Office for Nuclear Regulation

# New Reactors Division – Generic Design Assessment

# Step 2 Assessment of Structural Integrity for the UK HPR1000 Reactor

Assessment Report ONR-GDA-UKHPR1000-AR-18-018
Revision 0
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# EXECUTIVE SUMMARY

This report presents the results of my Structural Integrity assessment of the UK HPR1000 reactor 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 Structural Integrity 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 Structural Integrity have been primarily ONR's Safety Assessment Principles (SAPs), in particular SAPs EMC.1 to EMC.34 on the Integrity of Metal Components and Structures (EMC.1 to EMC.3 are relevant to highest reliability claims). I have also used ECS.1 to ECS.3 on Safety Classification and Standards; EAD.1 to EAD.4 on Ageing and Degradation; and ONR's Technical Assessment Guides NS-TAST-GD-016 on the Integrity of Metal Components and Structures, NS-TAST-GD-094 Categorisation of Safety Functions and Classification of Structures, Systems and Components, and NS-TAST-GD-005 Guidance on the Demonstration of ALARP (As Low as Reasonably Practicable). I have also made use of other relevant standards and guidance, notably, the ASME III and RCC-M nuclear design and construction codes, the R6 defect assessment procedure and the European Network for Inspection Qualification (ENIQ) methodology for inspection qualification.

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 Structural Integrity, as presented in the PSR, its supporting references and the supplementary documents submitted by the RP, can be summarised as follows:

- An outline of the overall approach to Structural Integrity, including key interactions with other technical disciplines.
- The basis for the Structural Integrity Classification including the identification of those structures and components needing a highest reliability claim (referred to as High Integrity Components (HICs)).
- An outline of the applicable codes and standards.
- The Structural Integrity safety case strategy, including the approach to providing beyond design code compliance justifications for highest reliability claims.
- The basis for an avoidance of fracture justification in support of highest reliably claims.
- Design summaries for the main metallic components in the reactor plant.
- An overview of the principles for material selection along with the identification and an outline of the mitigation strategies to underpin the 60 year design life.
- ALARP considerations for Structural Integrity.

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

- The RP recognises the importance of Structural Integrity to the overall plant safety case by including a PSR chapter dedicated to Structural Integrity.
- The RP has proposed a Structural Integrity classification scheme that identifies the claims needed to support the overall safety case along with the need to separately classify structures and components for which highest reliability claims are invoked.
- The Structural Integrity claims for the design, construction and operation of the UK HPR1000 are based on established nuclear codes. The RP has recognised the need for additional measures beyond code to underpin highest reliability claims.
- The RP is developing an understanding of the means for demonstrating the ‘avoidance of fracture’ of HICs that aligns with ONR’s SAPs, for example, the application of defect tolerance assessment using the R6 fracture mechanics methodology and proposals to qualify the manufacturing Non Destructive Testing (NDT) using the ENIQ methodology.
- The design summaries show that the main metallic structures and components of the reactor plant are generally based on conventional Pressurised Water Reactor (PWR) technology, giving a basis for confidence that the UK HPR1000 is likely to comply with modern PWR standards; there are also some design features that I judge to be beneficial to Structural Integrity.
- The RP is developing an understanding of ALARP and committed to consider and implement additional measures for Structural Integrity to reduce relevant risks, where reasonably practicable.

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

- There are some structures and components that the RP has identified as HIC candidates with limited descriptions of the reasons. These candidates may be speculative at this stage, but where appropriate, I will seek assurances from the RP that ALARP measures are taken to minimise the number of HICs. In particular, I will issue a regulatory observation (RO) for the RP to justify the classification of the Main Coolant Line (MCL).
- I consider there may still be opportunities to optimise certain aspects of the UK HPR1000 design, from a Structural Integrity perspective. For example, by increasing the use of integrated forgings to reduce welded regions. I expect the RP to consider all available operational experience (OPEX) and potential options, and where relevant, to provide robust and proportionate ALARP justifications as part of the generic safety case.
- The RP is considering several options with regard to the nuclear codes to be applied for the SGs. I will formally assess the RP’s SG ALARP justification covering codes and standards to determine whether a robust process has been applied, to underpin a defensible decision.
- There did not appear to be a clear link between the avoidance of fracture demonstration and the overall Structural Integrity claims for HICs. In addition, the RP needs to further develop arrangements to ensure an integrated approach to develop the avoidance of fracture demonstration is adopted within the Structural Integrity discipline. I will issue a RO to seek the necessary improvements in this area.
- The RP’s approach to ranking areas for detailed defect tolerance and NDT assessment during GDA had only been applied to the Reactor Pressure Vessel (RPV). I need to be satisfied that the RP has a programme of work that is adequately resourced and prioritised.
- The RP claimed that, in general terms, the UK HPR1000 is designed to facilitate NDT. I will seek more detailed evidence of sound design and design for inspectability.

- The above listing includes some key points to follow-up with the RP, a complete listing of follow-up items is provided in Section 4 of this report, which I will progress in GDA Steps 3 and 4.

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

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ALARP | As Low As Reasonably Practicable |
| ASME | American Society of Mechanical Engineers |
| CAE | Claims Arguments Evidence |
| DTA | Defect Tolerance Assessment |
| EA | Environment Agency |
| EDF | Électricité de France |
| ENIQ | European Network for Inspection & Qualification |
| FCG3 | Fangchenggang Unit 3 (Reference plant for the UKHPR1000) |
| FMEA | Failure Modes & Effects Analysis |
| GNS | Generic Nuclear System Ltd |
| HIC | High Integrity Component |
| IAEA | International Atomic Energy Agency |
| IoF | Incredibility of Failure |
| ISI | In-service Inspection |
| LBB | Leak Before Break |
| MSQA | Management for Safety and Quality Assurance |
| MCL | Main Coolant Line |
| MSL | Main Steam Line |
| NDT | Non Destructive Testing |
| ONR | Office for Nuclear Regulation |
| OPEX | Operational Experience |
| PCSR | Pre-construction Safety Report |
| PSI | Pre-service Inspection |
| PWR | Pressurised Water Reactor |
| RCC-M | Règles de Conception et de Construction des Matériels Mècaniques des Ilots Nucléaires PWR (Design and Construction Rules for the Mechanical Components of PWR Nuclear Islands) |
| RGP | Relevant Good Practice |
| RO | Regulatory Observation |

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|---|---|
| RP | Requesting Party |
| RPV | Reactor Pressure Vessel |
| RQ | Regulatory Query |
| RSE-M | Regles de Surveillance en Exploitation des Materiels Mecaniques des Ilots Nucleaires REP ('In-Service Inspection Rules for the Mechanical Components of PWR Nuclear Islands) |
| SAP(s) | Safety Assessment Principle(s) |
| SCC | Stress Corrosion Cracking |
| SFAIRP | So far as is reasonably practicable |
| SG | Steam Generator |
| SSC | Structures, Systems and Components |
| TAG | Technical Assessment Guide(s) |
| TAGSI | UK Technical advisory Group on the Structural Integrity of High Integrity Plant |
| WENRA | Western European Nuclear Regulators’ Association |

## TABLE OF CONTENTS

## Tables

# 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 (GB), 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 Structural Integrity (Ref. 1) prepared in October 2017 and shared with GNS to maximise openness and transparency.

