations of gases reaching the intake after dispersing. However, as the RP’s ventilation system design is not yet mature it is not possible to comment further on this point and this will be progressed at Step 3.
13. For the purposes of the site hazards assessment, the RP focussed on the potential effects of a hydrogen explosion at the bulk hydrogen store (assumed to be at the off-site chemistry store, located at the CWI). The RP’s preliminary analysis (ref. [66]) derives consequences which would be significant for target structures (nuclear island). However, I acknowledge that the RP has based its analysis on conservative assumptions due to the maturity of design information. My assessment has identified that a key aspect will be the routing of hydrogen pipework required for the main generator cooling. During Step 3 I will explore the effect that leaks under the plant shell roof may have on nuclear safety and how these would be mitigated.
14. Overall, I am satisfied that the layout information provided by the RP relevant to areas outside the hazard shield is consistent with UK relevant good practice. I consider that the approaches adopted should enable the RP to further develop its generic Rolls-Royce SMR design and associated E3S case evidence. I recognise that current analysis is based on layout which may change as the design matures and the analysis is expected to be updated as a result. A key finding from my assessment is the need for the RP to progress its internal hazards case for MCR/SCR tenability which I will follow up in Step 3 as a residual matter.

### Novel aspects of the design

1. This section details my assessment of the novel features which I considered relevant to my assessment. For each sample area I focused on:

* Hazards introduced by the feature.
* Impact to nuclear safety SSCs including barriers.

#### Modular structures

1. The RP’s approach to its application of modular structures is defined in its MKoP definition report and strategy (ref. [73, 34]). The report provides an overview of the fundamental considerations as well as the standards considered in defining its approach to modularisation implementation including the approach to hazard withstand. The RP has identified several standards that apply to modular structures as well as its barrier solutions, however, as stated in section 4.3.3.1 of this report, at this stage the exact approach has not been decided and needs to be progressed at Step 3.
2. The implementation of modular structures across the plant and their classification remains to be clarified by the RP as the layout of key SSCs is yet to be finalised, thus the modularisation solutions remain at low maturity (DR1). I note that this lack of maturity is acknowledged as a risk by the RP (ref. [73]). I agree with the RP view that further work is required in Step 3 to provide confidence that it can satisfy the build standard requirements for its modular structures with respect to their application, especially those that will be supporting class 1 and VHR SSCs. As stated in section 4.3.3.1 of this report, the RP also needs to ensure that all its safety measure requirements are captured, especially the necessary space requirements and fixing arrangements such as pipe whip restraints, as this will have an impact on the overall available space within a module.
3. Furthermore, the RP’s strategies (ref. [27, 34]) are yet to clarify how it will meet UK regulatory expectations of defence in depth to minimise the progression of hazard conditions (ONR SAP EKP. 3) within its modules, through deployment of its MKoP. I consider that this aspect is relevant to both CHS and life fire safety (LFS). For example, I note that within the fluid blocks layout report (ref. [44]) there are minimal MKoP internal barriers identified to prevent escalation of hazard conditions throughout a module cluster. It is my understanding that this layout decision is driven by the RP’s classification of the safety systems (class 2) that are supported within the modular cluster based on its deterministic analysis (see sub section 4.3.1.2) and claims on the main block envelope (civil barrier).
4. Although, I consider this is acceptable from a loss of system perspective, due to the availability of other safety trains, it is my expectation that the RP will demonstrate that the risks from internal hazards are reduced ALARP. This should also include CHS and LFS aspects. I have discussed this observation with the relevant CHS and LFS ONR specialists and this point will be progressed through their specific areas during Step 3. I am encouraged that the RP also recognised this point (ref. [44]) and committed to review the need to incorporate hazard barriers to mitigate conventional & fire safety risks as the design develops and further hazard analysis is undertaken.
5. At this stage, I acknowledge that the fundamental design attributes and safety case claims have not yet been fully established as the RP finalises its layout considerations. I consider that a fundamental aspect of this process is the outputs of the RP’s hazard analysis, and it is my expectation that the analysis needs to be representative of the reference design layout which is yet to be completed. It is also my view that during Step 3 the RP needs to demonstrate that all claims relevant to its deterministic approach, hazard analysis and safety case are consistent across all aspects of the E3S case.
6. In summary, I am satisfied that the implementation of modular structures does not undermine the RP’s internal hazards safety case. However, given the potential vulnerability of the structures to both individual and combined (including seismic induced) internal hazards a robust safety demonstration on a case-by-case basis needs to be provided, which is not available at this point in the GDA. This includes the need by the RP to demonstrate that the risks from hazards are ALARP across the module stacks for all elements of the E3S case. I consider this is a potential shortfall against ONR SAPs EKP.3, ELO.4, EHA.3 and EHA.14 and I will follow this up in Step 3 as a residual matter.

