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| ONR Assessment Report  Generic Design Assessment of the Rolls-Royce SMR – Step 2 assessment of Severe Accident Analysis |



ONR Assessment Report

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

**Report Title**: Step 2 assessment of Severe Accident Analysis

**Authored by**: [Redacted]

**Report Issue No**: 1

**Document ID**: ONRW-2126615823-2780

**Publication Date**: Jun-24

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# Executive Summary

This report presents the outcomes of my Severe Accident Analysis 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 Severe Accident Analysis against the expectations of ONR’s Safety Assessment Principles (SAPs) and Technical Assessment Guides (TAGs) and other guidance which ONR regards as relevant good practice.

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

* The adequacy severe accident management strategy.
* Severe accident analysis methodology.
* Identification of severe accident sequences.
* Deterministic analysis of the effectiveness of severe accident safety features.
* Verification and validation of the codes used for deterministic analysis.
* Radiological consequences methods and analysis.
* Claims related to practical elimination of large or early releases.

Based upon my assessment, I have concluded the following:

* The RP has identified relevant severe accident phenomena that should be prevented/mitigated. From my sampling I judge that the RP has identified appropriate safety features to provide for severe accident management.
* The RP’s proposed methodology for constructing a severe accident analysis safety case is appropriate.
* The selected severe accidents sequences provide an adequate basis for the analysis provided during Step 2. I judge that the RP’s sensitivity analyses cover current design uncertainties, providing me with confidence regarding the future refinements and updates to the analyses to be assessed in Step 3 for the mature design.
* The MAAP5 code is appropriate for use in performing severe accident deterministic analysis for the Rolls Royce SMR and the RP’s approach to verification and validation of the code has progressed satisfactorily for Step 2.
* The RP’s proposed methodology for performing radiological consequence analysis is adequate, although analysis has not been presented for assessment in Step 2.
* I have confidence that the RP has a valid approach to demonstrate in Step 3 that the design practically eliminates sequences with the potential to lead to large or early releases.
* Further work is required to demonstrate that the risks have been reduced ALARP, including justification of the exclusion of a filtered containment venting system and containment leakage filtration.

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

ADS [JNF] Automatic Depressurisation System

AICC Adiabatic Isochoric Complete Combustion

ALARP As low as is reasonably practicable

CCS Component Cooling System

CCSF Containment Cooling and Spray Function

CHF Critical Heat Flux

CSCS [JNA] Cold Shutdown Cooling System

DAC Design Acceptance Confirmation

DCH Direct Containment Heating

DEC-(A/B) Design Extension Conditions (A/B)

EBD Emergency Blowdown

ESWS [PB] Essential Service Water System

E3S Environmental, Safety, Security and Safeguards (case)

FWS [XGB] Fire Water System

GDA Generic Design Assessment

HOW2 ONR’s Management System internal online portal

HPME High Pressure Melt Ejection

HRS [JMT] Hydrogen Reduction System

HTOP High Temperature Over-Pressure

HX Heat Exchanger

IAEA International Atomic Energy Agency

IVR In-Vessel Retention

LB LOCA Large Break Loss of Coolant Accident

LOCA Loss of Coolant Accident

LUHS [JNK] Local Ultimate Heat Sink

NRW Natural Resources Wales

ONMACS ONR Nuclear Material Accountancy Control and Safeguards

ONR Office for Nuclear Regulation

PCC Passive Containment Cooling

PIRT Phenomena Identification and Ranking Table

PSA Probabilistic Safety Assessment

PWR Pressurised Water Reactor

RCP Reactor Coolant Pump

RCVIS [JNM] Reactor Vessel Cavity Injection System

RGP Relevant Good Practice

RMI Reflective Metallic Insulation

RP Requesting Party

RPV [JAA] Reactor Pressure Vessel

SAP Safety Assessment Principle(s)

SAMS Severe Accident Management System

SBO Station Blackout

SDP Slow Depressurisation

SG Steam Generator

SSC Structure, System and Component

TAG Technical Assessment Guide(s) (ONR)

TAM Test and Assessment Matrix

TSC Technical Support Contractor

WENRA Western European Nuclear Regulators’ Association

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# Introduction

1. This report presents the outcomes of my Severe Accident Analysis assessment of the Rolls-Royce Small Modular Reactor (SMR) as part of Step 2 of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA). This assessment is based upon the information presented in version 2 of Rolls-Royce SMR Limited’s Environmental, Safety, Security and Safeguards (E3S) case chapters (refs [1], [2], [3] & [4]) and supporting documentation.
2. Assessment was undertaken in accordance with the requirements of the Office for Nuclear Regulation (ONR) Management System and follows ONR’s guidance on the mechanics of assessment, NS-TAST-GD-096 (ref. [5]). The ONR Safety Assessment Principles (SAPs) (ref. [6]) (ref. [7]), together with supporting Technical Assessment Guides (TAGs) (ref. [8]), have been used as the basis for this assessment.
3. This is a Major report (refer to NS-TAST-GD-108 (ref. [9])).
   1. Background
4. The ONR’s GDA process (ref. [10]) calls for a step-wise assessment of the Requesting Party's (RP) submissions with the assessments increasing in detail as the project progresses. Rolls-Royce SMR Limited is the RP for the GDA of the Rolls-Royce SMR design.
5. In April 2022 ONR, together with the Environment Agency and Natural Resources Wales (NRW), began Step 1 of the GDA for the generic Rolls-Royce SMR design. Step 1, which is the preparatory part of the design assessment process and mainly associated with initiation of the project and preparation for technical assessment in later steps, was successfully completed in 12 months.
6. Step 2 commenced in April 2023. This is the first substantive technical assessment step. The focus of ONR’s assessments in this step is towards the fundamental adequacy of the design and safety and security cases, and the suitability of the methodologies, approaches, codes, standards and philosophies which form the building blocks for the design and generic safety and security cases. The objective is to undertake an assessment of the design against regulatory expectations to identify any fundamental safety or security shortfalls that could prevent ONR permissioning the construction of a power station based on the design.
7. Prior to the start of Step 2 I prepared a detailed Assessment Plan for Severe Accident Analysis (ref. [11]). This has formed the basis of this assessment and was also shared with the RP to maximise openness and transparency.
8. This report is one of a series of Assessments which support ONR’s overall judgements at the end of Step 2 which are recorded in the Step 2 Summary Report (ref. [12]).
   1. Scope
9. The assessment 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.
10. The overall scope of the Rolls-Royce SMR GDA is described in (ref. [13]). Rolls-Royce SMR Limited has indicated that it intends to complete a three step GDA, with the objective of receiving a 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.
11. However, given the step-wise 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:

* Severe accident analysis of shutdown modes and non-reactor faults. The RP has not developed its safety case in this area. This will form part of my Step 3 assessment.
* Non-permanent / Mobile Equipment – no information has been submitted during Step 2. This does not prevent me from making judgements against the objective of Step 2.
* Equipment Qualification – limited information has been submitted during Step 2. This does not prevent me from making judgements against the objective of Step 2.
* Deterministic analysis of severe accident sequences to support the Level 2 Probabilistic Safety Analysis (PSA). Any analysis that supports the PSA is within the scope of the PSA assessment.

1. My assessment has considered the following aspects:

* The severe accident management strategy employed in the Rolls-Royce SMR - This relates to the understanding of applicable severe accident phenomena and identification of appropriate safety features.
* Severe accident analysis methodology - I have assessed the adequacy of the safety case methodology and use of deterministic methods to demonstrate that the safety case claims will be met.
* Identification of severe accident sequences – I have assessed the adequacy of the sequences chosen by the RP to demonstrate the adequacy of the severe accident safety features[[1]](#footnote-2).
* Sequence analysis – I have assessed the adequacy of the severe accident model of the Rolls-Royce SMR and the analysis of several sequences to demonstrate the effectiveness of safety features.
* Verification and validation - The RP has used the MAAP5 severe accident code in the demonstration of the effectiveness of the severe accident safety features. I have assessed the general approach to verification and validation of this code.
* Radiological consequences – Together with a radiological consequences inspector, I have assessed the overall intentions for performing radiological consequence analysis.
* Practical elimination – I have assessed the RP’s proposed approach to the demonstration of ‘practical elimination’[[2]](#footnote-3) of sequences that have the potential to lead to large or early releases.

# Assessment standards and interfaces

1. For ONR, the primary goal of the GDA Step 2 assessment is to reach an independent and informed judgment on the adequacy of a safety, security and safeguards case for the reactor technology being assessed.
2. ONR has a range of internal guidance to enable Inspectors to undertake a proportionate and consistent assessment of such cases. This section identifies the standards which have been considered in this assessment.
3. This section also identifies the key interfaces with other technical topic areas.
   1. Standards
4. The ONR Safety Assessment Principles (SAPs) (ref. [6]), Security Assessment Principles (ref. [14]) and Nuclear Material Accountancy, Control, and Safeguards Assessment Principles (ONMACS) (ref. [7]) constitute the regulatory principles against which the RP’s case is judged. Consequently, the SAPs, SYAPs and ONMACs are the basis for ONR’s assessment and have therefore been used for the Step 2 assessment of the Rolls-Royce SMR. As this assessment only relates to nuclear safety, only the SAPs have been applied here.
5. The International Atomic Energy Agency (IAEA) safety standards (ref. [15]) and nuclear security series (ref. [16]) are a cornerstone of the global nuclear safety and security regime. They provide a framework of fundamental principles, requirements and guidance. They are applicable, as relevant, throughout the entire lifetime of facilities and activities.
6. Furthermore, ONR is a member of the Western European Nuclear Regulators Association (WENRA). WENRA has developed Reference Levels (ref. [17]), which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors (ref. [18]).
7. The relevant SAPs, IAEA standards and WENRA reference levels/objectives are embodied and expanded on in the TAGs (ref. [8]).
   * 1. Safety Assessment Principles (SAPs)
8. The key SAPs (ref. [6]) applied within my assessment are:

* FA.2, FA.3, FA.15, FA.16, and FA.25 – These relate to the identification of faults and accident sequences, the scope and use of severe accident analysis and the relationship with DBA and PSA.
* EKP.3, EKP.4 and EKP.5 – These relate to defence in depth, identification of safety functions and identification of structures, systems and components (SSCs) to deliver those safety functions.
* AV.1 – AV.6 – These relate to verification and validation of the codes used to support the safety case.
* EES.1 and ESR.1 – These relate to providing adequate support to the severe accident safety features to enable them to carry out their safety functions.

