Office for Nuclear Regulation

New Reactor Division – Generic Design Assessment

Step 2 Assessment of the Severe Accident Analysis of UK HPR1000 Reactor

Assessment Report ONR-GDA-UKHPR1000-AR-18-011
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EXECUTIVE SUMMARY

This report presents the results of my Severe Accident Analysis (SAA) assessment of the UK HPR1000 undertaken as part of Step 2 of the Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA).

The GDA process calls for a step-wise assessment of the Requesting Party's (RP) safety submission with the assessments increasing in detail as the project progresses. Step 2 of GDA is an overview of the acceptability, in accordance with the regulatory regime of Great Britain, of the design fundamentals, including ONR's review of key nuclear safety and nuclear security claims (or assertions). The aim is to identify any fundamental safety or security shortfalls that could prevent ONR from permitting the construction of a power station based on the design.

During GDA Step 2 my work has focused on the assessment of the SAA aspects within the UK HPR1000 Preliminary Safety Report (PSR), and a number of supporting references and supplementary documents submitted by the RP, focusing on design concepts and claims.

The standards I have used to judge the adequacy of the RP's submissions in the area of SAA have been primarily ONR's Safety Assessment Principles (SAPs), in particular SAPs FA.1, FA.15 and FA.16, and ONR's Technical Assessment Guide NS-TAST-GD-007, Severe Accidents.

My GDA Step 2 assessment work has involved regular engagement with the RP in the form of technical exchange workshops and progress meetings, including meetings with the plant designers.

The UK HPR1000 PSR is primarily based on the Reference Design, Fangchenggang Unit 3 (FCG3), which is currently under construction in China. Key aspects of the UK HPR1000 preliminary safety case related to severe accidents, as presented in the PSR, its supporting references and the supplementary documents submitted by the RP, can be summarised as follows:

- The RP has conducted SAA for the reference design, FCG3. The RP intends to perform SAA with a similar approach and scope for the UK HPR1000 design.
- For the UK HPR1000, the RP intends to practically eliminate core melting sequences which could lead to large or early release and to prevent radioactive release (including containment bypass and core melting sequences) which exceed safety objectives. To achieve these objectives, the basic severe accident management strategy is to maintain the integrity of the RPV and the containment in both short and long term as far as possible.
- The RP has prepared a programme to schedule the development of the SAA modelling and safety case documentation through GDA.

During my GDA Step 2 assessment of the UK HPR1000 aspects of the safety case related to SAA I have identified the following areas of strength:

- the RP has presented a SAA work programme whereby it is likely that enough SAA will be completed to allow for meaningful assessment during GDA timescales;
- the RP's list of severe accident phenomenon to be considered during GDA timescales largely meets UK expectations;
- the RP has provided preliminary design descriptions of the severe accident systems and high-level information describing how these systems will be used during a severe accident;
- The RP has considered lessons learnt from Fukushima and has made changes to the design that it deems appropriate and practicable;

- the RP has provided an overview of the general approaches that are proposed to be used to model the progression of the severe accident sequences, the behaviour of fission products and to optimise the SAA engineered measures during GDA;
- the proposed approaches for SAA generally meet expectations;
- the RP has provided a list of typical radionuclide behaviours; and
- the RP has demonstrated that the engineered measures have been included due to learning from international modern NPP design.

During my GDA Step 2 assessment of the UK HPR1000 aspects of the safety case related to SAA I have identified the following areas that require follow-up:

- clarity regarding the definition of SAA computer codes and standards to be used during GDA;
- further development of the proposed approaches for all aspects of SAA;
- improved descriptions of the severe accident phenomenon with specific application to the UK HPR1000 design;
- further details of the intent, application and justification for the use of ‘practical elimination’ as part of the safety case;
- further justification for exclusion of analysis of in-vessel steam explosion and re-criticality;
- improved descriptions of severe accident engineered measures, strategies and procedures with specific application to the UK HPR1000 design;
- expanded information regarding the RPs’ intent for performing SAA in the SFP building;
- improved information regarding the use of filtered containment venting;
- further justification in the completeness of the list of areas that were considered in light of lessons learnt from the Fukushima accident;
- improved descriptions of the changes made to the design as a result of lessons learnt from Fukushima;
- improved description of the deterministic approach for screening of the severe accident sequences; and
- expanded descriptions of the fission product behaviour with specific application to the UK HPR1000 design; and
- improved demonstration that optioneering studies have been used to justify the claim that there are no further reasonably practicable improvements within any of the individual severe accident mitigation measures or accident management strategies.

During my GDA Step 2 assessment, I have not identified any fundamental safety shortfalls in the area of SAA that might prevent the issue of a Design Acceptance Confirmation (DAC) for the UK HPR1000 design.

LIST OF ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
ALARP	As Low As Reasonably Practicable
ASP	Secondary Passive Heat Removal System (also known as SPHRS)
BMS	Business Management System
CGN	China General Nuclear Power Corporation
DAC	Design Acceptance Confirmation
DBA	Design Basis Analysis
DWL	Safeguard Building Controlled Area Ventilation System (also known as SBCAVS)
EA	Environment Agency
EDE	Annulus Ventilation System (also known as AVS)
EDF	Électricité de France
EDG	Emergency Diesel Generator
EHR	Containment Heat Removal System (also known as CHRS)
EUF	Containment Filtration and Exhaust System (also known as CFES)
EUH	Containment Combustible Gas Control System (also known as CCGCS)
ECS	Extra Cooling System
FCG3	Fangchenggang Unit 3
GDA	Generic Design Assessment
GNI	General Nuclear International
GNS	Generic Nuclear System Ltd
HF	Human Factors
IAEA	International Atomic Energy Agency
IRWST	In-containment Refuelling Water Storage Tank
IVR	In-vessel Retention
LOCA	Loss of Coolant Accident
ONR	Office for Nuclear Regulation
PCSR	Pre-construction Safety Report
PSA	Probabilistic Safety Analysis

PSR	Preliminary Safety Report (includes security and environment)
PTR	Fuel Pool Cooling and Treatment System (also known as FPCTS)
PWR	Pressurised Water Reactor
RCP	Reactor Coolant System [RCS]
RGP	Relevant Good Practice
RIS	Safety Injection System (also known as SIS)
RO	Regulatory Observation
ROA	Regulatory Observation Action
RP	Requesting Party
RPV	Reactor Pressure Vessel
RQ	Regulatory Query
RRI	Component Cooling Water System (also known as CCWS)
SA	Severe Accident
SAA	Severe Accident Analysis
SADV(s)	Severe Accident Dedicated Valve(s)
SAP(s)	Safety Assessment Principle(s)
SBO	Station Black Out
TAG	Technical Assessment Guide(s)
TSC	Technical Support Contractor
WENRA	Western European Nuclear Regulators' Association

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1 INTRODUCTION

1. The Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA) process calls for a step-wise assessment of the Requesting Party's (RP) safety submission with the assessments increasing in detail as the project progresses. General Nuclear System Ltd (GNS) has been established to act on behalf of the three joint requesting parties (China General Nuclear Power Corporation (CGN), Électricité de France (EDF) and General Nuclear International (GNI)) to implement the GDA of the UK HPR1000 reactor. For practical purposes GNS is referred to as the 'UK HPR1000 GDA Requesting Party'.

2. During Step 1 of GDA, which is the preparatory part of the design assessment process, the RP established its project management and technical teams and made arrangements for the GDA of the UK HPR1000 reactor. Also, during Step 1 the RP prepared submissions to be assessed by ONR and the Environment Agency (EA) during Step 2.

3. Step 2 commenced in November 2017. Step 2 of GDA is an overview of the acceptability, in accordance with the regulatory regime of Great Britain, of the design fundamentals, including ONR's assessment of key nuclear safety and nuclear security claims (or assertions). The aim is to identify any fundamental safety or security shortfalls that could prevent ONR permitting the construction of a power station based on the design.