5. This report presents the results of my Structural Integrity assessment of the UK HPR1000 as presented in the UK HPR1000 Preliminary Safety Report (PSR) (Ref. 2 and Ref. 3) and its supporting documentation (Refs 4 to 17).

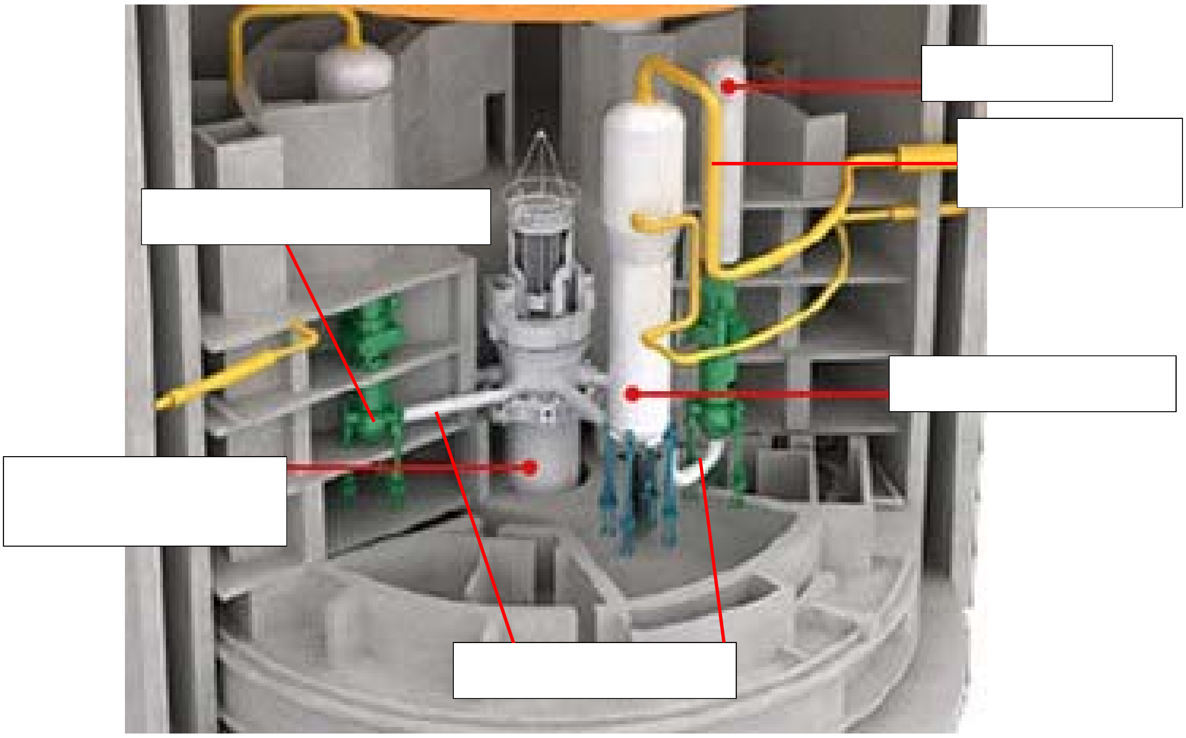

Figure 1: Principal items of interest for Structural Integrity

6. Within ONR, Structural Integrity assessment is primarily concerned with the integrity of metal structures and components, for example: pressure vessels and piping; their

supports; and vessel internals. Figure 1 illustrates the principal items of the UK HPR1000 design that are of the most interest to Structural Integrity and which are presented in the RP's Step 2 submissions.

## 2 ASSESSMENT STRATEGY

7. This section presents my strategy for the GDA Step 2 assessment of the Structural Integrity aspects of the UK HPR1000 (Refs. 2 and 3). It also includes the scope of the assessment and the standards and criteria I have applied.

### 2.1 Scope of the Step 2 Structural Integrity Assessment

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

- The Structural Integrity safety claims for structures and components necessary to support the overall safety case for the UK HPR1000.
- The identification of those structures and components that form a principal means of ensuring nuclear safety and the likelihood of gross failure is claimed to be so low that the consequences of gross failure can be discounted , i.e. highest reliability structures and components, typically including the RPV.
- The development of suitable approaches to infer integrity levels, in particular, for highest reliability claims.
- Initial consideration of the design of the major vessels and piping.
- The principles for material selection along with through-life degradation mechanisms that could potentially affect the achievement of a 60 year design life for the UK HPR1000.
- ALARP considerations.

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

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

- Preparation of regulatory observations covering the more significant shortfalls against regulatory expectations.
- Review of the level of technical support contracts for Step 3 and Step 4.
- Initiated a review of PWR operating experience (OPEX) feedback relating to Structural Integrity post closure of the UK EPR$^{TM}$ GDA.
- Engaged with the RP to develop a Structural Integrity Step 3 submission schedule. This will allow me to develop a Step 3 assessment plan.
- Liaised with ONR inspectors, as appropriate, to identify potential common areas of focus for Step 3.
- Undertaken a coarse review of an early version of the Pre-Construction Safety Report (PCSR).

### 2.2 Standards and Criteria

11. 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 ONR How2 Business Management System guide NS-PER-GD-014 (Ref. 18).

12. In addition, the safety assessment principles (SAPs) (Ref. 19) 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.

13. Furthermore, ONR is a member of the Western European Nuclear Regulators Association (WENRA). WENRA has developed reference levels (Ref. 22) which represents good practices for existing nuclear power plants, and safety objectives for new reactors.