1. A list of the SAPs used in this assessment is recorded in Appendix 1.
   * 1. Technical Assessment Guides (TAGs)
2. The following TAGs have been used as part of this assessment:

* NS-TAST-GD-007 - Severe Accident Analysis (ref. [19])
* NS-TAST-GD-042 – Verification and Validation of Computer Codes (ref. [20])
* NS-TAST-GD-005 – Guidance on the Demonstration of ALARP (ref. [21])
  + 1. National and international standards and guidance

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

* IAEA, Safety of Nuclear Power Plants: Design, Specific Safety Requirements No. SSR 2/1 (ref. [22])
* IAEA, Deterministic Safety Analysis for Nuclear Power Plants, Specific Safety Guide No. SSG-2 (ref. [23])
* IAEA, Design Extension Conditions and the Concept of Practical Elimination in the Design of Nuclear Power Plants, Safety Guide No. SSG-88 (ref. [24])
* WENRA, Practical Elimination Applied to New NPP designs - Key Elements and Expectations (ref. [25])
  1. Integration with other assessment topics

1. I worked closely with other topics as part of my Severe Accident Analysis 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:

* Fault Studies – I worked closely with Fault Studies to understand how the Rolls-Royce SMR design responds to design basis faults and accidents with limited core damage. The early stages of an accident influence the severe accident progression. I also worked closely with Fault Studies to gain confidence that the design incorporates adequate independence between levels of defence in depth[[3]](#footnote-4).
* Control & Instrumentation (C&I) – I worked with the Control & Instrumentation specialism to understand the support provided by C&I platforms that enables the safety features to carry out their safety functions.
* Electrical Engineering – I worked with Electrical Engineering to understand how safety features and C&I platforms are supported for severe accident mitigation.
* Structural Integrity – I have worked closely with Structural Integrity to gain confidence that the containment safety function will be met.
  1. Use of technical support contractors

1. During Step 2 I engaged Technical Support Contractors (TSCs) to support the following specific aspects of my assessment of Severe Accident Analysis for the Rolls-Royce SMR design:

* Verification and validation – The majority of the deterministic analysis in support of the severe accident analysis is performed using MAAP5. I commissioned work on a review of the verification and validation of the severe accident integral code MAAP5. The TSC’s review also considers the GOTHIC code, which, in Step 2, is used in support of design basis analysis. The RP has not decided, at this point of the assessment, if GOTHIC will be used to directly support the severe accident analysis.

1. The TSC provided me with technical advice and supported my assessment, working under my close direction and supervision. It should be noted that all regulatory judgements have been made exclusively by ONR.

# Requesting Party’s submission

1. Rolls-Royce SMR Limited submitted a series of E3S chapters, or summary reports, and other supporting references, which outline the preliminary E3S case for the generic Rolls-Royce SMR design. This section presents a summary of the RP’s preliminary safety case for Severe Accident Analysis. It also identifies the documents submitted by the RP which have formed the basis of my Severe Accident Analysis assessment of the Rolls-Royce SMR.
   1. Summary of the Rolls-Royce SMR design
2. The generic Rolls-Royce SMR design is a three loop Pressurised Water Reactor (PWR) with a target electrical power output of 470 MWe (from a thermal power of 1,358 MWth) and a design life of 60 years for non-replaceable components.
3. The Rolls-Royce SMR design has been developed by the RP based upon well-established PWR technology, in use all over the world. Innovation comes in the form of its modular approach to construction which would see the majority of the power station built in factory conditions and assembled on site.
4. The reactor itself is of a typical PWR design, including a steel Reactor Pressure Vessel (RPV) holding fuel assemblies, Steam Generators (SG), Reactor Coolant Pumps (RCP) and piping, all held within a steel containment vessel. The reactor is equipped with a number of supporting systems for normal operations and a range of safety measures are present in the design to provide cooling, control criticality and contain radioactivity under fault conditions. Passive safety features are preferred to active components, reflecting the RP’s design philosophy.
5. The Rolls-Royce SMR includes several design basis safety measures and severe accident safety features. The design basis safety measures are assessed in the Fault Studies topic area. Basic information regarding the operation of the design basis safety features are of importance to my assessment. I provide information within this report where relevant.
6. The Rolls-Royce SMR design employs In-Vessel Retention (IVR) as its molten core (referred to as corium hereon) cooling strategy. The corium is retained within the RPV [JAA] and is cooled via ex-vessel cooling. Figure 1 below shows a schematic diagram of the relevant SSCs that support IVR (ref. [26]).

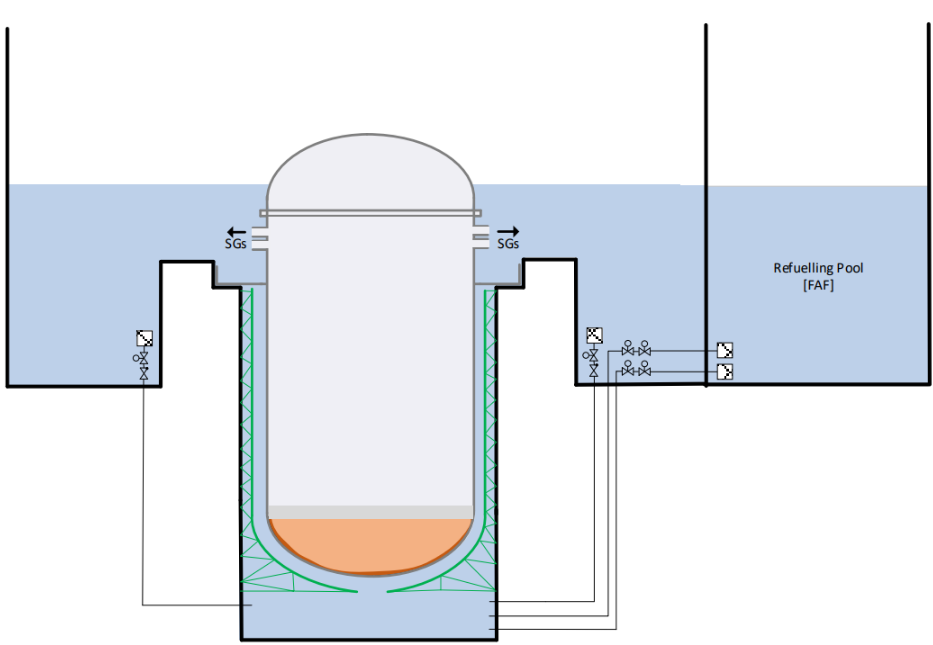


Figure 1 - Schematic of In-Vessel Retention – Shown in the diagram is the (1) containment sump, (2) Reactor Cavity and (3) the Refuelling Pool [FAF] (ref. [26])

1. Upon entry into severe accident management, operators can initiate the Reactor Vessel Cavity Injection System (RVCIS [JNM]) cavity flooding lines to allow water to drain via gravity from the Refuelling Pool [FAF][[4]](#footnote-5) to the Reactor Cavity[[5]](#footnote-6). The reactor cavity is hydraulically connected to the sump via several pipes and valves. This set of valves and pipes that allow filling of the cavity are referred to as the RVCIS [JNM]. The RPV [JAA] is surrounded by reflective metal insulation (RMI) which prevents heat losses during normal operation and forms a channel to guide water flow during IVR. The channel is designed to enhance heat removal from the RPV [JAA] during IVR. The RMI surrounding is open at the bottom, which allows water to fill and surround the RPV. The water is heated and moves up through the annulus and exits at a higher temperature through openings where the RPV [JAA] is anchored to the concrete containment basemat. Evaporated water is released into the containment atmosphere.
2. Steam generated from IVR and any released directly from the primary circuit is condensed by the Passive Containment Cooling (PCC) Heat Exchangers (HX) of the Local Ultimate Heat Sink (LUHS [JNK]). The condensate then drains back into the Reactor Cavity via the containment sump. No containment spray is claimed during this mode. The containment sump is hydraulically connected to the Reactor Cavity during a severe accident, allowing the condensed water to be reused for IVR. The water which cools the containment atmosphere, which is on the inside of the PCC HX tubes, evaporates and exits the LUHS [JNK] into the atmosphere.
3. An alternative method of heat removal using active systems was in development during Step 2. This employs a spray system and duty heat removal systems (i.e. systems used in normal operation). When spray is used, the function is referred to as the Containment Cooling and Spray Function (CCSF). The spray aids the condensation of steam. Water that is collected in the containment sump is cooled via the Cold Shutdown Cooling System (CSCS) [JNA]. Heat is exchanged with the Component Cooling System (CCS) [KAA], and later the Essential Service Water System (ESWS) [PB] cooling towers.
4. Generally, during a severe accident in a PWR, there is potential for RPV failure whilst the reactor is still at high pressure. This can lead to high pressure melt ejection (HPME) of the corium from the RPV, which can challenge the containment. A decision has been made by the RP to include a severe accident depressurisation function in order to avoid HPME. However, the design of this function is still in development. The RP has stated that the likely routes are via the High Temperature Overpressure Protection (HTOP) valve of the Reactor Coolant Relief System [JEG] or the Automatic Depressurisation System (ADS) [JNF].
5. Hydrogen generated during a severe accident also poses a threat to the containment. The Rolls-Royce SMR design includes a Hydrogen Reduction System (HRS) [JMT], consisting of Passive Autocatalytic Recombiners (PARs), located inside the containment to prevent conditions which could challenge integrity of the containment.
   1. E3S case approach and structure
6. 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’.
7. 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.
8. 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 2.