4. My assessment has followed my GDA Step 2 Assessment Plan for Severe Accident Analysis (SAA) (Ref. 1) prepared in October 2017 and shared with RP to maximise openness and transparency.

5. This report presents the results of my SAA assessment of the UK HPR1000 as presented in the UK HPR1000 Preliminary Safety Report (PSR) (Ref. 2) and its supporting documentation (Refs 3 to 5).

2 ASSESSMENT STRATEGY

6. This section presents my strategy for the GDA Step 2 assessment of the SAA aspects of the UK HPR1000 (Ref. 1). It also includes the scope of the assessment and the standards and criteria I have applied.

2.1 Scope of the Step 2 SAA Assessment

7. The objective of my GDA Step 2 assessment was to assess relevant design concepts and claims made by the RP related to SAA. In particular, my assessment has focussed on the following:

- Specific statements about severe accident (SA) phenomena relevant for the UK HPR1000 and the progressive challenges to, and the potential failure of the multiple barriers;
- Specific statements about engineered measures and strategies and procedures to deal with severe accident sequences in the UK HPR1000;
- Specific statements about the progression of severe accident sequences and the behaviour of fission products in the UK HPR1000, including information on the SAA code(s), tools and sources of information used, and their applicability to the UK HPR1000 and confirmation that they represent current state of knowledge;
- Specific statements of how the RP has reduced the risk ALARP and why it would not be reasonably practicable to reduce the risk further by incorporating changes to the design

8. During GDA Step 2 I have also evaluated whether the safety claims related to SAA are supported by a body of technical documentation sufficient to allow me to proceed with GDA work beyond Step 2.

9. Finally, during Step 2 I have undertaken the following preparatory work for my Step 3 assessment:

- Increased familiarisation with the UK HPR1000 design to provide a basis for planning subsequent, more detailed, assessment during Steps 3 and 4 of GDA.
- I have started discussion with the RP on a programme of submission in the area of SAA for Steps 3 and 4 of the GDA.

2.2 Standards and Criteria

10. For ONR, the primary goal of the GDA Step 2 assessment is to reach an independent and informed judgment on the adequacy of a preliminary nuclear safety and security case for the reactor technology being assessed. Assessment was undertaken in accordance with the requirements of the Office for Nuclear Regulation (ONR) How2 Business Management System (BMS) guide NS-PER-GD-014 (Ref. 6).

11. In addition, the Safety Assessment Principles (SAPs) (Ref. 7) constitute the regulatory principles against which duty holders' and RP's safety cases are judged. Consequently the SAPs are the basis for ONR's nuclear safety assessment and have therefore been used for the GDA Step 2 assessment of the UK HPR1000. The SAPs 2014 Edition is aligned with the International Atomic Energy Agency (IAEA) standards and guidance.

12. Furthermore, ONR is a member of the Western European Nuclear Regulators Association (WENRA). WENRA has developed Reference Levels, which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors.

13. The relevant SAPs, IAEA standards and WENRA reference levels are embodied and expanded on in the Technical Assessment Guides (TAGs) on SAA (Ref. 8). These guides provide the principal means for assessing the SAA aspects in practice.

2.2.1 Safety Assessment Principles

14. The key SAPs (Ref. 7) applied within my assessment are SAPs FA.1 (design basis analysis (DBA), probabilistic safety analysis (PSA) and SAA), FA.15 (scope of severe accident sequences) and FA.16 (Use of severe accident sequences) (see also Table 1 for further details).

2.2.2 Technical Assessment Guides

15. The following Technical Assessment Guides have been used as part of this assessment (Ref. 8):

- NS-TAST-GD-007, Severe Accident Analysis

2.2.3 National and International Standards and Guidance

16. The following national and international standards and guidance have been considered as part of this assessment:

- Relevant IAEA standards (Ref. 9)
  - Safety Standard – Safety Guide No. NS-G-2.15, Severe Accident Management Programmes for Nuclear Power Plants.
  - Safety Report Series No 56 – Approaches and Tools for Severe Accident Analysis for Nuclear Power Plants
- WENRA references (Ref. 10)
  - Safety Reference Levels for Existing Reactors Update in Relation to Lessons Learned from TEPCO Dai-Ichi Accident

2.3 Use of Technical Support Contractors

17. During Step 2 I have not engaged Technical Support Contractors (TSCs) to support the assessment of the SAA for the UK HPR1000

2.4 Integration with Other Assessment Topics

18. Early in GDA, I recognised the importance of working closely with other inspectors as part of the SAA assessment process. Similarly, other inspectors sought input from my assessment of the SAA for the UK HPR1000. I consider these interactions are key to the success of the project in order to prevent or mitigate any gaps, duplications or inconsistencies in ONR's assessment. From the start of the project, I have endeavoured to identify potential interactions between the SAA and other technical areas, with the understanding that this position will evolve throughout the UK HPR1000 GDA.

19. The key interactions I have identified are:

- Human factors: provides input to the HF aspects of the SAA. This formal interaction has not commenced during GDA Step 2. This work will be led by the HF Inspector.

- Fault studies: this provides input into the assessment of the SAA accident sequences, SAA phenomenon and claims for the mitigating measures. This work will be led by the fault studies team.
- PSA: the Level 2 PSA calls on input from the SAA to support the analysis. This formal interaction has commenced during Step 2. In Step 2, this work has been led by the ONR PSA inspector in coordination with the fault studies team.
- Civil Engineering: provides input to the assessment of the containment structural analysis used in the SAA. This work has not commenced during GDA Step 2, due to the progress made on the assessment, but will develop during Step 3. This work will be led by the civil engineering inspector.
- In addition to the above key interactions, there will also be interactions with other relevant disciplines such as C&I, electrical engineering, chemistry, and others. These will be developed further during later GDA Steps.

3 REQUESTING PARTY'S SAFETY CASE

20. During Step 2 of GDA RP submitted a PSR and other supporting references, which outline a preliminary nuclear safety case for the UK HPR1000. This section presents a summary of RP's preliminary safety case in the area of SAA. It also identifies the documents submitted by RP which have formed the basis of my SAA assessment of the UK HPR1000 during GDA Step 2.

21. The RP has committed to consider severe accident phenomenon, engineered measures, strategies and procedures to prevent or mitigate the severe accident phenomenon and analyse the progression of severe accident sequences and the behaviour of fission products in the UK HPR1000.

22. The overall objective for SAA is to practically eliminate core melting sequences which could lead to large or early release and to prevent radioactive release (including containment bypass and core melting sequences) which exceed safety objectives.

23. The term 'practical elimination' is used by the RP in different areas of the severe accident safety case. The RP defines this term as meaning either: demonstration of 'practically eliminated' via physical impossibility; or, demonstration of 'practically eliminated' as extremely unlikely with a high degree of confidence.

3.1 Brief Description of the UK HPR1000 Design

24. The UK HPR1000 design is an evolutionary design based on the RP's experience building and designing successful NPPs in China.

25. The RP claims that the overall severe accident management strategy is to maintain as many barriers between the core and the environment as possible for as long as possible. This means preventing reactor pressure vessel (RPV) failure and consequential containment failure or if this cannot be avoided to delay failure for as long as possible and to avoid failure at high pressure.

26. Depressurisation of the primary circuit is manually initiated after severe accident conditions have been entered (e.g. core outlet temperature reaches 650 degrees Celsius) to avoid high-pressure core melt ejection. High-pressure core melt can result in corium ejection into the containment, which can threaten the integrity of containment due to impulse waves, direct containment heating or core melt damage of other plant systems. To achieve depressurisation of the primary circuit, the RP claims that the severe accident dedicated valves (SADVs) are designed to open and lower the primary pressure to 2.0 MPa. The SADV system has a single line from the pressuriser that divides into two trains of dedicated severe accident depressurisation valve banks, which are connected to the top of the pressurizer and empty into the pressurizer relief tank. The discharge capacity of the SADVs is claimed to be 630 L/h at 17.23 MPA abs. in saturated steam conditions if only one SADV train is open. Actuation of the SADV system is through operator action when a severe accident is indicated (e.g. core outlet temperature reaches 650 degrees Celsius).