14. The relevant SAPs, IAEA standards and WENRA reference levels are embodied and expanded on in the 'Technical Assessment Guide (TAG) on Integrity of Metal Components and Structures' (Ref. 20). This guide provides the principal means for assessing the Structural Integrity aspects in practice.

### 2.2.1 Safety Assessment Principles

15. The key SAPs (Ref. 19) applied within my assessment are: EMC.1 to EMC.34 on the integrity of metal components and structures (EMC.1 to EMC.3 are relevant to highest reliability claims); ECS.1 to ECS.3 on safety classification; and EAD.1 to EAD.4 on ageing and degradation (see also Table 2 for further details).

### 2.2.2 Technical Assessment Guides

16. The following TAGs have been used as part of this assessment (Ref.20):

- ONR-TAST-GD-016 Revision 5, March 2017. Integrity of Metal Components and Structures;
- ONR-TAST-GD-005 Revision 9, March 2018. Guidance on the Demonstration of ALARP (As Low as Reasonably Practicable);
- ONR-TAST-GD-051 Revision 5, July 2016. The Purpose, Scope and Content of Safety Cases;
- ONR-TAST-GD-094 Revision 0, November 2015. Categorisation of Safety Functions and Classification of Structures, Systems and Components.

### 2.2.3 National and International Standards and Guidance

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

- Relevant IAEA standards:

    - IAEA, Safety Classification of Structures, Systems and Components in Nuclear Power Plants, No.SSG-30, May 2014 (Ref. 21);
    - The relevant guidance from IAEA standards as discussed in Appendix A2 of ONR-TAST-GD-016 (Ref. 20).

- WENRA references:

    - The relevant guidance from WENRA reference levels as discussed in Appendix A1 of ONR-TAST-GD-016 (Ref. 20).

- Other national standards:

    - R6 – Assessment of the Integrity of Structures Containing Defects, Revision 4, EDF Energy Nuclear Generation Ltd. (Ref. 23)

- Other international standards:

    - The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Sections III and XI (Ref. 24).
    - RCC-M. Design and Construction Rules for Mechanical Components of PWR Nuclear Islands. 2007 Edition. Published by the French Association for Design, Construction and In-Service Inspection Rules for Nuclear Island Components – AFCEN, Paris (Ref.25).
    - RSE-M. In-Service Inspection Rules for Mechanical Components of PWR Nuclear Islands, RSE-M, 2010 edition+2012 addendum, 2010, 2012, AFCEN (Ref. 26).
    - European Methodology for Qualification of Non-Destructive Testing. Third Issue. ENIQ Report No. 31 EUR 22906 EN. August 2007 (Ref. 27).
    - ENIQ Recommended Practice 2. Strategy and Recommended Contents for Technical Justifications, Issue 2. ENIQ Report No.39. EUR 24111EN-2010. June 2010 (Ref.28).

## 2.3 Use of Technical Support Contractors

18. During Step 2, I have not engaged technical support contractors to support the assessment of the Structural Integrity for the UK HPR1000.

## 2.4 Integration with Other Assessment Topics

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

20. The key interactions I have identified are:

- The Structural Integrity assessment provides input to the categorisation of safety functions and the classification of structures systems and components (SSCs) aspects of the fault studies assessment. The fault studies inspectors provide advice on the Structural Integrity claims needed to support the overall safety case for the plant. This formal interaction has commenced during GDA Step 2. This work is being led by ONR's fault studies discipline.
- The Structural Integrity assessment provides input to the missile generation, pipe-whip and internal flooding aspects of the internal hazards assessment. The results of the RP's indirect consequence assessment inform the Structural Integrity classifications. This formal interaction has commenced during GDA Step 2. This work is being led by ONR's internal hazards discipline.
- The Structural Integrity assessment provides input on the metallic components used in the containment structure. This formal interaction has commenced during GDA Step 2, with some initial considerations of the materials selection proposed for the containment liner. This work is being led by ONR's civil engineering inspectors.
- The reactor chemistry, radiation protection and mechanical engineering disciplines provide input to the material selection and the assessment of potential through-life degradation aspects of the Structural Integrity assessment. This formal interaction has commenced during GDA Step 2. This

work is being led by Structural Integrity in coordination with other technical disciplines and the EA.

21. In addition to the above there have been interactions between Structural Integrity and several other technical areas, e.g. fuel and core and management for safety and quality assurance (MSQA). These interactions are mostly of an informal nature, but are important to ensure consistency across ONR's assessment. These informal interactions are expected to continue through GDA.

# 3 REQUESTING PARTY'S SAFETY CASE

22. During Step 2 of GDA, the 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 the RP's preliminary safety case in the area of Structural Integrity. It also identifies the documents submitted by the RP which have formed the basis of my Structural Integrity assessment of the UK HPR1000 during GDA Step 2.

## 3.1 Summary of the RP's Preliminary Safety Case in the Area of Structural Integrity

23. The aspects covered by the UK HPR1000 preliminary safety case in the area of Structural Integrity can be broadly grouped under eight headings which can be summarised as follows.

### 3.1.1 Overall Approach to Structural Integrity Demonstration

24. The importance of Structural Integrity to nuclear safety is recognised by the RP with the discipline covered in a dedicated chapter of the PSR (Ref. 2). Several PSR chapters also relate to Structural Integrity, key ones include:

- Chapter 4 (General Safety and Design Principles, Ref. 29);
- Chapter 6 (Reactor Coolant System, Ref. 3);
- Chapter 11 (Steam and Power Conversion System, Ref. 30).

25. In PSR Chapter 17 (Ref. 2), the RP acknowledges the potential for differences between the Structural Integrity demonstration for the reference design, Fangchenggang Unit 3 (FCG3), and meeting ONR's expectations for the UK HPR1000. The RP also acknowledges that the level of Structural Integrity demonstration should be commensurate with the importance of the SSC to maintaining nuclear safety. Its Structural Integrity demonstration for SSCs is therefore founded on compliance with appropriate: design, construction and inspection provisions, taking cognisance of the plant design life.

26. A Structural Integrity specific classification methodology was proposed based on the consideration of the failure consequences and informed by the plant safety categorisation of functions and classification of structures, systems and components. Notably, to meet ONR's expectations, the RP has accepted that for metallic structures and components where the consequences of failure are unacceptable, and where it is not reasonably practicable to provide physical defence-in-depth, then a case to discount gross failure i.e. highest reliability claim is required. This would be based on a multi-legged type presentation with the inference of highest reliability derived from the inclusion of additional measures over and above recognised nuclear design and construction code requirements (Section 3.1.4).