#### Seismic isolation

1. The RP has implemented a class 1 seismic isolation system into its design for the reactor island. The system consists of a series of reinforced concrete pedestals and elastomeric bearings. I note that the majority of the reactor island, except for the support building, sits on these bearings. I consider that the impact of internal hazards such as fire and flooding need to be considered to ensure resilience in the design as well as understanding capacity and redundancy of the bearings. Furthermore, the impact of the bearings themselves on the seismic response of the civil structure and module stacks need to be assessed.
2. I have assessed the RP’s hazard analysis summary report (ref. [36]) and note that the report does not cover assessment of hazards to the bearings or quantify how the bearing responds to a seismic load, and its influence on the internal civil and modular structures. The analysis summary report (ref. [36]), recognises that the aseismic bearings will need to be considered, as a potential initiator for fire and flood, to ensure that the design is robust to internal hazards caused by earthquake. To ensure that consideration is being made to hazards in the design of the plant and of the aseismic bearings I liaised with the ONR civil engineering inspector to query the RP’s approach (RQ-1128, ref. [49]).
3. My assessment has found that the impact of the bearing performance with respect to seismically induced hazards has not yet been analysed by the RP (ref. [36]). I recognise that seismic hazards are identified by the RP as a combined hazard initiator in the IH combined hazards report (ref. [29]) stating that SSCs required to prevent or protect against the potential induced hazard may be seismically qualified. However, I note that no specific claims on safety measures are identified. I consider the absence of claims on the seismic response of both safety measures and structural modules to be a shortfall against ONR SAPs EHA.9, ECS.2 and ECS.3. I have discussed the aspect of seismic qualification of SSCs with the ONR mechanical and civil engineering inspectors who concur with my views and will therefore progress assessment as part of Step 3.
4. In summary, the RP’s layout and design aspects of its elastomeric bearings is still under development. The RP is considering aspects of hazard protection, including the requirement for a flexible joint covering the void space around the island that enables slab movement. The joint would provide a watertight seal/cap between the precast shells of the retaining wall to protect against ingress of water in to the void in which the elastomeric bearings are located. Given the novel nature of this detail, the RP highlighted that testing is ongoing to determine if the joint can provide adequate waterproofing. The RP also stated (ref. [49]) that identification of any hazards related to failure of the bearings is being developed and will be presented to ONR during GDA Step 3.
5. I have not identified any fundamental issues with the proposed elastomeric bearing system through my Step 2 assessment. I take assurance from the RP’s recognition of the need to protect the system from internal hazards and are developing mitigation measures. However, It is my opinion that at this stage of GDA insufficient detail has been presented by the RP to form a judgement on the adequacy of its seismic isolation system from an internal hazards perspective and I will seek further information in Step 3.

#### HVAC – Chilled water system

1. The RP’s heating, ventilation, and air-conditioning (HVAC) system is defined within the RP’s HVAC system description document (ref. [74]). A novel aspect of this system is the implementation of ice storage as part of its chilled water system in support of key EC&I systems. The internal hazards summary report (ref. [36]) stated its chilled water system consists of a 2-loop cooling chain, with the loops connected at a heat exchanger located within the ice stores. Each of these loops is considered by the RP as a separate flooding source. The RP also highlighted chilled water system as a pressurised system.
2. The RP assessed the hazards associated with its chilled water system (ref. [36]). The RP claimed that operating pressures will be relatively low compared to the defined ‘high pressure’ limit in the IH methodology (ref. [28]), and the operating temperature will also be very low due to the role of the system. Hence, the chilled water system was not considered by the RP to be a source of pipe whip, blast, or missile hazards. The RP also stated that it considered that the chilled water system will have no significant water sources within the ‘charging circuit’ (the closed loop between the ice stores and chillers that sit outside of the EC&I block). As a result, the RP considered the risks of flooding from the chilled water system including melting of the ice store to be very low and was not considered further.
3. I have assessed the RP’s analysis and I note that there is limited design information available on the chilled water system. Notwithstanding this, I have not identified any fundamental issues with the proposed system as described. The RP considers that the flood volume capacity within the block is sufficient to bound the assumed water inventory. This provides some assurance, but remains to be justified as the design matures through Step 3. I also noted that the RP has not included assessment of water spray from the water system which could impact the functionality of the EC&I systems it is serving as well as initiating fire. Given the lack of maturity of the system at this time, this will need to be followed up at Step 3. It is my expectation that all water hazards are adequately identified and assessed, I consider this is shortfall against ONR SAPs EHA.15 and I will seek further information in Step 3.