27. Corium is intended to be retained within the RPV during a severe accident. The RP claims that if depressurised, external reactor vessel cooling will retain corium in the RPV and keep the reactor vessel intact. If successful, the RP claims that most ex-vessel phenomena such as direct containment heating, steam explosion and molten corium-concrete interaction is likely to be prevented.

28. In a severe accident, eventually corium may collapse into the RPV lower head. The severe accident state implies that significant systems in the RCP [RCS] has failed, but the RP claims that operators and emergency response staff will attempt to restore

injection into the RCP [RCS] based on a severe accident management strategy that will be established in the site licensing phase.

29. The UK HPR1000 in-vessel retention (IVR) system is designed to provide ex-vessel cooling of the corium and thus maintain the integrity of the RPV. At the beginning of the severe accident, natural convection of the IVR is initiated through manual action by the operator in the main control room. Isolation valves on the IVR injection tank outlet are opened to inject water into the cavity between the RPV and the IVR by gravity. The substantial decay heat is transferred through the RPV into the IVR water. The IVR tank is designed to be able to provide for decay heat removal passively for ten hours. After the IVR tank is drained, the operator can manually initiate the active reactor pit flooding system to pump water from the in-containment refuelling water storage tank (IRWST) into the IVR cavity. The RP claims that the IVR has been designed such that the heat flux from the corium through the RPV lower head outer surface is smaller than the local critical heat flux, and if part of the RPV lower head wall melts, the wall with the minimum thickness is expected to retain its mechanical strength to maintain the RPV integrity.

30. The UK HPR1000 is designed to use the containment heat removal system (EHR [CHRS]) to remove decay heat from the containment during a severe accident. Thus, decay heat from the corium is removed by the IVR system into the containment atmosphere, and is then designed to be removed from the containment atmosphere to the ultimate heat sink by the EHR [CHRS]. The EHR [CHRS] is a two train cooling system that is designed to transfer containment heat to the ultimate heat sink. Each train of the system includes: a dedicated suction line for the IRWST, an EHR [CHRS] pump and heat exchanger (cooled by the component cooling water system (RRI [CCWS]) or the extra cooling system (ECS)), three discharge lines (dome sprays, reactor pit water injection, and sump screen back-wash) downstream of the heat exchanger, a dome spray subsystem to reduce temperature and pressure inside containment via spraying, and a connection between the pump inlet and adjacent safety injection system (RIS [SIS]) pump inlets for backwashing purposes.

31. The RP claims that the EHR [CHRS] can control containment pressure passively to below 0.2 MPa. for up to twelve hours without operator intervention with one train operating. After the initial passive phase of operation, operators can configure the system to operative in active mode to continue to maintain the containment pressure below 0.2 MPa. for the long term.

32. The UK HPR1000 design includes the containment filtration and exhaust system (EUF [CFES]) to avoid containment overpressure during a severe accident. If containment pressure rises to 0.52 MPa, the EUF [CFES] can be manually operated to depressurise containment through a venture water scrubber and a metal fibre filter. If the EUF [CFES] is initiated, the depressurisation mass flow is designed for 4 kg/s. The RP claims that the water volume in the venture water scrubber is sufficient for twelve hours of uninterrupted operation. The RP claims that if the IVR requires water injection from mobile diesel pumps, the EUF [CFES] system will need to be used to lower containment pressure.

33. The UK HPR1000 design includes the containment combustible gas control system (EUH [CCGCS]) to reduce hydrogen risk. The system includes 18 large passive autolytic hydrogen recombiners (PARs) and 11 small PARs. The RP claims that when the atmospheric concentration of hydrogen reaches 2% by volume, the PARs will start to function passively.

34. Outside of the reactor facilities, the SFP is an area of the plant where a severe accident may occur. This is primarily due to two accident scenarios: loss of SFP cooling flow, and loss of SFP inventory. The SFP facility has been provided with engineered measures to protect spent fuel from becoming uncovered and damaged.

35. The safety objectives are: only limited protective measures in area and time are needed for the public (i.e. no permanent relocation, no need for emergency evacuation beyond the immediate vicinity of the plant, limited sheltering and no long-term restrictions on food consumption) and that sufficient time is available to implement these measures.

36. To achieve the safety objectives, the basic severe accident management strategy is to maintain the integrity of the containment in both short and long term as far as possible. However, the integrity of the containment can be challenged by various phenomenon and threats occurring during the postulated event. To provide cooling to the melted core material and to maintain the integrity of the containment, severe accident mitigation measures have been developed for the reference design (FCG3) and these will form the basis of the provisions for the UK HPR1000.

37. The RP has submitted preliminary safety case documentation that can be summarised into three important areas: severe accident phenomena; RP's claims on the engineered measures, strategies and procedures that have been designed to address each relevant phenomenon; and, progression of severe accident sequences and behaviour of the fission products. The preliminary safety case is presented in Refs 2 to 5.

3.2 Basis of Assessment: RP's Documentation

38. The RP's documentation that has formed the basis for my GDA Step 2 assessment of the safety claims related to the SAA aspects of the UK HPR1000 is presented in Refs 2 to 5.

39. Reference 2 is the PSR Chapter 13, Design Extension Conditions and Severe Accident Analysis. This PSR chapter presents a summary of the preliminary SAA safety case.

40. Reference 3 is the Methodology to Identify Severe Accident Sequences for the UK HPR1000. This document outlines the RP's approach to screen and group all of the possible severe accident sequences to a manageable number for further analysis. The approach follows both a probabilistic cut-off methodology combined with a methodology that uses deterministic analysis and engineering judgement.

41. Reference 4 is the Overall Methodology of Severe Accident Analysis for the UK HPR1000. This report contains the RP's proposed approaches for:

- severe accident sequence selection;
- severe accident progression and phenomenon
- analysis of the severe accident engineered measures discussed above
- computer codes to be used in SAA;
- source term analysis; and,
- ALARP assessment

42. Reference 5 is the SAA Safety Case Strategy. This document contains:

- The scope and objectives of SAA for GDA;
- An outline of the SAA safety case route map and supporting deliverables;
- Inputs for the SAA safety case strategy and consideration of RGP;
- The strategy for assessing severe accidents in the SFP and during shutdown;
- Lessons learnt from the Fukushima accident; and,
- The gap between the SAA performed for the reference design (FCG3) and the expectations for the UK.

43. In addition, during April 2018 RP submitted to ONR, for information, an advance copy of the UK HPR1000 Pre-Construction Safety Report (PCSR). Chapter 13 (Ref. 14) addresses SAA. Having early visibility of the scope and content of this chapter/s has been useful in the planning and preparation of my GDA Step 3 assessment work.

4 ONR ASSESSMENT

44. This assessment has been carried out in accordance with HOW2 guide NS-PER-GD-014, “Purpose and Scope of Permissioning” (Ref. 6).

45. My Step 2 assessment work has involved regular engagement with the RP’s SAA specialists, i.e., including technical exchange workshops (in China) and six progress meetings.

46. During my GDA Step 2 assessment, I have identified gaps in the documentation formally submitted to ONR. Consistent with ONR’s Guidance to Requesting Parties (Ref. 11), these normally lead to regulatory queries (RQs) being issued. Thus, during Step 2, I have raised four RQs to facilitate my assessment.