### 3.1.2 Structural Integrity Classification

27. The RP's Structural Integrity classification will be derived from the overall plant safety categorisation of safety functions and classification of structures, systems and components process (Ref.5). A sub-set of structures and components is then identified within the plant standard class 1 SSC as Structural Integrity class 1 (SIC-1) structures and components, which require a higher reliability claim than can be demonstrated by compliance with a recognised nuclear design and construction code alone. These components are identified as 'high integrity components' (HIC) in the RP's safety case. For a HIC, the RP deems the consequences of a postulated gross failure, in the absence of physical safeguards and barriers, to be unacceptable. In contrast, where gross failure is not discounted the SSC is

assigned to one of three Structural Integrity classes: Standard Class 1 (SIC-1), Standard Class 2 (SIC-2) and Standard Class 3 (SIC-3) with class dependent on the consequences of postulated failures and the level of protection offered in the design (Ref. 32).

28. The RP's decisions on the Structural Integrity classification will be based on a failure modes and effects analysis (FMEA) with contributions from other technical disciplines. A key output is the equipment Structural Integrity list. At Step 2 of GDA, this has been limited to identifying HIC candidates (Ref. 12).

### 3.1.3 Applicable Codes and Standards

29. The French RCC-M design and construction rules for mechanical components of PWR nuclear islands will be used for the majority of the SIC-1 and SIC-2 components. SIC-3 structures and components will be designed and constructed to either nuclear or non-nuclear standards, supplemented by other recognised international standards as appropriate.

30. For the UK HPR1000 steam generator (SG), the RP proposes (Ref. 2) a combination of United States (US) and French codes, as implemented in FCG3. Design and construction is to ASME III Class 1 (with RCC-M supplements), whilst the pre-service inspection (PSI) and in-service inspection (ISI) is to the French RSE-M inspection rules for mechanical components of PWR nuclear islands.

### 3.1.4 Safety Case Strategy

31. For structures and components designated as HIC, a four-legged safety case will be developed (Ref. 9) based on the guidance provided by the UK Technical Advisory Group on the Structural Integrity of High Integrity Plant (TAGSI) (Ref. 33).

32. For SIC-1, SIC-2 and SIC-3 components, the safety case will claim that design and manufacture to recognised nuclear and non-nuclear design codes will provide the evidence to support the reliability claims necessary.

### 3.1.5 Avoidance of Fracture

33. Chapter 17 of the PSR (Ref. 2) identifies a need to undertake defect tolerance assessments (DTAs) in support of an avoidance of fracture demonstration for HIC structures and components. The role of the avoidance of fracture demonstration in the safety case is described in an update to the RP's safety case methodology for HIC (Ref. 9). The declared purpose is to demonstrate for bounding locations that the HIC structure or component is tolerant of defects during the plant life. This is based on a conceptual 'defence-in-depth' approach with supporting arguments covering: the absence of crack-like defects at the end of manufacture; specified material fracture toughness giving good resistance to propagation of crack-like defects; and the consideration of in-service sub-critical crack growth mechanisms.

34. A key input to the avoidance of fracture demonstration includes undertaking elastic-plastic fracture analyses using appropriate conservative assumptions, notably fracture toughness properties, to establish the limiting defect sizes for HIC structures and components, whilst taking account of any potential to grow the defects through life. The role of qualified non-destructive testing (NDT) during manufacture to ensure the absence of structurally significant defects (derived from DTA) with high reliability is identified, along with the basis for gaining confidence in the achievement of full inspection qualification during construction. The NDT qualification will confirm that the NDT examinations proposed for the bounding HIC locations will reliably detect such postulated start of life defects with a suitable margin.

35. The safety case methodology document (Ref. 9) is underpinned by supporting documentation covering the identification of the limiting weld locations (Ref. 6), defect tolerance assessment methodology (Ref. 7), the inspection qualification strategy for HIC (Ref. 11) and the strategy and plan of NDT for HIC (Ref. 10).

36. Overall, this work is recognised as going beyond nuclear design code compliance and is needed to underpin a highest reliability claim using a TAGSI four-legged safety case presentation.

### 3.1.6 Design Scheme Descriptions for Major Structures and Components

37. Design summaries, from a Structural Integrity perspective, have been provided for the reactor components (RPV, reactor vessel internals and control rod drive mechanism), (Ref. 13), and the main loop equipment (SG, pressuriser, reactor coolant pump, reactor coolant piping, accumulator, containment liner, and main steam lines), (Ref. 14). These design scheme description documents compliment the reactor coolant system and steam and power conversion system overviews provided in chapters 6 and 11 (Refs. 3 and 30) of the PSR.

38. These design scheme descriptions are based on FCG3 and provide an overview of the safety functions, design principles/codes, design features, material selections, manufacture and inspection provisions. The design summaries provide key design information in advance of the PCSR. These design scheme documents were updated during GDA Step 2.

### 3.1.7 Material Selections and Degradation Mechanisms

39. Chapter 6 of the PSR (Ref. 3) provides a summary of the material selections proposed for the reactor coolant system of the UK HPR1000. These are based on the requirements of the RCC-M code, as implemented in FCG3, and cover the major structures and components; the RPV, reactor vessel internals, control rod drive mechanism, pressuriser, reactor coolant pump, and the reactor coolant piping. The design principles include an explicit claim relating to ensuring integrity over a 60 year design life.

40. In addition, for each major structure or components, chapters 6 and 7 of the PSR cover the selection of materials to ensure compatibility with their environments. This includes the identification of potential through-life degradation mechanisms; these are typical for a PWR design and include general corrosion, stress corrosion cracking, erosion, fatigue and neutron irradiation embrittlement. The information presented in chapters 6 and 17 of the PSR was supplemented late in Step 2, with a material selection methodology, which describes the process, principles and key aspects of material selection for SSCs in the UK HPR1000 (Ref. 15).

### 3.1.8 ALARP Considerations

41. From a Structural Integrity perspective the following claims support the RP's ALARP fundamental safety objective (Ref. 35):

*Inspection and maintenance are considered in the design, and reduce operator exposure As Low As Reasonably Practicable (ALARP) (Ref. 3 ).*

*For the components and structures with general reliability requirements, depending on their impact on nuclear safety, the Structural Integrity demonstration for such components will be based on compliance with corresponding nuclear or non-nuclear design codes and standards. The failure risk can be controlled at the level of both tolerable and As Low As Reasonably Practicable (ALARP) over the plant design lifetime (Ref. 2).*

42. Towards the end of Step 2, and in advance of the issue of the RP's cross-cutting ALARP methodology document (Ref. 16), the RP outlined an approach to demonstrating ALARP for Structural Integrity (Ref. 61). This includes the identification of design measures taking cognisance of OPEX and the SSC classification with, in particular, additional measures for HIC structures and components to reduce risk.