#### Coolant purification system

1. The coolant purification system is stated by the RP (ref. [75]), to be a high-pressure system operating at normal reactor coolant system pressure (15.5Mpa). The system is classified as a class 3 system providing the means of fulfilling the Cat C safety function of flow for coolant purification. Given the high operating pressure outside of containment I chose to sample the system. It is my view that the system presents a significant internal hazard source both from a high-pressure pipe failure (Jet, pipe whip and missile (from heat exchanger)), but also from a radiological aspect as primary coolant could be discharged as well as any hazards that could impact the resin beds contained within a module structure.
2. At the exit of the containment boundary, the RP places a claim on its containment valve arrangement (ref. [75]). The valves are identified as a CAT A containment safety function and therefore are designated as a class 1 safety system. I am satisfied that this is appropriate, however the classification of the coolant purification system pipework remains unclear. I note from the system architecture diagram (ref. [75]) that the inlet and outlet pipes are located next to each other, thus potential failure of the pipes could impact the class 1 safety valves (via jet or whip) that might challenge its integrity.
3. Through my assessment of the internal hazards summary report (ref. [36]), I found that the RP had discounted both pipe whip and valve missiles from the coolant purification system as a credible hazard. The RP stated (ref. [36]) that although the coolant purification system is operating at a high pressure, due to its low temperature (approximately 55°C) the RP had judged that the system is not a credible pipe whip source or valve missile source. In contrast, the coolant purification system outline report (ref. [75]) states that, as the system operates at high pressure and has the potential to cause pipe whip and steam release following pipe rupture, ongoing layout work is being undertaken to protect other systems.
4. I judge that the RP’s exclusion of the pipe whip based on low temperature is not aligned to RGP (ref. [15, 22]) nor is it aligned to its own methodology (ref. [28]) as the pipe is operating at a significantly higher pressure than the RP’s 1.9Mpa criterion. It is my view that this exclusion needs to be revisited by the RP during step 3, together with any other instances where exclusion of high pressure systems on temperature has been applied. I consider this a shortfall against ONR SAP EHA.14, which I will progress at Step 3 as a residual matter.
5. I have also assessed the latest general arrangement drawings for the system (ref. [71]) and I note that the coolant purification heat exchanger appears to be within a segregated area. I consider this as good practice from a layout perspective to mitigate against end plate missiles, and thus satisfying ONR SAP ELO.4. However, at present no claims have been made on the walls to act as a barrier, however I consider that this can be addressed at Step 3 though the RP’s work to identify its safety measure claims.
6. Overall, it is my view that the design of the coolant purification system and associated hazards needs to be progressed at Step 3. The system transports reactor coolant at reactor pressure across the nuclear island and, in my view, presents a significant pipe whip and jet hazard which is yet to be adequately defined by the RP. I acknowledge that the coolant purification system design is at low maturity (ref. [48]) thus its design, layout and segregation solutions have not yet been defined and finalised.
7. For Step 2, the RP has been able to describe the fundamentals of its coolant purification system. I am satisfied that the RP has claims on containment, and has segregated the heat exchanger. This, in addition to the RP’s internal hazard design requirements, provides me with confidence that the RP can develop a solution that will consider internal hazard effects. I judge that the RP need to progress its design early in step 3 as at present there is insufficient information to draw any significant conclusions regarding the RP’s management of the hazards of the novel aspects this system. I will progress this in Step 3 as a residual mater.