47. Similarly, and again consistent with ONR’s Guidance to Requesting Parties (Ref. 11), more significant shortfalls against regulatory expectations in the generic safety case are captured by issuing regulatory observations (ROs). At the time of writing my assessment report in SAA during Step 2, I have raised one RO comprising the following:

- Suitable and Sufficient Severe Accident Analysis Safety Case (RO-UKHPR1000-0003, Ref. 15)

48. Details of my GDA Step 2 assessment of the UK HPR1000 preliminary safety case in the area of SAA, including the conclusions I have reached, are presented in the following sub-sections of the report.

4.1 SAA Safety Case Approach

4.1.1 Assessment

49. The SAPs (Ref. 7) expect that SAA should provide information:

- to assist in the identification of any further reasonably practicable preventative or mitigating measures beyond those derived from the design basis;
- to assist in the demonstrate that the severe accident safety measures are adequately engineered and can be substantiated ;
- to demonstrate that the level of risk is ALARP;
- to form a suitable basis for accident management strategies;
- to support the preparation of emergency plans for the protection of people;
- to determine the magnitude and characteristics of radiological consequences; and,
- to support the probabilistic safety analyses (PSA) of the facility’s design and operation.

50. During my assessment of the RPs’ submitted SAA documentation, I identified a gap: the documentation was not sufficient to enable meaningful assessment against UK expectations as outlined above. In addition, the RP did not have a plan to deliver a suitable and sufficient SAA safety case during GDA timescales such that UK expectations would be met.

51. Thus, I raised RO-UKHPR1000-0003 (Ref. 26) to ensure that the future SAA safety case developed for the UK HPR1000 would meet regulatory expectations.

52. The RP was requested, as part of the resolution of the regulatory observation (RO), to provide:

- a strategy for the SAA programme to help ONR gain confidence that sufficient SAA would be performed and documented during GDA such that the above expectations would be met;
- proposed SAA methodologies/ processes/ procedures (including any assumptions) which would be used to evaluate the severe accident sequences, including non-reactor sequences such as the SFP;
- a demonstration that the SAA programme and methodologies are sufficient to ensure that a suitable and sufficient SAA safety case will be completed in GDA timescales; and,
- a complete list of the claims for the severe accident engineered measures, and a demonstration that a systematic approach has been taken to understand and justify that the proposed safety functions (including human factors) of these systems can be met.

53. RO-UKHPR1000-0003 contained four regulatory observation actions (ROAs) to enable the provision of the above request in a logical and step-wise manner.

54. The RP responded with a resolution plan to address the issues raised in the RO. I consider the resolution plan produced by the RP (Ref. 15) to be a credible plan to respond to the expectations contained within the RO. At the time of writing this report, the RP had provided responses to some of the Actions under this RO. A summary of my assessment of these responses follows in the following sub-sections.

Severe Accident Strategy

55. In Action 1 of RO-UKHPR1000-0003, the RP was requested to provide their strategy for the completion of a suitable and sufficient SAA safety case during GDA. This action was given to the RP so that ONR could understand clearly “what” activities the RP intended to undertake to provide the SAA safety case for the UK HPR1000.

56. The response from the RP was outlined in the resolution plan (Ref. 15), whereby a document would be produced (Ref. 5) that would provide the strategy for SAA for the GDA program.

57. I have assessed Ref. 6 and am content with the strategy that the RP has submitted. The strategy outlines the following documents that the RP has committed to producing during Steps 3 and 4 of GDA:

- Assessment of standards and guides on SAA applied to UK HPR1000 – an introduction of technical standards, regulations and guides applied to SAA
- Applicability assessment on SAA codes used for UK HPR1000 – a demonstration that the computer codes to be used in SAA are capable to simulate the severe accident progression and phenomena of the UK HPR1000
- Identification of SAA sequences
- Assessment of SADV
- Assessment of IVR
- Assessment of EUH [CCGCS]
- Assessment of EHR [CHRS]
- Assessment of EUF [CFES]
- Topical report on SAA sequences
- Level 3 PSA Report
- Practical elimination evaluation
- SAA for the Spent Fuel Pool Building
- Lessons learnt from Fukushima
- ALARP evaluation of SAA measures

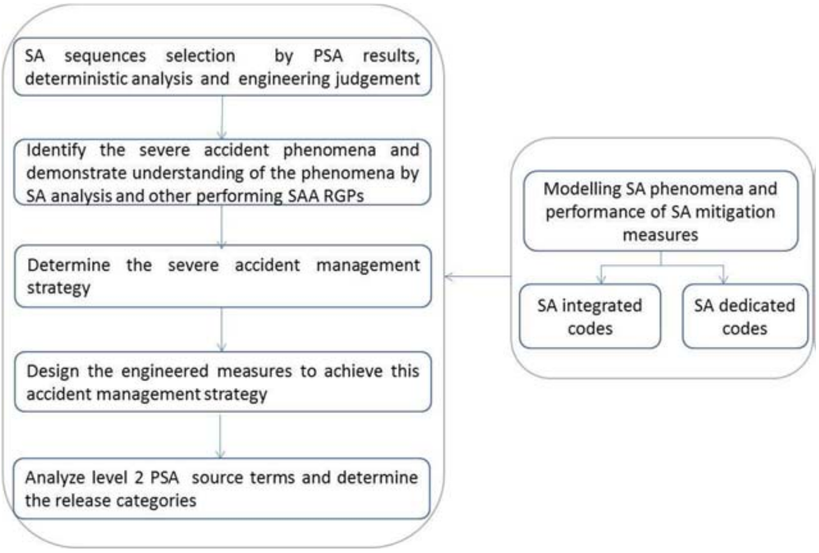
58. The document includes a programme for GDA that lists the documents, their scope and the timescales that are planned for future submission. I will be using this document during my planning for assessment of Step 3 and beyond.

59. This list is noted to be preliminary, but I am content with its scope for Step 2. During Step 3, this list is likely to be expanded as the programme develops.

Severe Accident Methodology

60. In Action 2 of RO-UKHPR1000-0003, the RP was requested to provide a methodology for SAA. This action was given to the RP so that the RP could present "how" it intended to undertake the activities that were identified in Ref. 5. As a response to ROA2, Ref. 4 was produced.

61. I have assessed Ref. 4 and I am content with the overall approach. The RP has proposed to follow an overall approach that is described in detail in Ref. 4, and outlined in the following flowchart:



62. The approach can be summarised as: selection of severe accident sequences, identification of applicable severe accident phenomenon relevant to a sequence, modelling the plant response (engineered measures and operator actions) to the sequence and phenomenon, and finally using the results of the model as input to the Level 2 PSA. I consider this general approach to be high-level, but reasonable for Step 2 of the GDA. I will expect further development of this approach in Step 3 and will follow-up with this in Step 3.

63. At the time of preparing this report, I note that the RP is still considering which SAA codes and methods will be used as part of the UK safety case. Although the outcome of this decision does not directly affect my Step 2 conclusions, as I am confident that a suitable set of codes and standards could be applied, the RP will need to have a clear strategy for how and when this will be resolved. It is my expectation that this decision will be taken prior to Step 3 such that my subsequent assessment can be undertaken in a timely manner. I will follow this up as part of my Step 3 assessment.

Other Aspects of the Resolution Plan

64. The RP has yet to respond to Actions 3 and 4 of RO-UKHPR1000-0003. This is in line with their resolution plan.

65. For Action 3, the RP was requested to provide sufficient evidence of the various outputs of the work items described in response to ROAs 1 and 2, and to demonstrate that an adequate safety case for SAA will be provided during GDA.

66. The RP's response to Action 3 was outlined in the resolution plan (Ref. 15) whereby the RP plans to create a topic report on the subject "Severe Accident Analysis of a Typical Sequence". As stated by the RP, this topic report will show an example of a complete safety case in SAA and implementation of Ref. 4.