## 3.2 Basis of Assessment: RP's Documentation

43. The RP's documentation that has formed the basis for my GDA Step 2 assessment of the safety claims related to the Structural Integrity aspects of the UK HPR1000 is listed below (Refs 2 to 17):

- UKHPR1000 GDA Project. Preliminary Safety Report Chapter 17 Structural Integrity.
- UKHPR1000 GDA Project. Preliminary Safety Report Chapter 6 Reactor Coolant System.
- Generic Design Assessment for UK HPR1000, Methodology of Safety Categorisation and Classification.
- Generic Design Assessment for UK HPR1000, Methodology and Requirements of Structural Integrity Classification.
- Generic Design Assessment for UK HPR1000: Weld Ranking Procedure.
- Generic Design Assessment for UK HPR1000, Defect Tolerance Assessment Methodology for HIC Components.
- Generic Design Assessment for UK HPR1000: Application of Weld Ranking Procedure.
- Generic Design Assessment for UK HPR1000, Safety Case Methodology for HIC Component.
- Generic Design Assessment for UK HPR1000: Strategy and Plan of Non-Destructive Testing for High Integrity Component.
- Generic Design Assessment for UK HPR1000: Inspection Qualification for High Integrity Component.
- Generic Design Assessment for UK HPR1000, Equipment Structural Integrity List.
- Generic Design Assessment for UK HPR1000, The Scheme Description of Reactor Components.
- Generic Design Assessment for UK HPR1000, The Scheme Description of Reactor Main Loop Equipment.
- Generic Design Assessment for UK HPR1000, Material Selection Methodology.
- Generic Design Assessment for UK HPR1000, ALARP Methodology.
- Generic Design Assessment for UK HPR1000, Safety Case Methodology for HIC and SIC Components.

44. My assessment was also informed by the RP's response to regulatory queries (RQ)s, which provided clarification for certain topics.

45. In addition, during April 2018 the RP submitted to ONR, for information, an advance copy of the UK HPR1000 Pre-Construction Safety Report (PCSR). Chapter 17 (Ref. 2) addresses Structural Integrity. Having early visibility of the scope and content of this chapter has been useful in the planning and preparation of my GDA Step 3 assessment work.

# 4 ONR ASSESSMENT

46. This assessment has been carried out in accordance with How2 guide NS-PER-GD-014, “Purpose and Scope of Permissioning” (Ref. 18).

47. My Step 2 assessment work has involved regular engagement with the RP’s Structural Integrity specialists, i.e., two technical exchange workshops (one in China and one in the UK) and six progress meetings have been held.

48. During my GDA Step 2 assessment, I have identified some gaps in the documentation formally submitted to ONR. Consistent with ONR’s guidance to requesting parties (Ref. 36), these normally lead to regulatory queries (RQs) being issued. At the time of writing my Step 2 assessment report, I had raised fifteen RQs to facilitate my assessment.

49. Similarly, and again consistent with ONR’s guidance to requesting parties (Ref. 36), 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, two ROs were being drafted in parallel with the production of my assessment report. These are discussed in the detailed assessment that follows.

50. Details of my GDA Step 2 assessment of the UK HPR1000 preliminary safety case in the area of Structural Integrity, including the conclusions I have reached, are presented in the following sub-sections of the report. This includes the areas of strength I have identified, as well as the items that require follow-up during subsequent Steps of the GDA of UK HPR1000.

51. It is seldom possible, or necessary, to assess a safety case in its entirety, therefore sampling is used to limit the areas scrutinised, and to improve the overall efficiency of the assessment process. My assessment for GDA Step 2 is based on a broad, shallow sampling approach with the emphasis on understanding the RP’s claims and gaining familiarity with the UK HPR 1000 design in accordance with the aims of GDA Step 2. I have found the RP to be receptive to ONR’s approach and pragmatic in accepting the need to provide beyond design code compliance justifications for the highest reliability components in line with ONR’s expectations. The RP has delivered documentation generally to a reasonable standard broadly in-line with the programme.

## 4.1 Overall Approach to Structural Integrity Demonstration

### 4.1.1 Assessment

52. ONR’s assessment of the RP’s proposals starts with a consideration of the Structural Integrity ‘safety claim’ in its most general sense. In particular, whether the approach to Structural Integrity is based on identifying the safety functions, SSCs that deliver those functions and the required integrity levels necessary to support the overall safety case, ONR SAP ECS.1 to ECS.3, (Ref. 19). In particular, SSCs important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate codes and standards. This is key to ensuring that the risk of failure is reduced ALARP (so far as is reasonably practicable (SFAIRP)) in accordance with the law of Great Britain).

53. The ONR SAPs include particular expectations in situations where structures or components form a principal means of ensuring nuclear safety and where the claim is that the likelihood of gross failure is so low that the consequences of gross failure can be discounted from the deterministic safety analysis i.e. those structures and

components needing a highest reliability claim. Therefore, for Structural Integrity, I have sought to establish the "safety claim" interpreted as:

- the integrity level claimed for a component or structure in order to support the overall safety case for the reactor;
- the identification of those structures and components needing a highest reliability claim.

54. In general, the integrity levels for structures and components will be justified primarily through compliance with internationally recognised nuclear and non-nuclear design and construction codes covering components such as pressure vessels, pipework, supports, reactor internal structures, etc. These codes provide a graded approach that link integrity levels to the overall safety case. The topic is discussed further under 'Structural Integrity Classification', the 'Safety Case Strategy' and the 'Applicable Codes and Standards topics below'.

55. For the assessment of highest reliability claims, I invoke SAPs EMC. 1 to EMC. 3. In this situation, the emphasis falls on the arguments and evidence to support the claim that the likelihood of gross failure is so low that it can be discounted from the deterministic safety assessment (ONR SAPs paragraphs 280 to 291). Similar claims have featured in previous GDAs and in the safety cases for operating nuclear power stations in Great Britain.

56. The SAPs (paragraph 286) note that this is an onerous route to constructing a safety case, and there will need to be an in depth explanation of the measures over and above normal practice that support and justify the highest reliability claims.