#### EEC blowdown route

1. Chapter 6 of the E3S case (ref. [51]) stated that the Emergency Core Cooling System (ECCS) delivers the Emergency Core Cooling (ECC) safety measure to control fuel temperature (CoFT) in response to a range of fault conditions, including most Intact Circuit Faults (ICFs) and Loss of Coolant Accidents (LOCAs). On initiation of the ECCS the emergency blowdown valves open, allowing the contents of the reactor coolant system to blowdown into the refuelling pool located within containment.
2. I sampled the ECCS because the refuelling pool is connected to the fuel transfer tube and spent fuel pond (ref. [76]). The spent fuel pond is isolated from the refuelling pool via the fuel transfer tube and the fuel transfer gates. Although, I recognise that it is not novel to utilise water sources to blowdown steam into via spargers, I do consider it as a novel as compared to other plant designs to be utilising the refuelling pool that is directly connected to the fuel pond (via the transfer tube and gates).
3. The sealing arrangement and functionality of the gate valves under blowdown conditions is a requirement yet to be demonstrated by the RP as stated in its response to the ONR Mechanical engineering inspector (RQ-1183, ref. [49]). It is my view that failure of the gates, seals and penetrations could lead to internal hazards being generated which could potentially impact the functionality of the ECCS itself. The geometry of the tank is tall and slender, which under blowdown conditions may present high demands on the refuelling pool internal isolation measures, which will need to be considered in the design of the system.
4. I have discussed this finding with the mechanical engineering inspector who will consider these aspects further in their assessment of the ECCS design at Step 3, to ensure the design is adequate for the generated operational loads. However, for Step 2 the mechanical engineering inspector concluded that the RP had demonstrated the fundamental design parameters for this system are adequate (ref. [77]).

#### HVAC – Hazard management

1. The heating, ventilation, air conditioning (HVAC) system serving both the controlled and uncontrolled areas of the reactor island is described in the HVAC system description report (ref. [74]). The system is intended to provide HVAC functions across all the key operating modes. The internal hazards report (ref. [36]) highlights multiple hazards that will require claims to and from the HVAC system to minimise the impacts of hazard conditions. These hazards include fire, steam release, blast, and the release of asphyxiant gases such as hydrogen (that also presents an explosion hazard), argon (from the fire suppression system in the EC&I block) and nitrogen.
2. I am satisfied that the HVAC system report (ref. [74]) states a requirement for the system to provide protection against internal hazards. The report highlights that fire/smoke dampers at all fire barriers are to prevent the transfer of fire/smoke through the building as well as ensuring the habitability of the MCR during hazard conditions.
3. However, at this stage of the design, I have noted that further work is required by the RP to develop its HVAC design as it remains at low maturity (ref. [48, 74]). However, it is my view that the RP need to address this early in Step 3 to ensure the system has adequate requirements established to inform the design. I have liaised with the ONR mechanical engineering inspector who supports my view that at this stage there is insufficient information on the HVAC system to form a judgement on the adequacy of its design with respect to hazards. The mechanical engineering inspector provided assurance that in their opinion the HVAC design does not present a fundamental gap against regulatory expectations. This is because the RP has recognised these gaps and presented a plan to resolve them (ref. [77]) . I am therefore satisfied that this will be progressed by the RP in step 3 and I will follow this up as a residual matter.

### ALARP

1. From my assessment of the RP’s safety case, including its ALARP summary report (ref. [42]), I am satisfied that:

* The RP has identified and presented its approach to hazard identification (ref. [27]) and analysis methodologies (ref. [28]) and these approaches are in line with RGP.
* The RP has implemented appropriate consideration of the hierarchy of safety measures set out in the Engineering Key Principles (EKP.1 to 5) and supporting guidance, with requirements set out to eliminate or minimise the impact of hazards, primarily using segregation.
* The RP has demonstrated that the design evolution with respect to hazards has improved from the RD6 layout. This includes better segregation of safety train blocks and hazard sources.

1. At this stage further work is required by the RP to align its internal hazards analysis and overall case to the latest reference design and to demonstrate the risks to the plant, operators and public are ALARP. Notwithstanding this, I am content that the RP has made sufficient progress in line with RGP (ref. [18]) to have confidence that it is working to demonstrate the risks from internal hazards are ALARP. The overall adequacy of this demonstration will be assessed at Step 3.