67. For Action 4 of RO-UKHPR1000-0004, the RP was requested to demonstrate that a systematic approach has been taken to the identification of safety functions for SAA and that the list of claims made on the severe accident engineered measures (including human actions) is complete.

68. The RP's response to Action 4 was outlined in the resolution plan (Ref. 15) whereby the RP plans to create two reports on the subjects: "Severe Accident Engineered Measures Summary Report" and "ALARP evaluation on Severe Accident Measures". As stated by the RP, this report will describe each of the severe accident systems, listing all the claims made for each system. The safety functions delivered by each system will be determined in a systematic way which will be described in the PCSR. The qualification specific for each severe accident system will be based on the output for the SAA to ensure the systems will be able to perform as intended and deliver their safety function under the conditions they will be required to operate. The rationale for the choice of each of the mitigating measures will be described, including detailed ALARP evaluations.

69. I will assess the adequacy of the responses to these Actions during my work in Step 3 to judge if it meets the requirements of the RO.

4.1.2 Strengths

70. During my assessment of the SAA safety case approach, I have identified the following strengths:

- The RP has presented a SAA work programme whereby it is likely that enough SAA will be completed to allow for meaningful assessment during GDA timescales.
- The proposed approaches for SAA generally meet expectations.

4.1.3 Items that Require Follow-up

71. During my assessment of the SAA safety case approach, I have identified the following potential shortfalls that I will follow-up during Step 3 of GDA:

- Further development of the proposed approaches for all aspects of SAA; and
- Clear definition of what SAA codes and standards will be used.

4.1.4 Conclusions

72. Based on the outcome of my Step 2 assessment of the SAA safety case approach, I have concluded that the general approaches for the SAA safety case are sufficient for Step 2, but more work is required during next Steps in GDA to be able to understand if the SAA work will fully meet regulatory expectations. As noted above, the SAA computer codes and standards have yet been defined by the RP. My below

conclusion is based on the information received at the time of writing this report and if this information significantly changes after this report has been written, I may have to re-visit the conclusions of this report. Therefore, and based on the information received at the time of writing this report, I am confident that the proposed work programme is likely to lead to a suitable and sufficient SAA safety case.

4.2 Severe Accident Phenomena Considered in the UK HPR1000 SAA

4.2.1 Assessment

73. I have assessed the completeness of the severe accident phenomena described in Refs 2 and 4 against the guidance summarised in Ref. **Error! Reference source not found.** and regulatory expectations in SAP FA.15.

74. The RP described in some detail the physicochemical and radiological phenomena in severe accidents for PWRs with some HPR 1000 design specific details for the three phases (loss of primary cooling, core damage/relocation and containment damage/off-site release) of some severe accidents.

75. The RP has confirmed that the following severe accident phenomenon will be included in the scope of the SAA to be completed during GDA timescales:

- High pressure melt ejection and direct containment heating
- Hydrogen combustion
- Molten core-concrete interaction
- Ex-vessel steam explosion
- Containment overpressure

76. The list of sever accident phenomenon to be assessed and the preliminary descriptive information provided in Refs 2 and 4 is high level and somewhat generic for all PWRs, and while acceptable for Step 2, I will expect more design specific information to be submitted in Step 3.

77. The RP stated that the following phenomena were screened-out of further analysis:

- In-vessel steam explosion
- Re-criticality

78. In assessing the RP claims for severe accident phenomenon, I noted that the RP has used the term ‘practical elimination’, and yet did not fully justify what was meant by practical elimination. ONR understanding of this term is based on IAEA NS-G-1.10 and as per ONR guidance for SAA (Ref. 8) to mean: *“the possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high degree of confidence to be extremely unlikely to arise”.* Thus I raised RQ-UKHPR1000-0079 (Ref. 16) to clarify which of the severe accident phenomenon the RP planned to explicitly analyse during GDA. I asked the RP to: provide a list of severe accident phenomena intended to be analysed during GDA; identify screened-out severe accident phenomena and provide justification; provide a summary of the intended approach to be used for the safety case to support the screening out of the relevant phenomenon; and, how the screened-out phenomena were modelled in the PSA.

79. In response to RQ-UKHPR1000-0079, the RP stated that the term ‘practical elimination’ was intended to mean either: physical impossibility; extremely unlikely with a high degree of confidence. Furthermore, the RP stated that re-criticality and ex-vessel steam explosion remain excluded from consideration during GDA but that more justification would be prepared. Ref. 5 includes this further justification.

80. I have assessed Ref. 4 including the justification of exclusion of in-vessel steam explosion. The justification references international studies on in-vessel steam explosion and the probability of a resulting RPV failure that the references estimate is low. In my opinion, Ref. 4 does not contain sufficient justification for excluding re-criticality and ex-vessel steam explosion from consideration, and I will require more justification during Step 3.

81. ONR SAP FA.15 states that for SAA, *“states and scenarios should not be dismissed from the analysis on frequency grounds alone. Indeed, SAA is not normally concerned with the sequences leading to the severe accident (these being the province of DBA and PSA), but instead should be focused on how the accident state or scenario will be controlled and/or mitigated”.* Thus, in my opinion, the RP’s claim that the phenomenon should be excluded has not yet been fully justified, and I will require additional justification during Step 3.

82. In assessing the RP’s claims on severe accident phenomenon, I noted that the RP’s focus on SAA was primarily on reactor accidents and did not discuss other areas of the plant, such as the SFP, where a severe accident could occur. Thus, I raised RQ-UKHPR1000-0065 (Ref. 16) to clarify the RP’s intentions for assessing severe accidents in non-reactor facilities. In response to this RQ, the RP agreed that a gap existed for assessing severe accidents in the SFP. The RP subsequently agreed to address non-reactor facility severe accidents during GDA. I will follow this up as the safety case develops later in GDA.

4.2.2 Strengths

83. During my assessment of the severe accident phenomenon, I have identified the following strength:

- The RP’s list of severe accident phenomenon to be considered during GDA timescales largely meets UK expectations for SAA as outlined in Ref. **Error! Reference source not found.**.

4.2.3 Items that Require Follow-up

84. During my GDA Step 2 assessment of the severe accident phenomena considered in the UK HPR1000 SAA I have identified the following potential shortfalls that I will follow-up during Step 3 of GDA.

- improved descriptions of the severe accident phenomenon with specific application to the UK HPR1000 design;
- further details of the intent, application and justification for the use of ‘practical elimination’ as part of the safety case; and,
- further justification for exclusion of analysis of in-vessel steam explosion and re-criticality.

4.2.4 Conclusions

85. The RP has provided preliminary descriptions of relevant PWR severe accident phenomenon and preliminary justification for any exclusion from analysis. The descriptions have been helpful to understand the phenomena which lead to challenges for severe accident mitigating measures, strategies and procedures. Nevertheless, future documentation will need to provide a UK HPR1000 design-specific demonstration. This expanded information will be required before the RP can claim that regulatory expectations in SAP FA.15 and FA.16 are fully met.

4.3 Engineered Measures, Strategies and Procedures for Severe Accident Sequences in the UKHPR1000

4.3.1 Assessment

86. I have assessed the completeness of the severe accident engineered measures, strategies and procedures to deal with severe accident sequences in the UK HPR1000 in Refs 2 to 4 and 13 against the guidance summarised in Ref. 8 and regulatory expectations in SAP FA.16. A summary of the RP's description of the five engineered measures can be found in Section 3.1 of this report.

87. The engineered measures and their function claimed for exclusive severe accident use are summarised as follows:

- severe accident dedicated valves (SADVs): depressurisation of the primary circuit (note the function of the SADVs is claimed by the RP only for severe accidents, not for design basis sequences such as feed and bleed; this claim will be assessed during Steps 3 and 4);
- in-vessel retention system (IVR): removal of decay heat from core debris to the containment atmosphere while maintaining the integrity of the RPV;
- containment combustible gas control system (EUH [CCGCS]): reduce combustible gas risk;
- containment heat removal system (EHR [CHRS]): remove heat from containment atmosphere to ultimate heat sink; and,
- containment filtration and exhaust system (EUF [CFES]) – filtered containment venting.