57. Thus the identification and justification of these highest reliability components is an important aspect of considering the 'safety claim' relating to Structural Integrity. The RP is unfamiliar with the concept of highest reliability and such claims require significant work to provide a justification. Accordingly, it will form a significant focus of ONR's Structural Integrity assessment for GDA progression. In summary, I have sought to confirm that the RP is proposing an approach that will identify those components which need a claim that the likelihood of gross failure is so low that it can be discounted from deterministic safety assessments, and that a suitable approach can be developed to justify such claims.

### 4.1.2 Links to Fault Studies and Internal Hazards

58. A corollary of the above approach is that where structures and components are not in the highest reliability (HIC) category, there needs to be a robust consequences case against gross failure. It follows that to ensure coherency in the safety case assessment, a multi-discipline approach is needed. I have liaised with fault studies inspectors in terms of the direct effects e.g. the effects loss of coolant inventory or reactivity excursions. Notably, I have made ONR's fault studies inspectors aware of the RP's proposals for HIC, as for these structures and components, the consequences of postulated gross failures will be dismissed from the deterministic analysis.

59. I have also worked closely with ONR's internal hazards inspectors in terms of the indirect effects e.g. flooding, pipe-whip, jets, missiles, and overpressure. Indeed, experience from previous GDAs indicates that the assumptions used in the safety analysis may differ from the RP's previous approaches.

60. I raised RQ-UKHPR1000- 0007 (Ref. 37) early in GDA Step 2 to seek clarification that the RP's underlying assumptions for the Structural Integrity and internal hazards assessments were aligned with meeting ONR's expectations. I questioned whether the safety analyses would consider the direct and indirect consequences of

postulated gross failures, the basis for discounting gross failure and the role of leak-before-break (LBB) in the safety case. LBB relates to a situation whereby a defect propagates through-wall and the subsequent leakage is detected prior to the defect becoming unstable. The primary reason for invoking LBB arguments internationally was initially to avoid fitting pipe whip restraints, which were held to limit access for inspection with attendant increases in the in-service dose accrued during in-service inspection and maintenance activities. The corollary is that where LBB is applied gross failure is effectively discounted.

61. ONR considers that LBB provides defence-in-depth to a Structural Integrity case, but it is not usually viewed as a primary argument, mainly because of the uncertainties associated with defect propagation, reliable leakage detection and margins to the limiting defect size. Instead, the emphasis is placed on maintaining Structural Integrity and robust defence-in-depth provision via the consideration of the consequences of gross failure (Ref. 20). In addition, to discount gross failure the demanding expectations of EMC.1 to EMC.3 are invoked.

62. In response, the RP committed to considering the consequences (direct and indirect) of postulated gross failures and that highest reliability claims would be invoked where, in the absence of protection, the consequences of postulated gross failure were deemed unacceptable. In addition, LBB would play a supporting role in the safety case.

63. Similarly, experience from previous GDAs indicates that internal hazards assessment methods can differ from the approaches previously adopted by RPs. In particular, the following approaches have been challenged:

- the failure mode for medium energy nuclear safety classified pipework in internal flooding assessments;
- the failure locations for nuclear safety classified high energy pipework in pipe-whip assessments;
- use of low utilisation criteria for systems that are not normally in operation, as a basis to claim they may be neglected from safety analyses.

64. In terms of the failure mode for medium energy nuclear safety classified pipework in internal flooding assessments, the approach can be to assume only a crack-like (partial) failure mode with a consequentially small leak area. ONR does not accept that this can be the only failure mode, so that much larger leak areas, typically full bore ruptures, need to be considered in the internal flooding assessments.

65. With regard to the failure locations for nuclear safety classified high energy pipework in pipe-whip assessments, the approach can be to discount failure at welds away for the terminal ends if certain stress and fatigue criteria are met. ONR does not accept that this will always be the case and expects that the consequences of failure at intermediate locations are considered in pipe-whip assessments.

66. The use of low utilisation criteria, typically 1- 2% of the operating time is not accepted by ONR, primarily from an internal hazards perspective, as a basis for dismissing these structures and components from consequence assessments.

67. The challenge to these approaches affects the internal hazards safety case. I therefore worked with the internal hazards inspector by attending joint meetings with the RP to explain ONR’s position and expectations on these aspects. This is discussed in the Step 2 internal hazards assessment report (Ref. 38). However, I consider certain implications in my report, notably, for the Structural Integrity classification process, along with the need to consider structure and components previously underpinned by either LBB or the break preclusion type arguments.

### 4.1.3 Strengths

68. I have identified several strengths in the RPs proposals for the overall Structural Integrity demonstration. The RP has recognised the importance of the Structural Integrity discipline through a dedicated chapter in the generic safety case. The RP also acknowledges the need for the levels of Structural Integrity demonstration to be commensurate with the importance to nuclear safety.

69. At an early stage in Step 2, the RP recognised that, to meet the expectations of ONR's SAPs relating to Structural Integrity, there were potential differences between the approaches developed for FCG3 and those needed for the UK HPR1000. In particular, the RP accepted the need for highest reliability claims and that additional measures beyond compliance with an established nuclear design and construction code would be needed to justify such claims. The RP has also committed to implementing assumptions in the Structural Integrity classification approach and in the assessment of consequences of gross failure aligned with meeting ONR's expectations.

### 4.1.4 Items that Require Follow-up

70. During my GDA Step 2 assessment of the overall approach to Structural Integrity demonstration, I have identified the following additional potential shortfalls that I will follow-up during Step 3 of GDA:

- In collaboration with ONR's internal hazards inspector review the development and application of internal hazards consequence analyses to inform the SSC Structural Integrity classifications, in particular, for those SSC identified as HIC candidates, including a sample of SSC failures which provide a potential threat to HIC structures and components.
- In collaboration with ONR's internal hazards inspector assess the development and application of the internal hazard assessment methods for pipe-whip and missiles.

### 4.1.5 Conclusions

71. Based on the outcome of my Step 2 assessment of the Overall Approach to Structural Integrity Demonstration, I have concluded that the RP is proposing an approach to Structural Integrity demonstration commensurate with the importance to nuclear safety. I am satisfied that, provided consequence analyses are implemented in accordance with ONR's expectations, particularly within the internal hazards' discipline, the RP's approach will include the identification of the components which need a claim that the likelihood of gross failure is so low that it can be discounted from deterministic safety assessments, and that subsequently a suitable approach will be developed to justify such claims.