****

**Figure 2: Claim, Argument and Evidence (CAE) structure within the E3S hierarchy** (ref. [27])

1. The structure of the E3S case largely aligns with the IAEA guidance for safety cases, SSG-61 (ref. [28]), supplemented to include UK specific expectations and expanded to include the other E3S purposes.
   1. Summary of the requesting party’s E3S case for Severe Accident Analysis
2. The aspects covered by the Rolls-Royce SMR safety case in the area of Severe Accident Analysis can be broadly grouped under eight headings which are summarised as follows:
   * 1. Severe accident management strategy
3. The RP claims that it has identified relevant phenomena for severe accidents, and that the Rolls-Royce SMR design incorporates severe accident safety features which prevent or mitigate these severe accident phenomena that would challenge the containment.
4. The severe accident management strategies are IVR, hydrogen management using PARs, primary circuit depressurisation, and containment heat removal. The safety features that enable these strategies are described in Section 3.1 of this report.
   * 1. Severe accident analysis methodology
5. The RP claims that its methodology of analysing severe accident sequences is sufficient to demonstrate the effectiveness of the Rolls-Royce SMR severe accident safety features.
6. The safety case submitted to date is supported by deterministic analysis performed using the MAAP5 code. The RP has assessed several severe accident sequences against technical acceptance criteria for various phenomena to demonstrate the effectiveness of the safety features. As stated, the RP has not submitted radiological consequence assessment during step 2.
7. The RP acknowledges where there are limitations of the MAAP5 analysis, and identifies areas of further work for Step 3 (for example detailed hydrogen analysis).
   * 1. Identification of severe accident sequences
8. The RP claims that it has identified suitable severe accident sequences to demonstrate the effectiveness of the majority of the generic Rolls-Royce SMR safety features (excluding active heat removal). The RP has identified these sequences using engineering judgements and comparisons with other practices. The RP has analysed large break Loss Of Coolant Accident (LOCA), slow depressurisation and station blackout.
9. The choice is based on finding the worst conditions for a particular phenomenon to provide the evidence that the safety features are effective for bounding cases.

### Sequence analysis

1. The RP claims that the deterministic analysis performed to date demonstrates the feasibility of each of its safety features (excluding active heat removal). It claims that the deterministic analysis demonstrates that the technical acceptance criteria are met and therefore that severe accident phenomena are adequately prevented/mitigated.

### Verification and validation

1. The RP claims that the MAAP5 code is adequately verified and validated for use in the analysis submitted during Step 2.
2. The RP has provided a validation summary to date. This summarises the current status of the Phenomena Identification and Ranking Tables (PIRT) and Test and Assessment Matrix (TAM) for the MAAP5 code. The PIRT identifies the most important influencing phenomena for a given accident, and the TAM is a demonstration of the status of validation of a code. Whilst the verification and validation is not complete at this stage, the RP claims that the sensitivity studies it has carried out are bounding and encompass any code uncertainty.

### Radiological consequences

1. The RP has developed a methodology for determining the source term and any off-site radiological consequences.
2. No Radiological consequence analysis has been performed and submitted to ONR during Step 2.

### Practical elimination

1. The RP claims that the Rolls-Royce SMR design intent is to practically eliminate sequences that lead to a large or early release.
2. Only the methodology for demonstrating practical elimination has been submitted during Step 2. The methodology combines probabilistic and deterministic arguments.
   * 1. ALARP by design
3. The RP claims that Rolls-Royce SMR severe accident safety features reduce risks to ALARP. When discussing ALARP, the RP also refers to claims related to practical elimination of large or early releases.
4. The RP highlights specific areas in which ALARP arguments are made or will be made (for example choosing IVR over an ex-vessel retention strategy, choosing not to include a filtered containment vent).
   1. Basis of assessment: Requesting Party’s documentation
5. The principal documents that have formed the basis of my Severe Accident Analysis assessment of the E3S case are:

* Severe Accident Management Strategy (ref. [29]) – This document describes the typical progression of a severe accident in the Rolls-Royce SMR, the important phenomena, the severe accident safety features, and an overview of how the safety case will be structured.
* Severe Accident MAAP5 Methodology Report (ref. [30]) – This document provides an overview of the MAAP5 model used for the Rolls-Royce SMR model used in Step 2, the MAAP5 verification and validation status, the severe accident sequences identified for Step 2, a description of how MAAP5 is used to support the severe accident analysis safety case, and the figures of merit used in the severe accident analysis.
* Severe Accident Analysis Summary Report (ref. [31]) – This document summarises the deterministic analysis performed during Step 2 to demonstrate the effectiveness of the severe accident safety features (and other design provisions claimed in severe accident mitigation). The analysis of three accidents are presented: a large break LOCA, a slow depressurisation, and a station blackout.
* Verification and validation of the MAAP5 code (refs. [32], [33], [34]) - This suite of documents presents the current status of the verification and validation for the MAAP5 code.
* Containment Safety Measure Design Description (ref. [35]) – This report summarises the severe accident safety features incorporated in the Rolls-Royce SMR design.
* Severe Accident Off-site Consequences Methodology (ref. [36]) – This report summarises the RP’s approach to radiological consequence analysis; describing the validation methodology, the proposed numerical targets, assumptions in the analysis, inputs to the analysis and links the severe accident deterministic analysis to the PSA.

1. My assessment has considered the lower-tier documents (see above) which support Chapter 15. The information in Issue 3 of Chapter 15 (ref. [1]) appears consistent with the supporting lower-tier references, and I have not assessed this report in detail.

# ONR assessment

* 1. Assessment strategy

1. The scope of my assessment and the targeted areas are set out in sections 1 and 2 of this report. The design and demonstration of the effectiveness of safety features is based on a set of conditions which the RP deems reasonable. These conditions are referred to as Design Extension Conditions (DEC) in both IAEA and WENRA guidance. The deterministic analysis that is used for severe accident safety features is referred to as DEC-B analysis hereon, and is a significant targeted area of my assessment. DECs with limited fuel failure (often referred to as DEC-A) are covered in the Fault Studies assessment.
2. My assessment strategy has been to sample the analysis of each of the safety features specifically designed to prevent/mitigate severe accident phenomena that have the potential to lead to large or early releases.
3. Specifically, I have sampled parts of the safety case supporting the design of the IVR strategy, hydrogen removal, severe accident depressurisation and containment heat removal. In my opinion, these systems provide the fundamental basis for severe accident mitigation, and my sampling is therefore aligned with a key objective of Step 2.
4. During Step 2, the design and model maturity in relation to the severe accident mitigation strategies was at a relatively early stage. At the time of performing deterministic analysis, there was large uncertainty in the design with several open options still being evaluated by the RP. The lower-tier safety case documentation, therefore, is not fully aligned with Design Reference Point (DRP) 1 [37]. However, the RP has anticipated this and covers the design uncertainties by including wide ranging sensitivity analyses. Safety case documents that support DRP 1 recognise that gap, and explain why the sensitivity analyse that was performed prior to DRP 1 still provide adequate design substantiation for Step 2. My assessment has therefore focussed on the RP’s sensitivity analyses to determine whether any of the potential options could undermine the fundamental adequacy of the design.
   1. Assessment
      1. Severe accident management strategy
5. It is my expectation that a systematic approach is taken to analysing severe accident scenarios and that reasonably practicable measures are identified to mitigate severe accident phenomena. These expectations are informed by ONR’s SAPs, FA.15, FA.16 (ref. [6]) and the guidance provided in NS-TAST-GD-007 (ref. [19]).
6. Severe accident safety features provide a significant contribution to the practical elimination of phenomena that could challenge the containment and lead to a large or early release. This is recognised in SSR-2/1 (ref. [22]). My assessment of the RP’s approach to practical elimination as a whole is summarised in section ‎4.2.7. However, both SSG-2 (ref. [23]) and SSG-88 (ref. [24]) provide useful lists of PWR severe accident states which should be practically eliminated. These have been used here to inform my judgement on the RP’s approach to severe accident management.
7. In identifying reasonably practicable safety features to provide safety functions during severe accident conditions, it is my expectation that they are sufficiently independent to those claimed in other levels of defence in depth, so far as reasonably practicable. This expectation is informed by EKP.3 (ref. [6])
8. In addition to the above, it is my expectation that essential services, such as heat removal and power supplies, and appropriate C&I is provided to support the safety functions of severe accident safety features. My expectations are informed by EES.1 and ESR.1 (ref. [6]).
9. In this section, I summarise my assessment of the approach to severe accident management summarised in the RP’s severe accident management strategy (ref. [29]).

**Identification of relevant severe accident phenomena**

1. The RP presents an overview of the typical progression of a severe accident in the Rolls-Royce SMR. The RP categorises the severe accident progression into four phases:

* initial loss of coolant/heat removal;
* in-vessel phenomena
* ex-vessel phenomena; and
* containment response.

1. The RP identifies which phenomena should be considered for analysis for design extension conditions. The RP identifies IVR, hydrogen reduction, primary circuit depressurisation and containment heat removal as severe accident mitigation strategies. No strategies are identified for ex-vessel phenomena mitigation as the RP aims to demonstrate that the severe accident safety features will prevent RPV [JAA] failure in DEC-B scenarios.
2. In addition to the phenomena identified above, the RP recognises that re-criticality and in-vessel steam explosions should be considered during severe accident progression (ref. [38]). Re-criticality and in-vessel steam explosions have the potential to challenge the severe accident management strategies. Whilst the effectiveness of the severe accident management strategies is within the scope of my Step 2 assessment, the analysis has not been submitted during Step 2. However, based on previous experience, I have confidence that the RP will be able to demonstrate that these phenomena can be avoided, and I will revisit this in Step 3.
3. The RP also recognises the need to consider containment bypass in the Rolls-Royce SMR Ltd. design (ref. [29]). In my opinion, due to the closed cycle and passive nature of the RP’s severe accident management strategy, this is likely to be of importance to sustaining prolonged severe accident management. The safety case for this has not yet been developed, and I will follow this up in Step 3.
4. I judge that the RP has clearly demonstrated an understanding of severe accident progression in the Rolls-Royce SMR. The phenomena identified for severe accident mitigation and ultimately practical elimination aligns with my expectations, as informed by SSG-2 (ref. [23]) and SSG-88 (ref. [24]). Overall, the RP’s approach to identifying relevant severe accident phenomena meets my expectations, which are informed by FA.15 (ref. [6]) and NS-TAST-GD-007 (ref. [19]).

**Identification of severe accident safety features**

1. It is my expectation that the RP identifies appropriate safety features to prevent/mitigate relevant identified phenomena. These expectations are informed by FA.16 (ref. [6]) and NS-TAST-GD-007 (ref. [19]). In the following sections I summarise my assessment of the RP’s approach to identifying severe accident safety features to prevent/mitigate the phenomena identified.