# Conclusions

## Conclusions

1. This report presents the Step 2 internal 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 provided by Rolls-Royce SMR Limited to form my judgements. I targeted my assessment, in accordance with my assessment plan (ref. [7]), at the content of most relevance to internal hazards against the expectations of ONR’s SAPs, TAGs and other guidance which ONR regards as relevant good practice.
2. Based upon my assessment, I have concluded the following:

* The RP has in place suitable methodologies to enable assessment of IH hazards to be undertaken. The adequacy and justification of their application remains to be demonstrated at Step 3.
* The RP has demonstrated that it is developing its design layout taking cognisance of internal hazards and the risks they present. The RP has in place sufficient internal hazard requirements to inform design decisions relating to the siting and location of hazard sources and hazard targets.
* The RP has in place a robust set of requirements and transverse requirements that if implemented and satisfied should result in a design that is aligned to UK expectations. However, due to the low maturity of the design the demonstration that these have been satisfied remains to be provided.
* The hazard analysis available at Step 2 requires development and updates to be complete and representative of the reference design, and this will continue to be the case until layout reaches appropriate maturity through Step 3. Nevertheless I am satisfied that the RP’s hazard analysis has highlighted key hazard sources, have adequate methodology and design requirements to inform the development of the design.
* I am satisfied that the RP’s latest design (RD7) has sufficiently demonstrated an improvement in hazard robustness over the previous design (RD6) of which the current internal hazards safety case is based. My assessment has identified several areas where the management of hazard sources and their segregation has not been demonstrated. These areas include the interspace, MCR, fuelling block and containment. There is a significant amount of work to be undertaken by the RP, but I am satisfied that the RP understands the work required, and has committed to undertake it. I am also content that the RP has in place a robust set of hazard requirements that are to be considered in its design to demonstrate that the risk from hazards is ALARP.
* The RP’s E3S Chapters are consistent with its Tier 2 and 3 submissions. However, the RP’s internal hazards E3S case does not yet provide a complete set of claims arguments and evidence narrative that justifies bounding cases and enables identification of all claimed safety measures and substantiation.

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.

## Recommendations

1. My recommendations are 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.

# References

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# Appendix 1 – Relevant SAPs considered during the assessment

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| SAP No. | SAP Title |
| ECS.2 | Engineering principles: safety classification and standards: Safety classification of structures, systems, and components |
| ECS.3 | Engineering principles: safety classification and standards: Codes and standards |
| EHA.1 | Engineering principles: external and internal hazards: Identification and characterisation |
| EHA.2 | Engineering principles: external and internal hazards: Data sources |
| EHA.3 | Engineering principles: external and internal hazards: Design basis events |
| EHA.4 | Engineering principles: external and internal hazards: Frequency of initiating event |
| EHA.5 | Engineering principles: external and internal hazards: Design basis event operating states |
| EHA.6 | Engineering principles: external and internal hazards: Analysis |
| EHA.9 | Engineering principles: external and internal hazards: Earthquakes |
| EHA.14 | Engineering principles: external and internal hazards: Fire, explosion, missiles, toxic gases etc – sources of harm |
| EHA.15 | Engineering principles: external and internal hazards: Hazards due to water |
| EHA.16 | Engineering principles: external and internal hazards: Fire detection and fighting |
| EHA.19 | Engineering principles: external and internal hazards: Screening |
| EMC.1 | Engineering principles: integrity of metal components and structures: highest reliability components and structures: Safety case and assessment |
| EMC.2 | Engineering principles: integrity of metal components and structures: highest reliability components and structures: Use of scientific and technical issues |
| EMC.3 | Engineering principles: integrity of metal components and structures: highest reliability components and structures: Evidence |
| EKP.2 | Engineering principles: key principles: Fault tolerance |
| EKP.3 | Engineering principles: key principles: Defence in depth |
| EKP.5 | Engineering principles: key principles: Safety function |
| ELO.4 | Engineering principles: layout: Minimisation of the effects of incidents |
| FP.4 | Fundamental principles: Safety assessment |
| FA.5 | Fault analysis: design basis analysis: Initiating faults |
| FA.6 | Fault analysis: design basis analysis: Fault sequences |
| SC.4 | The regulatory assessment of safety cases: Safety case characteristics |
| SC.5 | The regulatory assessment of safety cases: Optimism, uncertainty, and conservatism |
| AV.3 | Fault analysis: assurance of validity of data and models: Use of data |
| AV.6 | Fault analysis: assurance of validity of data and models: Sensitivity studies |
| AV.7 | Fault analysis: assurance of validity of data and models: Data collection |