72. I am satisfied with the approach described, and that it meet's ONR's expectations in the general sense of the identification of the Structural Integrity safety claims.

## 4.2 Structural Integrity Classification

### 4.2.1 Assessment - General

73. The basis of the RP's proposals for Structural Integrity classification, including the approach to identifying structures and components needing a highest reliability claim (i.e. HIC in the RP's Structural Integrity classification scheme), were initially provided in (Ref. 5). My assessment of the RP's proposals for Structural Integrity classification sampled three aspects, namely: demonstration of linkage to the

overall plant categorisation of safety functions and classification of SSC; the methodology; and the HIC candidate listing.

74. It is preferable that the plant categorisation of safety functions and classification of SSC methodology is in place to inform the development of the Structural Integrity classification process. However, during Step 2, delivery of the UK HPR1000 plant safety categorisation of safety functions and classification of SSC came after (Ref. 5). In consequence, the RP's Structural Integrity classification approach proceeded in advance of the UK HPR1000 plant categorisation of safety functions and classification of SSC process.

75. The RP's approach to the UK HPR1000 plant categorisation of safety functions and classification of SSC is to use the FCG3 system with supplements as a means to develop a specific classification scheme for the UK HPR1000. This relies on the identification and closure of gaps to meet ONR's expectations. I am satisfied from a Structural Integrity perspective that the approach to categorisation of safety functions and classification of SSC is sufficiently mature at this stage of GDA. ONR's overall assessment of the RP's arrangements for the safety categorisation and classification of SSCs is being coordinated by the Project Technical Inspector, and is reported in ONR-GDA-UKHPR1000-020 (Ref.62).

76. In terms of Structural Integrity, an interface between the plant categorisation of safety functions and classification of SSC and the Structural Integrity classification is acknowledged in Ref. 5. However, the implementation of a set of underlying assumptions (e.g. role of LBB, basis for break preclusion and the development of internal hazards methods, pipe-whip, missiles etc.) that differ from FCG3 is not explicitly identified as a gap to meeting ONR's expectations. Clearly, these may influence the plant and Structural Integrity classification of structures and components. A further point is that there is no explicit link or reference to the quality classes for structures and components. In Step 3, I will work with ONR's MSQA inspector to gain evidence that the RP is proposing adequate and proportionate quality assurance arrangements for structures and components within the Structural Integrity discipline.

77. A corollary of the RP's overall approach to the UK HPR1000 plant categorisation of safety functions and classification of SSC was that the FCG3 plant classification was used as the initial input to the Structural Integrity classification. As previously explained, this may not fully meet ONR's expectations because of the different underlying assumptions. In RQ-UKHPR1000- 0083 (Ref. 32), I therefore questioned why the use of the FCG3 plant classification provided a reasonable basis to inform the Structural Integrity classifications.

78. The RP explained that the FGC3 plant categorisation of safety functions and classification of SSC approach is founded on IAEA SSG-30 (Ref. 21). This uses a combination of functional classification for fault conditions and design provision (or barrier class - effectively direct classification) under normal operation to classify structures and components. In situations where a structure or component may fulfil both functional and design provision roles, the default position is to the highest classification. For Structural Integrity, the structure and component classification tends to be determined by the design provision (or barrier class). Thus the major vessels and piping in FCG3, and those proposed for the UK HPR1000, are classified as standard class 1 in FCG3. I consider this an appropriate plant classification for these components, many of which form a principal means of achieving nuclear safety.

79. The RP considered that the general principles and logic of categorisation of safety functions and classification of SSC between FCG3 and ONR's expectations were similar. As a result, the RP held the view that the use of the FCG3 classification

process would not significantly affect the method of Structural Integrity classification nor would it change the listing of HIC candidate structures and components identified for the UK HPR1000 (Ref. 12).

80. I consider it reasonable to use the FCG3 standard class 1 structures and components to inform an initial listing of Structural Integrity class SIC-1 and hence HIC candidate structure and components for GDA Step 2. This is because the plant classifications for several of the major vessels and piping are unlikely to change post implementation of proposals to meet ONR's categorisation of safety functions and classification of SSC expectations. However, this may not be the case for all structures and components, because the expectations for the UK HPR1000 relating to the fault studies and internal hazards disciplines are different to FCG3. The position warrants a review following the implementation of the proposals to meet ONR's categorisation of safety functions and classification of SSC expectations. The RP committed to undertaking this review early in Step 3. In addition the equipment Structural Integrity classification list will be updated to cover all the Structural Integrity classes taking cognisance of the results of consequence analyses, and if necessary and reasonably practicable, the implementation of design changes (Ref. 32).

81. For the Structural Integrity classification, three Structural Integrity classes; SIC-1, SIC-2 and SIC-3 derived from the standard plant classes 1 to 3 are proposed for the UK HPR1000. The listing of SIC-1 structures and components is then used to derive an initial listing of HIC structures and components along with the design and construction code class. Thus, at Step 2 the focus for this equipment Structural Integrity classification listing is SIC-1 and HIC. The Structural Integrity classifications are based on failure modes and effects analysis (FMEA) with the support of several technical disciplines (Ref. 32). It will also allow for the identification of locations within structures and components, where a demonstration of highest reliability is warranted. The use of a systematic approach to Structural Integrity classification informed by FMEA meets my expectations in terms of the intended approach. In Step 3, in collaboration with ONR's fault studies and internal hazards inspectors, I will sample several non-HIC structures and components to establish that they are underpinned by adequate consequence analyses. I will also sample the RP's application of the classification approach, in particular, the resulting design and construction code proposals across the range of the Structural Integrity classifications.

82. The initial listing of SIC-1 included structures and components I would expect, namely the RPV, pressuriser, SG, reactor coolant pump casing, main coolant line, sections of the main steam piping etc. However, for FCG3, LBB and break preclusion type arguments are invoked which effectively discount certain structures and components from the consideration of gross failure, but not through a rigorous assessment of the consequences. For these structures and components, it is less clear that the classification would not be affected by the consideration of the consequences of postulated gross failure. In addition, it may be reasonably practicable to implement design changes to avoid high reliability claims.