*In-Vessel Retention*

1. As stated, IVR is adopted in the Rolls-Royce SMR design. Amongst its reasons for choosing IVR, the RP claims that IVR prevents RPV [JAA] failure, maintaining an additional barrier to release, and therefore prevents large ex-vessel steam explosions and basemat penetration (ref. [38]).
2. The IVR approach has been adopted by several Generation III/III+ reactors. It is internationally recognised that a limiting factor for IVR is the reactor power, as the power density of the corium limits how much heat can be removed from the RPV [JAA] lower head. The Rolls-Royce SMR reactor power is lower than other Generation III/III+ reactors, has a similar geometry to other reactors and adopts an ex-vessel cooling channel. I therefore anticipate that the margins to cooling acceptance criteria to be greater than for gigawatt-scale reactors. Therefore, I judge that the IVR approach is appropriate for the Rolls-Royce SMR design.
3. I judge that the IVR approach is an appropriate strategy for preventing progression of core melt accidents leading to ex-vessel steam explosions and basemat penetration. This aligns with my expectations that appropriate SSCs are identified to prevent/mitigate relevant severe accident phenomena, informed by FA.16 (ref. [6]) and NS-TAST-GD-007 (ref. [19]). I assess the RP’s current substantiation of the IVR approach in section ‎3.3.4 below.

*Hydrogen Management*

1. Following optioneering performed during my Step 2 assessment, the RP has chosen to only include Passive Autocatalytic Recombiners (PARs) in its HRS [JMT] (ref. [39]), and has excluded the use of ignitors from its design. Whilst no explicit guidance exists as to what is relevant good practice for hydrogen mitigation, the use of PARs for severe accident hydrogen mitigation is common (ref. [40]), and has been assessed in previous GDAs. I therefore judge the implementation of PARs to be appropriate. The RP claims that PARs alone (with no ignitors) will be capable of sufficiently reducing hydrogen global concentrations. My Step 2 assessment of the current substantiation of the sizing of the PARs is covered in section ‎3.3.4.
2. It is common practice to provide hydrogen monitoring inside containment to aid operator decision-making in an accident situation (ref. [40]). The safety case related to containment monitoring is limited at present. However, the RP states that only two hydrogen monitors are proposed in the containment. Since the RP has not submitted any analysis related to localised phenomena to date, nor has the RP submitted detailed analysis of the containment spray, I have been unable to make a judgement on the adequacy of this system in Step 2. However, I judge that a later design solution will be achievable and that any later design modifications will not undermine my judgement of the fundamental adequacy of the design for Step 2, and I will follow this up as part of Step 3.
3. I judge that the adoption of PARs to prevent conditions that could challenge the containment is appropriate. The approach aligns with my expectations that appropriate SSCs are identified to prevent/mitigate relevant severe accident phenomena, informed by FA.16 (ref. [6])and NS-TAST-GD-007 (ref. [19]). This is dependent on the substantiation of the HRS [JMT], which is covered in section ‎3.3.4 below. I will assess the adequacy of the hydrogen monitoring during Step 3.

*Severe Accident Depressurisation*

1. During Step 2, the RP made a design decision to include safety functions to enable depressurisation of the primary circuit during severe accidents and prevent HPME (ref. [41]). The RP claims that the potential routes for depressurisation are either through the HTOP or the Low Pressure ADS [JNF] (ref. [35]), which form part of the safety measures for design basis accidents (at Level 3 defence in depth). Manual actuation of the motor operated pilot valves which actuate the HTOP SRVs [JNF] are controlled and powered by the Severe Accident Management System (SAMS) [34]. Primary circuit depressurisation is a recognised and commonly employed design provision for avoiding HPME (and subsequent direct containment heating) (ref. [24]), and in my opinion, is a beneficial improvement to the RP’s design.
2. Whilst there is ongoing optioneering and analysis (which I address in section ‎3.3.4), I judge that the inclusion of primary circuit depressurisation for severe accidents is a positive design modification and aligns with my expectations related to prevention of HPME. The approach aligns with my expectations that appropriate SSCs are identified to prevent/mitigate relevant severe accident phenomena, informed by FA.16 (ref. [6]) and NS-TAST-GD-007 (ref. [19]). I will assess the substantiation of the design during my Step 3 assessment.

*Containment heat removal systems*

1. The Rolls-Royce SMR design includes the PCC to remove heat from the containment and thus reduce containment pressure, with the goal of preventing containment overpressure.
2. The system comprises 3 sets of PCC heat exchangers, each supported by a LUHS [JNK]. The RP claims that heat can be removed is a passive mode of operation for up to 120 hours. I judge that the inclusion of a passive heat removal system is beneficial for plant autonomy and is aligned with RGP from some other Generation III/III+ reactors.
3. However, the function employs the same SSCs to those claimed for emergency core cooling as part of provisions for Level 3 defence in depth. During Step 2, the RP recognised potential shortfalls in independence between levels of defence in depth. The RP therefore introduced the CCSF, which is an active means of heat removal during severe accidents. The cooling chain is provided by the CSCS [JNA] or spent fuel pool cooling system. The spray function can be delivered via the Fire Water System (FWS) [XGB] or CSCS [JNA] via a cross connection to the FWS [XGB] (referred to as ‘CCSF spray mode’). The design details regarding this functionality have not been completed during Step 2. Unlike the severe accident depressurisation, is powered and actuated by SSCs dedicated for severe accident management (i.e. batteries and SAMS), the RP has not made a similar claim for the CCSF. The RP have not provided details of whether it intends to qualify SSCs claimed for CCSF for the environmental conditions that they may experience. Regardless, I judge that this is likely to be achievable and does not affect my judgement on the overall fundamental adequacy of the design. Along with an assessment of the general architecture, I will follow these aspects up during my Step 3 assessment.
4. Although there are open questions related to containment heat removal during severe accidents, in general, I judge that the RP has adequately identified safety features to prevent containment overpressure via heat removal systems (excluding containment venting, addressed below). The approach aligns with my expectations that appropriate SSCs are identified to prevent/mitigate relevant severe accident phenomena, informed by FA.16 (ref. [6]) and NS-TAST-GD-007 (ref. [19]).

*Containment filtration and venting system*

1. The RP has made a preliminary decision not to include filtered containment venting during Step 2 (ref. [42]). As the Level 2 and 3 PSA has not been completed, the full justification for this decision has not been submitted during step 2. However, the RP states that the option for including a filtered containment vent are not foreclosed by the design at this stage. There is still design uncertainty in this area. I judge that since the RP has not foreclosed options, this does not affect my overall judgement on the fundamental adequacy of the design for Step 2, and I will revisit this topic in Step 3.

*Containment Isolation*

1. In addition to my general expectation that severe accident safety features are identified to prevent/mitigate relevant phenomena, it is my expectation that a containment is provided to control and prevent the release of fission products during accident conditions, and that the containment penetrations can be isolated during those conditions. These expectations are informed by Requirements 54 and 56 of SSR-2/1 ref. [22].
2. The Rolls-Royce SMR containment design is a steel vessel that comprises the majority of major components of the primary circuit and steam generator. The provision of a reactor containment clearly aligns with the Requirement 54 of SSR-2/1 ref. [22]. Substantiation of the containment is within the scope of the Structural Integrity assessment [43], and the relevant acceptance criteria for the demonstration of the effectiveness of safety features are assumed to be valid in this report.
3. The containment isolation function is of importance in severe accidents, and it is my expectation that this safety function is independent of the measures which deliver protection at Level 3 of defence in depth, so far as reasonably practicable (EKP.3). The RP claims that the Rolls-Royce SMR design includes the provision for remote manual isolation of the containment during a severe accident and that these functions are assigned to the SAMS [JRQ20] (ref. [35]). However, the details of SAMS [JRQ20] C&I system are not currently available. It is my expectation that detailed design of the SAMS [JRQ20] is provided during Step 3 (which I consider appropriate and achievable), and I will assess this claim further in my Step 3 assessment.
4. Although open points remain for Step 3, in general, I judge that the RP’s proposed approach to provide dedicated isolation for severe accident scenarios is appropriate. The approach aligns with my expectations that appropriate SSCs are identified to prevent/mitigate relevant severe accident phenomena, informed by FA.16 and NS-TAST-GD-007 (ref. [19]).

*Conclusions related to identification of severe accident safety features*

1. In summary, although there are several open points that I will follow up during my Step 3 assessment (including the decision to exclude filtered containment venting), I judge the safety features identified are appropriate to prevent/mitigate the identified severe accident phenomena. In general, I judge that the approach aligns with my expectations that appropriate SSCs are identified to prevent/mitigate relevant severe accident phenomena, informed by FA.16 and NS-TAST-GD-007 (ref. [19]).

**Supporting systems**

1. As stated previously, it is my expectation that support from essential services and C&I is provided to enable severe accident management.
2. It is the RP’s intention to design the Rolls-Royce SMR such that severe accident mitigation can be supported by battery-backed DC power alone (except for CCSF and CSCS [JNA]), using the Low Voltage Uninterruptible DC Supply System for Safety Services [BQ] (refs. [4] and [35]). I have not assessed the safety case for sizing of the power supplies during Step 2.
3. Besides the cooling chains to support active heat removal, the RP claims that the PCC system is completely passive. The RP claims that the associated valves are normally open and the fail-safe position is open. Thus, no mechanical movement is required for PCCS to initiate. In my judgment, this is a positive aspect of the Rolls-Royce SMR. The RP claims that the LUHS [JNK] can provide cooling for 120 hours. I have not assessed this claim in detail and will follow this up in Step 3.
4. Limited C&I information is presented on the SAMS [JRQ20] (ref. [3]). The RP claims that the SAMS [JRQ20] is a two-division system and will be supported by dedicated batteries. Whilst these features may provide the basis for an adequate design, it is unclear which safety functions this system will enable. I cannot, therefore, draw any conclusions on the actuation of systems and monitoring during severe accidents. I will follow this up in my Step 3 assessment.
5. To conclude, the RP has clearly recognised the need to provide dedicated power supplies, cooling and C&I to support severe accident safety features. Whilst limited information is available for my Step 2 assessment, I have confidence that the design can be developed to meet my expectations for ESS.1 and ESR.1. I will assess this further during Step 3.
   * 1. Severe accident analysis methodology
6. The severe accident methodology is presented in both ref. [29] & [30]. The methodology can be divided into two parts: the overall safety case methodology, and the deterministic analysis methodology. In this section I discuss the two aspects in turn.