88. In assessing the descriptions provided for each of the severe accident engineered measures, I noted that the information is high-level, and while acceptable for Step 2, I will expect more detailed design information to be submitted in Step 3. I will also expect more information for the system response to the different severe accident phenomenon, as the current information is descriptive of the functionality of each engineered measure only against a generic severe accident. This functionality will be different for each of the sequences that are eventually analysed for each phenomenon.

89. To this effect, Ref. 5 states that each engineered measure will be the subject of an in depth SAA topic report to demonstrate the capabilities of each system for applicable different severe accident sequences. These reports will present the results of in-depth study using the SAA computer codes assessing the engineered measures during different severe accident sequences. I will assess these reports in Step 3.

90. While assessing the RP submissions I noted that the descriptions of the containment filtration and exhaust system (EUF [CFES]) stated that the system would be used to reduce pressure if the IVR was provided with makeup water via mobile diesel pumps outside the plant. Thus, I raised RQ-UKHPR1000-0123 (Ref. 16) to request for the RP to provide more information regarding claims for this system during other severe accident scenarios, for any claims for use of the system during DBA faults, and for more information on claims of mobile diesel pumps during severe accidents.

91. The RPs' response to this RQ stated that the EUF [CFES] is only claimed for severe accident backup containment pressure reduction, and would be used as a backup to lower containment pressure in the event of EHR [CHRS] failure during a severe accident. The EUF [CFES] system is not claimed for any DBA scenario, as the RP claims that any DBA scenario including steam link break inside containment will result in a maximum containment pressure less than the containment design pressure.

92. Mobile diesel pumps are claimed by the RP to be connected to the HER [CHRS] via connection nozzles outside the safety guard building. In scenarios such as long-term

loss of off-site power and large-break LOCA, the IVR will supply water to passively cool the RPV via the IVR storage tank for up to 10 hours. Before the IVR tank is completely drained, the mobile diesel pumps can be used to refill the IVR system for the long term.

93. Whilst I am content for the level of information provided for claims on filtered containment venting for Step 2, I will expect further information regarding this sub-system during Step 3.

94. Also while assessing the completeness of the severe accident engineered measures, strategies and procedures, I noted a gap in the information provided for the SFP facility. Thus I raised RQ-UKHPR1000-0065 (Ref. 16) to address this gap. The RP responded and provided more information regarding the severe accident engineered measures and strategy for responding to loss of cooling and loss of inventory in the SFP building. I have summarised this information in Section 3.1 of this report.

95. Whilst I am content on the level of information provided for claims on severe accidents in the SFP building for this phase of GDA, I will expect more information during Step 3.

4.3.2 Strengths

96. During my assessment of the severe accident engineered measures, strategies and procedures, I have identified the following strength:

- the RP has provided preliminary design descriptions of the severe accident systems and high-level information describing these systems' use during a severe accident.

4.3.3 Items that Require Follow-up

97. During my GDA Step 2 assessment of specific engineered measures, strategies and procedures for severe accident sequences in the UKHPR1000 I have identified the following potential shortfalls that I will follow-up during Step 3 of GDA:

- improved descriptions of severe accident engineered measure, strategies and procedures with specific application to the UK HPR1000 design;
- expanded information regarding the RPs' intent for performing SAA in the SFP building; and
- improved information regarding the use of filtered containment venting.

4.3.4 Conclusions

98. The RP has submitted preliminary descriptions of the engineered measures, strategies and procedures during a severe accident. The preliminary descriptions have been helpful to understand the plant response to severe accident scenarios. Nevertheless, future documentation will need to provide more in-depth demonstration of the function of the engineered measures, strategies and procedures during different severe accident scenarios that will be analysed. This expanded information will be required before it can be claimed that regulatory expectations in SAP FA.15 and FA.16 are fully met.

4.4 Lessons learnt from Fukushima

4.4.1 Assessment

99. In my assessment of the severe accident engineered measures, I have noted the RP claims that lessons have been learnt from the Fukushima accident. The RP claims that the UK HPR1000 design has been informed by these lessons learnt. The following paragraphs summarise the RP's demonstrations.

100. In light of the Fukushima accident, and in view of the international response including the Vienne declaration, the RP reviewed the reference design with the lessons learnt, analyses of the accident, international guidance documents and RGP. The reference design was reviewed for resiliency in the following areas:

- design basis flooding;
- emergency water makeup;
- flexible electrical supply;
- SFP monitoring system;
- hydrogen monitor and control system;
- habitability of the emergency control centre;
- radiation monitoring and emergency response; and,
- general plant response to external hazards.

101. This list contains an overview of some of those areas that I would expect to be addressed, however, whilst I am content with this list for Step 2, I expect justification to be provided for inclusion of these areas to share the RP is confidence that this list is sufficient. In addition, there may be areas that have not been examined for the UK HPR1000 that would be expected in the UK such as the European NSREG stress test approach which includes topics like beyond design basis seismic and flooding stress testing. I will follow up with this in Step 3.

102. The RP claims that analysis of these areas of the reference design led to changes in design and operations that will be included in the UK HPR1000 such as:

- a requirement for makeup water in the: primary loop (via EHR-RIS piping using EHR pumps); SFP (via secondary passive heat removal system (SPHRS); SGs (via SPHRS). Each of these are designed to have connection points for portable makeup via diesel pumps;
- EDGs, SBO DGs, and mobile diesel generators;
- continuous monitoring of safety parameters in the SFP facilities such as water level and temperature with redundant electrical supplies;
- the emergency control centre is a seismic class 1 structure and also designed against design basis floods. The reference plant has optimised ventilation systems to ensure that effective dose rates are low during a proposed emergency period; and
- monitoring equipment and locations should be reasonable and available, together with increased exercises and emergency drills.

103. The information provided was preliminary and high-level and while I am content with this level of detail for Step 2, I expect more information to be provided. I will follow-up with this area in Step 3.

4.4.2 Strengths

104. During my assessment of the lessons learnt from the Fukushima accident, I have identified the following strength:

- The RP has considered lessons learnt from Fukushima and has made changes to the design that it deems appropriate and practicable.

4.4.3 Items that Require Follow-up

105. During my GDA Step 2 assessment of specific engineered measures, strategies and procedures for severe accident sequences in the UKHPR1000 I have identified the following potential shortfalls that I will follow-up during Step 3 of GDA:

- further justification in the completeness of the list of areas that were considered in light of lessons learnt from the Fukushima accident; and
- improved descriptions of the changes made to the design as a result of lessons learnt from Fukushima.

4.4.4 Conclusions

106. The RP has submitted preliminary information to demonstrate how the UK HPR1000 design has been influenced by lessons learnt from the Fukushima accident. I am content that relevant areas of the design have been reviewed in light of the lessons learnt, and although the RP has made changes to the design as a result of the review, I would expect more information to be provided in GDA to justify that the RP has selected sufficient areas of the design in their review. I would also expect more information to be provided in GDA regarding the design changes that have been made. I will follow-up with this in Step 3.

4.5 Analysis of the Progression of the Severe Accident Sequences and the Behaviour of Fission Products in the UK HPR1000.

4.5.1 Assessment

107. I have assessed the completeness of the RP's submissions regarding the progression of severe accident sequences and the behaviour of the fission products in the UK HPR1000 described in Refs 2 to 4, against the guidance summarised in Ref. 8 and regulatory expectations in SAP FA.15 and FA.16.

108. Although the SAA for the UK HPR1000 has not been completed yet, the RP has provided an overview of the general methodology for severe accident sequence progression modelling and analysis of the fission product behaviour for the UK HPR1000 SAA.