**Safety case methodology**

1. It is my expectation that a severe accident analysis safety case is presented during GDA (ref. [44]). It is also my expectation that safety functions and safety measures that perform those safety functions are identified (EKP.4 and EKP.5 (ref. [6])). In addition, aligned with SAP ECS.1 (ref. [6]), I expect that the safety functions should be sufficiently detailed to facilitate a clear demonstration of their effective delivery.
2. The RP presents the overall severe accident safety case in ref. [29]. An overview of the ‘golden thread’ is presented, and can be found in Figure 3 below.

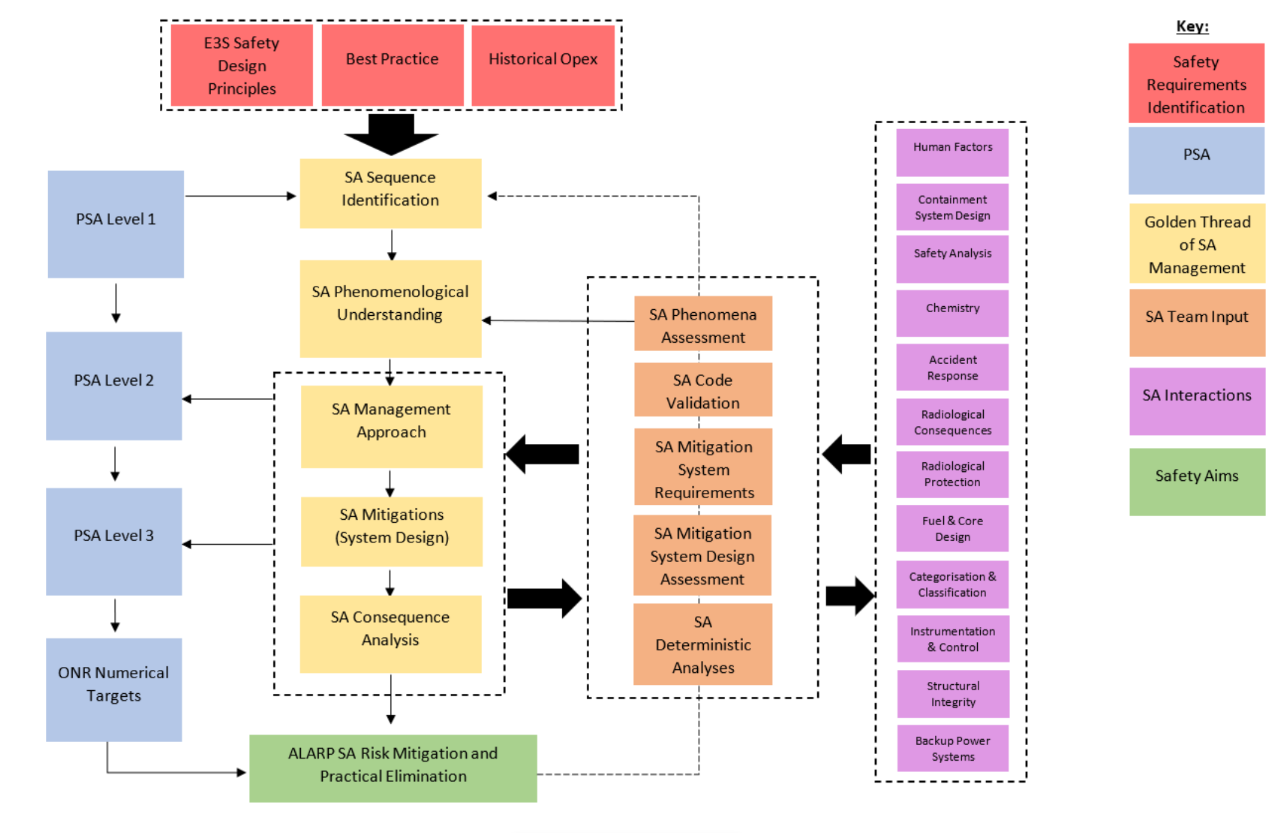


Figure 3 - Severe Accident Analysis Golden Thread (ref. [29])

1. The RP demonstrates the golden thread from understanding the severe accident phenomena, understanding which sequences should be considered within the design, designing severe accident safety features and demonstrating their effectiveness. The links to the PSA are clear, and the approach of combining probabilistic and deterministic analysis to demonstrate practical elimination can be seen. I judge that the severe accident analysis safety case structure is clear and the interfaces with other disciplines is well understood. I am therefore satisfied that my expectations as laid out in refs. [19] & [44] are met. During Step 3 I will assess these interfaces in more detail (for example equipment qualification).
2. However, the RP’s safety case (ref. [29]) only includes a high-level description of the safety functions. The safety case does not currently include a safety functional decomposition, and in my opinion, does not enable a clear demonstration of the effective delivery of their safety functions. As described in Section ‎3.3.1 above, the RP has clearly identified the relevant phenomena for which to design its severe accident safety features; therefore, this shortfall is not significant for Step 2. However, aligned with my expectations for EKP.4 and ECS.1 (ref. [6]), the derivation of safety functions is key to demonstrating that a comprehensive and holistic consideration of severe accident mitigation has been taken, and I will follow this up in Step 3.

**Deterministic analysis methodology**

1. It is my expectation that appropriate methods are used to demonstrate the effectiveness of the severe accident safety features. I expect that the RP identifies appropriate codes to perform the analysis which adequately model phenomena and that the sequences are analysed on a best estimate basis. I also expect that, in addition to radiological targets, technical criteria are identified to determine the effectiveness of the safety features identified. My expectations are derived from FA.15, FA.16 (ref. [6]), NS-TAST-GD-007 (ref. [19]) and SSG-2 (ref. [23]).
2. The methodology for demonstrating the effectiveness of the safety features is presented in the MAAP methodology report (ref. [30]). The methodology is focused on the use of the MAAP5 computer code as this provides the foundation for the substantiation of the effectiveness of the severe accident safety features. The RP provides an overview of the code validation, the model used, the identification of sequences, the analysis and sensitivity analysis performed to account for design uncertainties, future sensitivity analyses to be performed to account for inherent severe accident uncertainties, and the success criteria and figures or merit are described.
3. In the methodology report (ref. [30]), the RP explains that the analysis is performed on a best estimate basis using the MAAP5 code. The model is described at a high level. I note that, whilst a best estimate approach is taken, the large uncertainties in the design at this stage mean that the progression of severe accidents is not a best estimate prediction. For example, the analysis (ref. [31]) is based on an earlier design iteration which uses an accumulator pressure of 70 bar, whereas the latest design iteration has an accumulator pressure of 45 bar. In this particular example, I note that the sensitivity analysis conservatively assumes no accumulators are available to inject.
4. I judge that the RP’s approach to using sensitivity analyses to account for design uncertainties and limitations in the model are reasonable at this stage. My assessment of the sequences chosen and the deterministic analysis performed (including sensitivity studies) is summarised in section ‎3.3.3 and ‎3.3.4.
5. The RP lists the acceptance criteria for determining the effectiveness of the severe accidents safety features (ref. [30]). These are: successful depressurisation of the primary circuit to avoid HPME, success of IVR, avoidance of overpressure of the containment and meeting radiological targets. More specific acceptance criteria are identified in other submissions (ref. [31] and [35]) and it is unclear why these are not also articulated in the methodology report (ref. [30]). In Step 3, I expect that a full list of technical acceptance criteria are specified and justified.
6. It is notable that whilst the RP recognises that other specialist computer codes may be required for certain phenomena, none are committed to in ref. [30]. This is a consequence of the current safety case structure, where the RP uses MAAP5 as its foundation for deterministic analysis. Any areas of weakness in the code are determined in the PIRT and TAM (which are summarised in ref. [32]) and recommendations for the use of other codes is made. Although the RP recognises that other specialised codes may need to be employed for more detailed hydrogen analysis, no additional codes or analysis have been committed to (ref. [32]). In my opinion, detailed analysis of localised hydrogen behaviour and RPV [JAA] mechanical properties represent relevant good practice, and I will follow this up during my Step 3 assessment.
7. Overall, for my Step 2 assessment, I am content with the approach to deterministic analysis taken. The use of the MAAP5 code (subject to adequate verification and validation, see section ‎4.2.5) and best estimate modelling is aligned with my expectations for deterministic analysis of severe accidents. Although the models are not fully reflective of the developing Rolls-Royce SMR design, the use of sensitivity analysis to account for uncertainties is a pragmatic and reasonable approach at this stage. I am therefore content that the RP’s approach aligns with my expectations informed by FA.15, FA.16 (ref. [6]), NS-TAST-GD-007 (ref. [19]) and SSG-2 (ref. [23]) at Step 2.

### Identification of severe accident sequences

1. It is my expectation that appropriate severe accident sequences are identified in order to size the severe accident safety features and demonstrate their effectiveness. It is also my expectation that a systematic approach is taken in selecting severe accident sequences. My expectations are informed by Requirement 20 of SSR 2/1 (ref. [22]), SSG-2 (ref. [23]) and NS-TAST-GD-007 (ref. [19]) and FA.2 and FA.3 (ref. [6]).
2. To date, the RP has identified the following cases for analysis:

* Slow Depressurisation (SDP)
* Station Blackout (SBO)
* Large Break Loss of Coolant Accident (LB LOCA)

1. All are analysed initiating from full power, with varying assumptions related to system availability. In all cases, design basis (Level 3 defence in depth) measures for injection of water into the core from emergency core cooling and passive decay heat removal system are assumed to be unavailable. For more information on these systems, see the Fault Studies assessment report (ref. [45]). The RP has not assessed accidents initiated from other plant operational states (including spent fuel pool accidents) and they are not in the scope of my Step 2 assessment. I will consider these further in my Step 3 assessment. However, in my opinion, for the reactor, the full power case is likely to be the bounding case for the demonstration of the effectiveness of all of the severe accident safety features.
2. The RP has not taken a systematic approach in deriving these sequences. Instead, the RP has used engineering judgement and experience from other reactor designs. The justification for choosing the three scenarios is related to prolonging hydrogen generation (SDP), limiting conditions for system depressurisation (SBO) and increasing the speed of corium relocation (LB LOCA). In my opinion, the RP should take a systematic approach to identify the sequences to determine the most limiting scenarios for each severe accident safety feature. For example the size and release location of both a small break and severe accident depressurisation will have an impact on the limiting case for hydrogen, and the RP should demonstrate that the worst case has indeed been identified.
3. Nevertheless, I judge that the selected scenarios are a suitable preliminary set and I am satisfied in the approach of using sensitivity analyses to account for uncertainties in the design. I judge that the RP’s reasoning for the set of sequences produced to date is clear and logical, and is broadly aligned with what has been performed in other GDAs. I am therefore content that my expectations for Requirement 20 of SSR 2/1 (ref. [22]), SSG-2 (ref. [23]) and NS-TAST-GD-007 (ref. [19]) are broadly met at this stage.
4. However, during Step 3, I expect a more systematic approach to be taken during severe accident sequence selection. I will follow this up during Step 3.

### Analysis of severe accident sequences

1. As stated previously, it is my expectation that deterministic analysis is performed to demonstrate the effectiveness of the safety features based on appropriate severe accident sequences, and that the RP demonstrates a good understanding of the relevant phenomena and progression of accidents. My expectations are informed by FA.15, FA.16 (ref. [6]) and SSG-2 (ref. [23]) and NS-TAST-GD-007 (ref. [19]).
2. In this section, I present my assessment of the deterministic analyses submitted to date. During my Step 2 assessment, due to the uncertainties in the design, I have not assessed the modelling choices and assumptions made in the analysis in detail. I have instead taken a higher-level view of the analysis to allow me to make a judgement for Step 2 on whether there are any fundamental concerns with the design of the severe accident safety features. In Step 3, when the model and analysis is more reflective of the design, I will assess the analysis in more detail.
3. The analysis presented in ref. [31] is based on an earlier design iteration (‘Reference Design 6’ – (RD6)). Currently, the Rolls-Royce SMR design is at RD7. At RD6, some design decisions were (and still are) open, and design modifications have been made at RD7 that were not included at RD6. These include: depressurisation route (from primary circuit to containment), in-vessel retention initial filling and recirculation piping, capacity of the PCC HXs, PARs capacity and CCSF design. Additional preliminary analysis related to the CCSF and severe accident depressurisation, which is not presented in ref. [31], is presented in ref. [35] and [46].
4. The RP presents the ‘base case’ analyses for the LB LOCA, SDP and SBO sequences in ref. [31]. In lieu of detailed information related to the design of the severe accident depressurisation system, the base case assumes that the depressurisation of the primary circuit occurs based on the performance of the system which delivers protection for design basis faults. The base case also only assumes that the one accumulator and one train of the PCC system is available, amongst other conservative assumptions. It should be noted, therefore, that the base case does not provide a best-estimate representation of the progression of a severe accident; however, this is simply an issue of semantics, as the RP performs sensitivity studies to cover many scenarios.
5. For each base case, a description of the assumptions made and accident progression is provided, along with all relevant transient plots. For each case, additional sub-sections for sensitivity analyses are also provided. I judge that the analyses are presented clearly and are well described. The RP demonstrates a good understanding of accident progression. This meets my expectations which are informed by FA.15 and FA.16 (ref. [6]).
6. As stated above, it is my expectation that deterministic analysis is performed to demonstrate the effectiveness of the severe accident safety features identified. The ultimate goal is to demonstrate that large or early releases are practically eliminated. A major part of demonstrating practical elimination is to demonstrate that the safety features are capable of meeting appropriate acceptance criteria for a given safety feature/phenomenon, using appropriate severe accident sequences, using deterministic analysis. In the sub-sections below, I cover each of the analyses for severe accident safety features in turn.

**In-Vessel Retention**

1. The RP has presented analysis of the LB LOCA base case (which it claims to be bounding for IVR) and a range of sensitivity analyses related to filling of the reactor cavity and accumulator availability to demonstrate its effectiveness (ref. [31]).
2. The RP claims that the double-ended guillotine break LB LOCA presents the worst case for IVR. This is because the rapid onset of core degradation leads to large decay heat in the RPV lower head. This is commonly regarded as the worst case for IVR (ref. [47]) and I judge that this is appropriate in this case.
3. The RP presents results related to time to corium relocation and margin to critical heat flux (CHF) for the LB LOCA. The RP aims to demonstrate that CHF, using Yang’s correlation (see Section ‎4.2.5), is not reached, therefore demonstrating the effectiveness of IVR. It is widely accepted that avoidance of CHF allows sufficient heat to be removed and prevents excessive ablation of the RPV [JAA], which would otherwise lead to RPV [JAA] failure (ref. [47]). I therefore judge that the use of CHF as an acceptance criterion, in principle, is appropriate.
4. The RP claims that, in reality, RPV [JAA] failure is not instantaneous if no water is present in the lower head when corium is relocated, i.e. it takes time for the corium to ablate the RPV and weaken its structural integrity. I judge that this claim is reasonable, but is subject to the verification and validation of the MAAP5 code (see my assessment in Section ‎4.2.5). For analysis submitted to date, this claim is only important for the RP’s sensitivity studies, and I have assumed it is valid for my Step 2 assessment. However, in Step 3, I will target this claim if it cannot be demonstrated that the reactor cavity is filled prior to corium relocation.
5. In the base case, water from the break is assumed to partly fill the reactor cavity and the containment sump, providing a heat sink early in the accident progression. The 650 deg C severe accident management entry condition is reached at approximately [Redacted] hours, and cavity injection from the Refuelling Pool [FAF] occurs at [Redacted] hours. Several corium relocations to the lower head occur, with the maximum heat load in lower head observed at [Redacted] hours (where relocated decay heat is at a maximum). The analysis shows that maximum heat flux occurs at this time, which is approximately half of the critical heat flux. The RP concludes that IVR is therefore demonstrated to be effective.
6. During my Step 2 assessment there has been uncertainty relating to the configuration and architecture of the pipework for filling the reactor cavity and connecting the reactor cavity to the containment sump (where all condensate returns to). The RP therefore presents two sets of analysis related to delaying of opening the Refuelling Pool [FAF] valves: one set where water from the break can enter the cavity and one where no water from the break enters the cavity (i.e. it remains dry until the Refuelling Pool [FAF] valves are opened). The former set of analyses progress similarly to the base case. However, in the second set, in the worst case ([Redacted] hour delay to flooding reactor cavity from Refuelling Pool [FAF]) RPV [JAA] failure is predicted to occur within [Redacted] hours. The [Redacted] hour delay is viewed by the RP to be conservative, and smaller delays ([Redacted], [Redacted] and [Redacted] hours) result in successfully meeting acceptance criteria. The RP claims, therefore, that the demonstration of the effectiveness of IVR is not particularly sensitive to design uncertainty around the configuration of the IVR cavity to refuelling pool connections. I judge that the RP’s demonstration is robust and the conclusions are reasonable.
7. The RP also presents analysis related to the accumulator availability. Analysis is presented assuming no accumulators are available, which, in my opinion is overly conservative. The RP demonstrates that even without any accumulator injection, sufficient heat is removed to avoid CHF. I judge that this is a robust demonstration of the insensitivity of the IVR strategy to large uncertainties in the progression of a severe accident.
8. In conclusion, I judge that the RP has provided a robust demonstration of the IVR strategy to allow me to draw conclusions for Step 2. Whilst there are limitations in the analyses due to both model and design immaturity, the RP’s sensitivity analysis indicates that IVR is likely to be demonstrated to be successful in more up-to-date modelling which better represents the Rolls-Royce SMR design (which will be available for my Step 3 assessment). For the purposes of my Step 2 assessment I am therefore satisfied that the intent of SSG-2 ref. [28] has been demonstrated. However, I expect that the RP provides analysis which better represents the Rolls-Royce SMR design in Step 3. I will follow this up in Step 3.

**Containment heat removal**

1. The RP uses the cold-leg LB LOCA to demonstrate the effectiveness of the containment heat removal system. This is due to the initial fast depressurisation of the primary circuit following the LB LOCA and hydrogen generation. The hot-leg LB LOCA has presented the worst case scenario for containment overpressure in other GDAs due to the larger proportion of the leaked coolant being in the steam phase than the cold-leg. As stated previously, for Step 3, I expect a more systematic approach to be taken to determine the worst case. Nevertheless, for Step 2, I judge the chosen scenario to be reasonable.
2. The RP states that the ultimate capacity of the containment was not available at the time of writing the summary report (ref. [31]), therefore an acceptance criterion of 7 bara has been assumed by the RP. At this stage, I have not assessed substantiation of the acceptance criterion and I will follow this up as part of my Step 3 assessment. However, for the purposes of forming a judgement for my Step 2 assessment, it should be noted that the analysis incorporates significant pessimisms. Specifically, the model does not include spargers in the depressurisation route (important for intact circuit faults) and only one PCC HX is credited in the base case.
3. However, whilst a peak containment pressure acceptance criterion is aligned with what I expect for a demonstration of the effectiveness of the heat removal systems, it does not meet my expectations for demonstrating that containment functions can be provided in the long term. I also note that for other GDAs, long-term containment pressure acceptance criteria have been adopted. I will follow this up in Step 3.
4. The RP’s analysis of the base case, which only assumes one PCC HX is available, demonstrates that when the PCC system is aligned early, the containment pressure is ‘turned over’ and held below the acceptance criterion. In this case the peak containment pressure is approximately 6 bara. Whilst the predicted peak containment pressure initially appears relatively high, the RP notes that modelling of heat structures in the model used in ref. [31] are not well developed. In addition, as the base case assumes only one PCC HX is available. Although the RP identifies a potential optimism, I am satisfied that overall the analysis is conservative and that future analyses with a better estimate of the PCC HX capacity will demonstrate that the PCC HX is effective in reducing the pressure of the containment to within acceptable limits.
5. Due to uncertainty in the alignment and actuation of the PCC system during the time of performing the analysis, the RP analysed cases with delays to PCC actuation. Only the case where there is a [Redacted] hour delay to the alignment of the PCC system result in the acceptance criterion being exceeded. I note, however, that since the analysis, a design decision was made to have the PCC ‘wetted’ at all times (i.e. the PCC HX are normally aligned and require no actuation) (ref. [35]).
6. I judge that the RP’s analysis adequately demonstrates the effectiveness of PCC system accounting for current uncertainties. I am therefore satisfied that it meets my expectations, which are informed by NS-TAST-GD-007 and SSG-2, related to demonstration of the effectiveness of safety features and accounting for uncertainties. Notwithstanding this, I will assess the analysis in further detail in Step 3 when the model is more reflective of the Rolls-Royce SMR design. I will follow this up in Step 3.
7. In addition to the passive heat removal using the PCC, the RP provides a preliminary set of analysis related to the effectiveness of the active heat removal system (ref. [31]) which is still in development. I have not assessed this in detail, however, I note that the initial results provide confidence that active heat removal will also be effective in preventing the containment pressure from exceeding the 7 bara acceptance criterion. In Step 3, I will assess the analysis in more detail.