109. Refs 3 and 4 present preliminary descriptions of the approach for severe accident sequence selection. The described approach combines probabilistic and deterministic screening to arrive at the final list of severe accident sequences to be fully analysed.

110. The probabilistic screening approach states that all Level 1 PSA accident sequences will be screened in for SAA for frequencies that sum to 95% of the CDF, or individually frequencies exceeding 1% of the total CDF. For FCG3, this screening approach resulted in 15 at-power sequences, and 31 shutdown sequences. These 46 sequences are then grouped if they have the same IE, or if they lead to the same system function failure. In FCG3, after grouping, the original 46 sequences were grouped into 12 final sequences to be analysed. ONR SAP FA.15 states that for SAA, "states and scenarios should not be dismissed from the analysis on frequency grounds alone. Indeed, SAA is not normally concerned with the sequences leading to the severe accident (these being the province of DBA and PSA), but instead should be focused on how the accident state or scenario will be controlled and/or mitigated". Thus, in my opinion, the RP's claim that the phenomenon should be excluded has not yet been fully justified, and I will require additional justification during Step 3.

111. Next, the RP claims that a \`deterministic screening\` approach will be used to supplement the final list derived using the probabilistic approach. If additional sequences are identified through the deterministic approach, the probabilistic derived list will be supplemented with these additional sequences.

112. The RP also describes an additional \`engineering judgement\` selection step where additional sequences can be added to the list to ensure that even if a sequence does not meet probabilistic or deterministic screening criteria. Through these steps, the RP

claims that the SAA scope is comprehensive and that enough accident sequences will be selected such that the SAA envelopes all the severe accident consequences.

113. In my assessment of the approaches to be used in selection of severe accident sequences, the descriptions of the deterministic approach and engineering judgement step are not developed in detail. Although the RP's intention in performing these screening steps increases confidence that the SAA scope will be comprehensive, until further details are released as to the content of these approaches, it is difficult to assess whether or not this meets with the guidance outlined in Ref. 8 or with SAPs FA.15 and FA.16. I will follow up this with the RP early in Step 3.

114. Although the complete severe accident sequence list is not available during Step 2, the RP notes in Ref. 5 that more details of the screening approaches will be submitted in early Step 3, along with the completed severe accident sequence list. I will follow-up with assessment of the severe accident sequence selection approach and the final list during Step 3.

115. I have assessed the completeness of the RP's preliminary descriptions of fission product behaviour in the UK HPR1000. The RP notes that the results of the Level 2 PSA are not complete for the UK HPR1000, but that they will provide the source term information to be analysed, including release time, magnitude of release, physicochemical characteristics, and the height and frequency of release categories (RCs).

116. As stated above, the overall goal of the severe accident management strategy is to maintain as many barriers as possible between the core and the environment for as long as possible. Even when the RPV and containment are intact, some activity will be released from the primary circuit to the containment and some of this may be released to the environment by designed filtered venting paths. The containment can fail or be bypassed in a number of ways leading to a direct unfiltered release from the containment to the environment although these releases can be mitigated by engineered measures in the containment such as sprays or by other natural processes such as scrubbing in the steam generators.

117. The consideration of containment release paths is coordinated with Level 2 PSA. Since the Containment Event Trees (CETs) have had a large number of end states, for simplification reasons the end states are required to be grouped into RCs which will provide an effective interface between Level 2 PSA and Level 3 PSA. The source terms analysis will be then carried out for the RCs by representative severe accident sequences. The process of source terms analysis is as follows:

- Specifying the RCs;
- Grouping the end states of the CETs into the RCs; and,
- Carrying out the source terms analysis for the RCs using severe accident source terms analysis code.

118. Whilst I am content with this general approach for source term analysis, it is high-level and I will expect more information in Step 3.

119. The RP claims that the SAA will consider the following radionuclide behaviours:

- Fission products (activity or non-activity) release from clad rupture, core molten process, MCCI;
- Retention phenomena inside the Reactor Coolant System;
- Aerosols sedimentation, thermophoresis in the containment;
- Aerosols mass concentration and size composition;
- Spraying of EHR [CHRS] removal aerosols and element iodine in the containment atmosphere;

- Iodine chemistry influence on the chemical form in the containment;
- The ratio change of iodine chemical form which released to environment during whole release process;
- Retention phenomena in the IRWST and IRWST pH control;
- Phenomena in the bypass accident;
- Filtration effect in the annulus ventilation system (EDE [AVS]), safeguard building controlled area ventilation system (DWL [SBCAVS]) and EUF [CFES].

120. In addition, more detailed claims and evidences will be discussed in Step 3 in the chemistry topic area, (i.e. iodine chemistry).

121. In assessing the RP claims in the area of fission product behaviour I noted that the preliminary descriptions, while helpful in understanding the RP's plan for further analysis, are high level and generic to all PWRs. I will therefore expect further design specific information and more details of the proposed approaches to be used for the UK HPR1000 that I consider in my Step 3 assessment.

122. In the SAA strategy (Ref. 5), the RP has provided its' plan to provide the complete severe accident analysis during GDA timescales. Important deliverables in this topic area are noted to be scheduled for completion later in GDA, and thus, there is some risk that if important findings arise it may be more difficult to implement design changes. I will discuss this with the RP throughout Step 3 to ensure that the most important aspects are targeted earlier.

4.5.2 Strengths

123. During my assessment of the progression of the severe accident sequences and the behaviour of fission products, I have identified the following strength:

- the RP has provided an overview of the general approaches that are proposed to be used to model the progression of the severe accident sequences;
- the RP has provided a list of typical radionuclide behaviours; and
- the RP has provided an overview of the general approaches that are proposed to be used to model the behaviour of fission products.

4.5.3 Items that Require Follow-up

124. During my GDA Step 2 assessment of the progression of the severe accident sequences and the behaviour of fission products in the UKHPR1000 I have identified the following specific shortfalls:

- improved description of the deterministic approach for screening of the severe accident sequences; and
- expanded descriptions of the fission product behaviour with specific application to the UK HPR1000 design.

4.5.4 Conclusions

125. Based on the outcome of my assessment of the information provided by the RP regarding the progression of UK HPR1000 severe accident sequences and the behaviour of the fission products, I have concluded that the RP has provided preliminary descriptions of: the approaches proposed to be used in modelling the progression of severe accident sequences; and the behaviour of fission products. In my opinion, improved and expanded information needs to be provided in all areas of this topic in order to fully assess the RP claims against the guidance in Ref. 8 and the regulatory expectations in SAPs FA.15 and FA.16.

4.6 Categorisation of Safety Functions and Classification of Systems, Structures and Components

126. In my assessment of the severe accident engineered measures, the RP has noted that all SSCs are qualified to function under severe accident conditions. The RP states that detailed classification information will be demonstrated later in GDA. I will follow up this matter during Step 3.

4.7 ALARP Considerations

4.7.1 Assessment

127. I have assessed the adequacy of the RP's safety submissions to demonstrate that the level of risk associated with the UK HPR1000 is as low as reasonably practicable (ALARP) against ONR's expectations in SAP FA.10.

128. The RP claims that the reference plant (FCG3) has incorporated international good practice in the design of the severe accident engineered measures. The RP considers the HPR1000 (FCG3) to be an evolutionary design having progressively reduced risks as the design developed. These engineered severe accident mitigation measures and the overall severe accident strategy are part of this evolution.

129. In the SAA Step 2 submissions, the RP has presented a preliminary ALARP consideration of the SAA for the UK HPR1000. The RP's stated purpose for the SAA ALARP assessment is to demonstrate that there are no further reasonably practicable improvements within any of the individual severe accident mitigation measures or accident management strategies. The RP also states that any potential improvements that are identified will be assessed to determine whether they are ALARP to implement. The scope of the SAA ALARP assessment includes the reactor and non-reactor facilities such as the SFP building.