**Hydrogen management**

1. For the analysis I have considered in Step 2, the RP has only considered hydrogen effects globally within the containment. The RP has not performed analysis of localised phenomena (see Section ‎4.2.5). At the time of the analysis, there was significant uncertainty in the containment layout, free space and PARs capacity and location. The RP therefore performed several sensitivity analyses to account for design uncertainty (ref. [31])
2. The RP presents analysis for the SDP sequence. Initially, two cases are presented to determine the base case on which to perform sensitivity analysis: a 13 mm break and a 25 mm break. The latter is selected as the base case taken forward for sensitivity analysis as a larger hydrogen mass generation is predicted by the MAAP5 code. The RP presents sensitivity analysis on this base case related to primary circuit blowdown times and PAR availability.
3. The RP recognises in ref. [31] that these sequences may not represent the worst case scenario for hydrogen generation and further work is required to investigate the effect of break location and size. Recognising the relatively simplistic nature of the analysis presented so far, I judge that this is sufficient to provide confidence that the RP will be able to determine the design requirements for the HRS [JMT]. I will follow this up in Step 3.
4. The analysis presented in ref. [31] is based on the RD6 design iteration. Since then, the RP has reduced the capacity of the PARs by roughly half (ref. [35]). This design choice is supported by the RP’s sensitivity analysis that includes two cases in which only half of the originally planned and zero PARs are credited. The analysis demonstrates that the zero PARs case is the most limiting case, and the highest peak hydrogen concentration from all cases is approximately 6.2% by volume, which corresponds to rapid oxidation of the zircaloy cladding. The RP claims that although the PARs model is not representative of the latest (RD7) design, the sensitivity analysis presented in ref. [31] accounts for the differences and concludes that the 10% by volume global concentration acceptance criterion is not reached in ref. [35]. Although the RP has not, at this stage, performed analysis of localised phenomena, the global concentration compares favourably with that seen for other reactors. In my opinion, given that the Rolls-Royce SMR containment design is ‘open’ and allows free flow of gases and is designed to avoid ‘corridors’ forming, the low global concentration provides some confidence that the challenging localised phenomena (such as fast deflagration, localised clouds and deflagration to detonation) will also be avoided. However, unlike the analysis performed to date, which calculates oxidation on a best estimate basis, when performing localised analysis it is common practice to assume 100% zirconium cladding oxidation. Adoption of this conservatism in future analysis may challenge my assertion stated above and I will follow this up during Step 3.
5. The RP calculates the Adiabatic Isochoric Complete Combustion (AICC) energy (a theoretical calculation of maximum amount of energy that can be generated from hydrogen combustion) at each point in time (ref. [31]). The RP claims that this results in a containment pressure lower than the acceptance criterion of 7 bara. In my opinion, the AICC is a conservative prediction of the maximum energy that can be generated and the RP’s analysis provides confidence that the maximum pressure will not challenge the containment design pressure.
6. I judge that the analysis sufficiently envelopes the design uncertainties and provides confidence that when the model and design matures in Step 3, that adequate margin to global detonation and containment pressure limits should be achievable. The analysis has been performed on a best estimate basis, accounting for large uncertainties. I am therefore content that the intent of SSG-2 (ref. [23]) and NS-TAST-GD-007 (ref. [19]).
7. My assessment has only considered the RP’s analysis of global hydrogen behaviour. As discussed in Section 4.2.5, I will be looking for further evidence in Step 3 that the RP’s conclusions read across to localised hydrogen effects. In Step 3 I will also assess the RP’s updated analysis which should be more reflective of the design.

**Severe accident depressurisation**

1. During the development of the severe accident summary report (ref. [31]), a decision on the blowdown route had not been made by the RP. The analysis, therefore, made the assumption that the high pressure emergency blowdown lines (EBD) would be employed. These lines connect to the HP ADS [JNF] and HTOP valves. The RP claims that the analysis demonstrates that timely action to depressurise the primary circuit can prevent primary circuit and RPV [JAA] failure. If no action is taken, then the primary circuit is predicted to fail in [Redacted] hours due to the presence of hot gases, leading to preferential depressurisation through a primary circuit breach and avoiding RPV [JAA] failure. If primary circuit failure does not occur then the RP claims that failure of the RPV [JAA] only occurs following [Redacted] hours.
2. Since the issue of severe accident summary report (ref. [31]), the RP has been in the process of carrying out optioneering on the depressurisation route. It has provided preliminary analysis to support an option to blowdown via the HTOP valves (ref. [46]) which provides confidence that this route will achieve sufficient blowdown for severe accident depressurisation.
3. I judge that it is too early to comment on the adequacy of the RP’s chosen method for avoidance of HPME. However, the RP has recognised that it should include a severe accident safety feature to avoid HPME, and the early analysis in both refs. [31] & [46] provide confidence that it depressurisation should be achievable. I am therefore satisfied that the intent of SSG-2 (ref. [23]) in relation to HPME is met, and I will assess this in further detail during Step 3.

**Conclusion**

1. The RP has performed deterministic analysis to determine whether its proposed severe accident management strategies will be effective. The analysis accommodates large uncertainties that exist in the design, which the RP has accounted for using sensitivity analyses. Whilst there are many areas for follow up during Step 3, the RP’s work to date provides me with confidence about the RP’s approach to analysis of severe accident sequences. I am content that the RP’s approach is aligned with the expectations for FA.15, FA.16 (ref. [6]), NS-TAST-GD-007 (ref. [19]) and SSG-2 (ref. [23]). The initial analysis considered in my Step 2 assessment has provided an adequate demonstration at this stage of the effectiveness of the severe accident safety features. The RP will be updating aspects of this analysis as the design matures and I will re-visit this in Step 3.

### Verification and validation

1. It is my expectation that the codes used for severe accident analysis are appropriate verified and validated for their use. My expectations are informed by AV.1 to AV.6 (ref. [6]), NS-TAST-GD-007 (ref. [19]) and NS-TAST-GD-042 (ref. [20]).
2. During Step 2, I commissioned a TSC to review the verification and validation documentation for the MAAP5 code (ref. [48]). Overall, the TSC found that the MAAP5 code was an appropriate tool for deterministic severe accident analysis of the Rolls-Royce SMR safety features. However, the TSC did identify the following shortfalls based on the RP’s submissions (refs. [33] & [34]). Below, I summarise my findings which are informed by the TSC report (ref. [48]):

* The validation matrix for certain aspects, namely fission product effects on containment thermal hydraulics, iodine modelling, and hydrogen combustion/recombination appears less comprehensive than other modern integral codes.
* The RP states that iodine effects will not be modelled in MAAP5, and that an alternative means of analysing iodine for source term analysis will be performed. No details are available at this stage, but I will work closely with PSA and Chemistry topic areas to understand the implications of this choice during my Step 3 assessment.
* The PCC HXs are not validated in the MAAP5 code. The RP plans to build test rigs to obtain data related to the performance of the PCC HXs following GDA. The RP plans to use this data to validate the PCC HX models. Until then a conservative approach should be taken, and this is scenario dependent. I judge that the analysis I assessed in Step 2 is sufficiently conservative to account for the uncertainty introduced by this shortfall. However, I will follow this up during Step 3 to ensure that a conservative approach is taken where necessary and appropriate.
* The RP’s nodalisation of the containment using the MAAP5 code is relatively simplistic and analysis of localised behaviour is not possible. This has two significant consequences:
  + Localised thermal hydraulic effects are not modelled (for example, fission product behaviour).
  + Localised phenomena related to hydrogen cannot be modelled.

For the former point, the TSC has recommended that a code-to-code comparison of the containment response with the GOTHIC code should provide confidence in the MAAP5 modelling. Regarding modelling of localised hydrogen effects, as stated previously, the RP has recognised that higher fidelity modelling of hydrogen may be necessary. For reasons discussed in ‎3.3.4, this does not undermine my judgement on the fundamental aspects of the design. I will, however, seek evidence in my Step 3 assessment that localised effects have been considered in the design of the HRS [JMT] and will not challenge the containment (for example by avoidance of deflagration to detonation transition). I will also seek evidence that the code chosen by the RP for this is appropriately verified and validated for use.

* In the analysis presented to date, the RP has used Yang’s correlation as a CHF limit in the RPV lower head. Yang’s correlation was derived in a pool of water without a cooling channel. Generally, IVR cooling channels help to increase the critical heat flux by promoting flow and turbulence around the lower head of the RPV. When the boundary conditions (temperature and pressure) are similar, it is therefore conservative to use Yang’s correlation. Yang’s correlation provides a significantly lower value of CHF than that predicted for the AP1000 and UK HPR1000, and I judge it to be conservative for the Rolls-Royce SMR. I therefore judge that the use of Yang’s correlation at this stage, in lieu of any detailed analysis of appropriate correlations, is reasonable.
* The RP does not plan to build a bespoke test rig for the IVR cooling channel. Instead, existing data will be read across to the Rolls-Royce SMR. Since the RP’s current analysis demonstrates large margin to the Yang’s CHF correlation, I consider that this is a reasonable approach. However, I will look for evidence during Step 3 that the existing test data is used to better reflect the IVR design and behaviour.
* The MAAP5 code has been used to determine the mechanical failure of the RPV. The TSC notes that the MAAP5 code capability is aligned with other comparable integral codes. However, other, more sophisticated codes, have been used previously to model RPV behaviour during severe accidents. I will seek justification for the RP’s approach in Step 3.
* Sensitivity analyses of input parameters and models used in MAAP5 have not been presented to date. In my opinion, the dominant uncertainty in the analysis to date (besides the inherent uncertainty of modelling severe accidents, which cannot be resolved), is the design uncertainty. For example, the choice of recombination modelling for the PARs has a lesser effect than halving the number of PARs. Once the design and MAAP5 model have reached a more mature state, I expect that further sensitivity studies should be performed. My expectation is linked to the Chemistry assessment (ref. [49]), which concludes that the RP has provided insufficient detail related to accident chemistry during Step 2. In Step 3, I will work closely with Chemistry in Step 3 when assessing the sensitivity analysis performed.

1. In summary, although there are current shortfalls in the RP’s verification and validation which should be followed up in Step 3, I judge that the information provided to date supports the conclusions of the RP’s current deterministic analysis, meeting my expectations as informed by AV.1 to AV.6 (ref. [6]), NS-TAST-GD-007 (ref. [19]) and NS-TAST-GD-042 (ref. [20]).
2. During my Step 2 assessment, I have targeted the appropriate phenomena considered in the RP’s analysis. However, depending on how the RP intends to derive conditional probabilities for containment failure following ex-vessel phenomena (such as ex-vessel steam explosion) in the PSA, it may be necessary to assess the methods for ex-vessel phenomena in more detail. I will follow this up in collaboration with the PSA inspector in Step 3.

### Radiological consequences

1. It is my expectation that the severe accident deterministic analysis is used as an input into the PSA and that outputs from the PSA are used to determine whether radiological consequence success criteria are met. My expectations are informed by SSG-2 (ref. [23]), NS-TAST-GD-007 (ref. [19]) and FA.25 (ref. [6]).
2. The RP has submitted ref. [36] which describes the relationship between Severe Accident Analysis and PSA. The RP also describes the assumptions related to radiological consequence analysis, which is performed in Level 3 PSA. In ref. [50], the RP describes the radiological dose targets that it proposes to use for its Level 3 PSA. These are identical to ONR’s targets in NT.2 (ref. [6]).
3. At a high-level, the RP’s proposal is aligned with my expectations for the use of deterministic analysis to support the PSA. However, no details are provided in any of the documentation related to analysis of the derivation of the Level 2 source term, nor is any analysis related to transportation of radioactive nuclides or iodine chemistry presented. Whilst these aspects will mainly be in the scope of the PSA and Chemistry assessments during Step 3, I will sample the analysis to gain confidence that the modelling techniques and input assumptions are consistent with those used to demonstrate the effectiveness of the severe accident safety features.

### Practical elimination

1. It is my expectation that the RP should explicitly demonstrate that the Rolls-Royce SMR design practically eliminates sequences that have the potential to lead to a large or early release. This expectation is based on IAEA requirements and a collection of guidance which is summarised in ONR’s NS-TAST-GD-007 (ref. [22]). Based on technical assessment guidance for GDA (ref. [44]), it is my expectation that an explicit demonstration of this is made in the safety case. As part of this demonstration, based on expectations set out in SSG-88 (ref. [24])) and WENRA guidance (ref. [25]), I expect that the RP present both probabilistic and deterministic arguments. It is also my expectation that the demonstration does not only focus on preventing progression and mitigation of the severe accident phenomena, but also considers the contribution that measures at lower levels of defence in depth provide in preventing sequences that have the potential to lead to a large or early release.
2. The RP’s safety case (ref [1]) acknowledges the expectation to demonstrate practical elimination and sets out its methodology for doing so. The RP notes that the lower levels of defence-in-depth play a role in the demonstration of practical elimination, and explains that arguments relating to protective safety measures and high integrity components will be made. The RP states on multiple occasions that the Level 2 PSA will be used to confirm that a phenomenon is very unlikely to occur with a high degree of confidence. This implies that only the Level 2 PSA provides this confidence; however, the RP does note elsewhere that both deterministic and probabilistic arguments should be made and a commitment to do so in a future version of Chapter 15 and a stand-alone report on practical elimination is captured. In the demonstration of practical elimination, I expect that appropriate deterministic analysis of the ‘safety provisions’ is provided to demonstrate the high confidence in their efficacy, and I will follow this up during my Step 3 assessment.
3. In addition to ONR’s numerical targets, the RP proposes the use of core damage frequency and large release fraction/large early release fraction to demonstrate that sequences that have the potential to lead to large or early releases are practically eliminated. I judge that this is aligned with good practice (ref. [24] & [25]). However, the RP will need to justify the definitions of ‘large’ and ‘early’ when using the PSA metrics for this purpose.
4. I judge that the RP has sufficient understanding at this stage of how elements of the safety case will need to be drawn together to form a demonstration of practical elimination. Much of relevant arguments and evidence will be reliant on work across a number of disciplines that will need to be updated/completed during Step 3. I will follow this topic up during Step 3 when the RP presents its arguments and evidence.
   * 1. ALARP by design
5. It is my expectation that by performing severe accident analysis, the RP identifies any further reasonably practicable measures for mitigation of severe accidents. This expectation is informed by FA.16 (ref. [6]) and NS-TAST-GD-005 (ref. [21]).
6. The RP claims that the Rolls-Royce SMR reduces risks ALARP in the severe accident topic area. In my opinion, a large part of the demonstration of ALARP should be supported by the DEC-B analysis, and the demonstration of practical elimination of large or early releases.
7. However, there are some areas of particular interest relating to ALARP that should be noted in my Step 2 assessment. These are:

* The addition of active heat removal function – Whilst detailed design information on this is not yet available, this provides an alternative means of containment cooling for severe accidents. This tempers my concerns regarding shortfalls related to independence of the LUHS [JNK] and PCC HXs which are credited as both Level 3 and 4 defence in depth measures.
* No filtered containment venting – The RP claims that the inclusion of a containment filtration and venting system is grossly disproportionate. The justification for this claim is still in development and I will revisit this as part of my Step 3 assessment (see Section ‎3.3.1). For the purposes of Step 2, the Rolls-Royce SMR design has space provision for the inclusion of a filtered containment venting system, therefore, the incomplete justification should not preclude completion of Step 2.
* No interspace filtered venting system – The RP claims that it is not ALARP to include a filtered venting system in the interspace area. Such a system would filter any leakage from the containment during design basis and severe accidents and is commonly implemented in other gigawatt scale reactors. The RP claims that the Rolls-Royce SMR steel containment provides superior leak-tightness to other civil PWRs, which reduces radiological consequences. Since my assessment has focussed on safety features to prevent/mitigate severe accident phenomena I have not targeted this claim. I will assess this claim in further detail in Step 3 when the radiological consequences analyses are available.

1. Overall, the RP’s DEC-B analysis demonstrates sufficient margins to its technical acceptance criteria and I have confidence that claims related to practical elimination will be justified in Step 3. The supporting analyses are incomplete and will need to be updated during Step 3 to account for design maturity. Additionally, there are areas (as highlighted throughout this report) in which the substantiation and justifications which form part of the ALARP justification are incomplete; I will follow these up during my Step 3 assessment. Nevertheless, I have no significant concerns that an overall ALARP argument can be made and so this should not prevent completion of Step 2.

# Conclusions

* 1. Conclusions

1. This report presents the Step 2 Severe Accident Analysis 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. [11]), at the content of most relevance to Severe Accident Analysis 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 identified relevant severe accident phenomena that should be prevented/mitigated. From my sampling I judge that the RP has identified appropriate safety features to provide for severe accident management.
* The RP’s proposed methodology for constructing a severe accident analysis safety case is appropriate.
* The selected severe accidents sequences provide an adequate basis for the analysis provided during Step 2. I judge that the RP’s sensitivity analyses cover current design uncertainties, providing me with confidence regarding the future refinemented and updated to the analyses to be assessed in Step 3 for the mature design.
* The MAAP5 code is appropriate for use in performing severe accident deterministic analysis for the Rolls Royce SMR and the RP’s approach to verification and validation of the code has progressed satisfactorily for Step 2.
* The RP’s proposed methodology for performing radiological consequence analysis is adequate, although analysis has not been presented for assessment in Step 2.
* I have confidence that the RP has a valid approach to demonstrate in Step 3 that the design practically eliminates sequences with the potential to lead to large or early releases.
* Further work is required to demonstrate that the risks have been reduced ALARP, including justification of the exclusion of a filtered containment venting system and containment leakage filtration.

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.
   1. Recommendations
2. 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.

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# Appendix 1 – Relevant SAPs considered during the assessment

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| SAP No. | SAP Title |
| EKP.3 | Engineering principles: key principles - Defence in depth |
| EKP.4 | Engineering principles: key principles - Safety function |
| EKP.5 | Engineering principles: key principles - Safety measures |
| ECS.1 | Engineering principles: safety classification and standards – safety categorisation |
| EES.1 | Engineering principles: essential services - Provision |
| ESR.1 | Engineering principles: control and instrumentation of safety related systems - Provision in control rooms and other locations |
| FA.2 | Fault analysis: general - Identification of initiating faults |
| FA.3 | Fault analysis: general - Fault sequences |
| FA.15 | Fault analysis: severe accident analysis - Scope of severe accident analysis |
| FA.16 | Fault analysis: severe accident analysis - Use of severe accident analysis |
| FA.25 | Fault analysis: severe accident analysis - Relationship to DBA and PSA |
| AV.1 | Fault analysis: assurance of validity of data and models - Theoretical models |
| AV.2 | Fault analysis: assurance of validity of data and models - Calculation methods |
| AV.3 | Fault analysis: assurance of validity of data and models - Use of data |
| AV.4 | Fault analysis: assurance of validity of data and models - Computer models |
| AV.5 | Fault analysis: assurance of validity of data and models - Documentation |
| AV.6 | Fault analysis: assurance of validity of data and models - Sensitivity studies |

1. The International Atomic Energy Agency uses the term ‘safety feature’ to refer to plant and equipment that is intended to provide a safety function for design extension conditions (including severe accidents). [↑](#footnote-ref-2)
2. The term ‘practical elimination’ is widely used to refer to physically impossibility or is extremely unlikely to a high degree of confidence. [↑](#footnote-ref-3)
3. EKP.3 of the SAPs (ref. [6]) defines Level 3 defence in depth measures as those which control faults within the design basis to protect against escalation to an accident. Level 4 measures are those for control of severe plant conditions in which the design basis may have been exceeded, including protecting against further fault escalation and mitigation of the consequences of severe accidents. [↑](#footnote-ref-4)
4. An elevated pool of water within the containment that is used for both design basis and severe accidents. It also serves as the route by which fuel is discharged from the containment. [↑](#footnote-ref-5)
5. The cavity in which the RPV [JAA] resides. [↑](#footnote-ref-6)