130. The RP's approach considers comparison with RGP and an optimisation analysis against each of the severe accident engineered measures. For most of the severe accident engineered measures, the RP claims that the design will be optimised using sensitivity analysis.

131. For the containment filtration and exhaust system (EUF [CFES]), the RP claims that an optimisation process may be required to ensure the level of risk is balanced. Venting the containment reduces the risk of containment failure and a large release of radioactivity to the environment but involves a certain small release of radioactivity to the environment. The optimisation analysis will consider the optimum pressure at which to vent.

132. In SFP building, the RP claims that the PTR [FPCTS] design will be assessed and optimised. The maximum possible decay heat in SFP, the potential drainage flowrate, the period for power and cooling recovery, and the temperature limitation of pump would be expected to be considered.

133. For the design as a whole, the RP claims that risk assessment studies will inform the ALARP assessment. The potential risks related to severe accident will be identified based on insights from PSA, experience from the reference design and expert judgement. Risk-dominant sequences will be closely examined to determine if there is scope for further risk reduction and optimisation.

134. If any improvements are identified, the practicality of the implementing the measure will be evaluated and compared with the risk reduction achievable to determine whether this would be an ALARP solution or not. If so, it will be incorporated in the design.

135. Whilst the RP's proposed approaches for optimising the design of the severe accident engineered measures are reasonable, the described approach does not include optioneering. The SAPs clearly outline regulatory expectations for optioneering in ALARP assessments. The proposed approach does not include optioneering analysis for severe accident engineered measures, and thus I will expect additional information for how the RP intends to complete optioneering studies on the severe accident engineered measures during GDA. I will follow-up with this during Step 3.

4.7.2 Strengths

136. During my assessment of the progression of the ALARP Considerations, I have identified the following strength:

- the RP has demonstrated that the engineered measures have been included due to learning from international modern NPP design; and
- the RP has proposed an approach for optimising the severe accident engineered measures during GDA.

4.7.3 Items that Require Follow-up

137. During my assessment of the ALARP considerations, I have identified the following shortcomings that I will follow-up with during Step 3:

- Improved demonstration that optioneering studies have been used to justify the claim that there are no further reasonably practicable improvements within any of the individual severe accident mitigation measures or accident management strategies.

4.7.4 Conclusions

138. As the UK HPR1000 SAA is under development, the RP has provided high-level information to demonstrate that the level of risk associated with the UK HPR1000 is ALARP. The RP's decision to provide an ALARP assessment of the SAA is scheduled later in GDA. I will follow-up with the RP to ensure that optioneering approaches form a significant part of future ALARP assessment of the design. The consideration of the adequacy of the SAA into the ALARP demonstration against ONR's expectations in SAP FA.10 will be a key part of my assessment in Step 3.

4.8 Out of Scope Items

139. I have not left any items outside the scope of my GDA Step 2 assessment of the UK HPR1000 SAA.

4.9 Comparison with Standards, Guidance and Relevant Good Practice

140. In Section 2.2, above, I have listed the standards and criteria I have used during my GDA Step 2 assessment of the UK UKHPR1000 SAA, to judge the adequacy of the preliminary safety case. In this regard, my overall conclusions can be summarised as follows:

- SAA SAPs: The SAA information provided by the RP during Step 2 is preliminary in nature. More information will be required to demonstrate that regulatory expectations can be met. Table 1 provides further details.
- TAGs: The information provided was preliminary in nature and generic to PWR technology in general. More UK HPR1000 specific information will be required to demonstrate that the TAG guidance can be met.

4.10 Interactions with Other Regulators

141. I have not had any interactions with other regulators during Step 2.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

142. During Step 2 of GDA RP submitted a PSR and other supporting references, which outline a preliminary nuclear safety case for the UK HPR1000. These documents have been formally assessed by ONR. The PSR together with its supporting references present to some extent the claims in the area of SAA that underpin the safety of the UK HPR1000.

143. During Step 2 of GDA I have targeted my assessment at the content of the PSR and its references that is of most relevance to the area of SAA; against the expectations of ONR's SAPs and TAGs and other guidance which ONR regards as Relevant Good Practice. From the UK HPR1000 assessment done so far, I conclude the following:

- The RP has articulated reasonable, but incomplete claims in the area of SAA. Following the RP's response to RO-UKHPR1000-0003, I have increased confidence in the RP's ability to articulate reasonable claims in the PCSR and underpin them with sufficient arguments and robust evidence.
- The shortcomings identified in my review indicate that the RP will need to undertake a considerable amount of work to complete the UK HPR1000 SAA to meet regulatory expectations which is required to underpin the SAA claims outlined in Step 2. More information is required in all areas of SAA to be able to assess the SAA claims against ONR expectations in SAPs FA.15 and FA.16.
- My level of familiarity with the SAA design technology is high level at the moment and is commensurate with the level of detail required for Step 2, but will be developed as GDA progresses.
- The RP's current SAA delivery plan is sufficient to be able to complete the UK HPR1000 GDA SAA programme within expected timescales.
- I have confidence that the adequacy of arguments/evidence likely to be available later in GDA will be sufficient in the area of SAA.
- The indecision regarding which computer code will be used in SAA is an important matter that the RP had not decided at the time of preparing this assessment report. This will be the subject of follow-up at the earliest opportunity in Step 3.

144. Overall, during my GDA Step 2 assessment, I have not identified any fundamental safety shortfalls in the area of SAA that might prevent the issue of a Design Acceptance Confirmation (DAC) for the UK HPR1000 design.

5.2 Recommendations

145. My recommendations are as follows:

- Recommendation 1: ONR should consider the findings of my assessment in deciding whether to proceed to Step 3 of GDA for the UK HPR1000.
- Recommendation 2: All the items identified in Step 2 as important to be followed up should be included in ONR's GDA Step 3 SAA Assessment Plan for the UK HPR1000.

6 REFERENCES

1. Generic Design Assessment of GNS's UK HPR1000 - Step 2 Assessment Plan for SAA ONR-GDA-AP-17-011, Rev. 0, ONR, October 2017. TRIM Ref 2017/353291

2. Preliminary Safety Report, Chapter 13, Design Extension Conditions and Severe Accident Analysis, Rev. HPR-GDA-PSR-0013, Rev. 0, GNS, TRIM 2017/401365

3. Methodology to Identify Severe Accident Sequences for UK HPR1000, GHX00600137DRAF02TR, Rev. B, CGN, March 2018, TRIM 2018/112556

4. Overall Methodology of Severe Accident Analysis, GDA-REC-CGN-001770, Rev. A, CGN, June 2018, TRIM 2018/199788

5. Safety Case Strategy for Severe Accident Analysis, GDA-REC-CGN-001771, Rev. A, CGN, June 2018, TRIM 2018/199792

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Table 1

Relevant Safety Assessment Principles Considered During the Assessment

SAP No and Title	Description	Interpretation	Comment
FA.15 **Fault Analysis – Severe Accident Analysis – Fault sequences**	Fault sequences beyond the design basis that have the potential to lead to a severe accident should be analysed		Addressed in Section 4 of this report. This assessment report concludes that the severe accident analyses should be further developed and documented thoroughly. At this stage of GDA not enough information has been submitted, and hence the SAP is not fully met.
FA.16 **Fault Analysis – Severe Accident Analysis – Use of severe accident analysis**	The severe accident analysis should be used in the consideration of further risk-reducing measures		Addressed in Section 4 of this report. This assessment report concludes that the information provided regarding specific engineered measures, strategies and procedures to deal with severe accident sequences in the UK HPR1000, is preliminary in nature. More information will be required to provide a basis for a meaningful assessment during Steps 3 and 4 of GDA. Hence the SAP is not fully met.