83. I raised RQ- UKHPR1000-0102 (Ref. 39) to establish the extent to which LBB was applied in FCG3 (Ref. 39). A companion regulatory query, namely, RQ-UKHP1000-0115 was raised by ONR's internal hazards inspector to gain an understanding, for the reference design, of all areas currently excluded from consequences analyses other than those based on LBB concepts (Ref. 40). The RP confirmed that several structures and components, namely, the main steam lines, the SG blowdown lines in the safeguard buildings, the MCL and the surge line in the reactor building were precluded from consequence analyses for FCG3 either because of LBB claims, or because they are high energy pipes within containment penetration rupture exclusion rules applied to the reference design. The RP has

identified these structures and components for the completion of analyses to establish the direct and indirect consequences of postulated gross failures. I welcome this approach but also expect the RP to consider, where appropriate, whether design changes are reasonably practicable.

### 4.2.2 Assessment – Initial HIC Listing

84. For the UK HPR1000, the RP has classified the RPV, pressuriser, SG and MCL as HIC (Table 1). For established PWR technology and based on previous GDAs, I would expect the RPV, pressurizer and SG to warrant highest reliability claims. The classification of the MCL as HIC is less certain and depends on the PWR design. For example in Sizewell B, pipe-whip restraints are fitted and the MCL piping is not highest reliability. However, for the UK HPR1000, there is no recognition that further work is needed to justify that, on an ALARP basis, a HIC classification for the MCL is appropriate. I view this as an important shortfall in the RP's case.

85. In Step 3 of GDA, I will further establish the basis of the RP's MCL HIC classification and expect an adequate ALARP justification to be provided. At this stage in GDA, this is an important shortfall in the RP's case which needs to be given enhanced regulatory scrutiny as GDA progresses. A RO is being prepared with my assessment report, to address this gap.

86. ONR's position is that safety cases should not rely on claims of highest reliability, if reasonably practicable (SAP EMC.2 Paragraph 293). This is because it is out with the achievement of physical defence-in-depth in the plant design (SAP EKP.3). Furthermore, it is an onerous route to a safety justification with the expectations of measures beyond normal practice and extensive commitments to main Structural Integrity through-life.

**Table 1:** Initial HIC Listing for UK HPR1000

| Identified Component | Location | Structural Integrity Classification | Consequence |
|---|---|---|---|
| Reactor Pressure Vessel | BRX | HIC | break/missile |
| Pressuriser | BRX | HIC | break/missile |
| Steam Generator (primary and secondary shell & tubesheet) | BRX | HIC | break/beyond design basis/missile |
| Main Coolant Line | BRX | HIC | break (pipewhip) |
| Main Steam Line | BRX | Candidate HIC | break (pipewhip), analysis on-going |
| Main Steam Line | BSA/BSB | Candidate HIC | break (pipewhip) analysis on-going |
| Pressuriser Surge Line | BRX | Candidate HIC | break (pipewhip) analysis on-going |
| Steam Generator Blowdown Lines | BSA | SIC-1 | break (pipewhip) analysis on-going |
| Reactor Coolant Pump Casing & Flywheel | BRX | Candidate HIC | missile<br>analysis on-going |

87. Table 1 presents the RP's initial HIC listing compiled from Refs. 12 and 40.

88. From Table 1, I note that the majority of the consequences above relate to indirect effects though I would expect that it would be difficult to make a case for the RPV

on direct consequences due to the loss of fundamental safety function(s). I also note that the direct consequences of a postulated gross failure of the MCL is claimed to be within the design basis condition (Ref. 12). This claim may relate to the results of recent consequence analysis, because in the PSR, the design basis condition for a large break loss of coolant accident is associated with a gross failure of the surge line (Ref. 64). In Step 3, I will establish the position with ONR's fault studies inspector.

89. In addition, confirmation of the Structural Integrity classification of several SSC e.g. the surge line, reactor coolant pump flywheel and main steam line (MSL) depends on the results of consequence analyses scheduled for Step 3. The SSCs listed as HIC candidates are what I might expect for established PWR technology, but I am concerned to see the pressuriser surge line as a HIC candidate. This may be evidence that the RP is adopting a cautious approach pending completion of the consequence analysis. However, the substantiation of a highest reliability claim for a pressuriser surge line noting the potential for loadings arising from thermal stratification and fatigue (irrespective of any environmental enhancement for the LWR environment) is likely to be a challenging undertaking.

90. Likewise, I note that large sections of the MSL are HIC candidates (Table 1). I also expect the scope of these consequences analyses to include valves (bodies and their potential missiles). A demonstration of the Structural Integrity of the valve bodies, particularly if cast like the reactor coolant pump casings, may prove problematic, specifically for the avoidance of fracture demonstration where low fracture toughness may lead to small structurally significant defect sizes which are difficult to detect and reject with qualified inspection.

91. The RP's HIC candidate listing is also important to ONR's faults studies assessment, since HIC structures and components are discounted from deterministic analysis. Similarly, the need to consider the indirect consequences within the internal hazards discipline is crucial to establishing the plant and Structural Integrity classifications. I will target assessment of the RP's classification of these SSCs as GDA progresses, when the UK HPR1000 methodologies are fully developed and applied to the design (Ref. 38).

92. On the basis of my experience of LWR technology I will conduct a more detailed review of the basis of the Structural Integrity classifications, in particular, in collaboration with ONR's fault studies and internal hazards inspectors the results of consequence analyses. In Step 2, I have focussed on the integrity of vessels and piping at a high level. In later stages of the GDA I will also consider the RP's proposals for the classification of associated closure components and supports. The main emphasis of my assessment of this topic during Step 3 of GDA will be to seek, where appropriate, suitable and sufficient ALARP justifications from the RP that objectively demonstrate the reasonable practicability, or otherwise of implementing additional defence-in-depth measures into the UK HPR1000 design.

### 4.2.3 Strengths

93. The RP has developed an approach to Structural Integrity classification founded on systematic consideration of the direct and indirect consequences of postulated gross failures which will be informed by FMEA. The RP's approach will allow for the identification of those structures and components that require a highest reliability claim.

94. The interface between the Structural Integrity and the UK HPR1000 plant classification is also identified. The use of the FCG3 SSC classifications has allowed the initial Structural Integrity classifications for the UK HPR1000 to progress. This is because the major vessels and piping are classified directly

based on the design provision approach used in FCG3, and so the majority of the Structural Integrity classifications are unlikely to change when the UK HPR1000 plant categorisation of safety functions and classification of SSC is applied.

### 4.2.4 Items that Require Follow-up

95. During my GDA Step 2 assessment of Structural Integrity classification, I have identified the following additional potential shortfalls that I will follow-up during Step 3 of GDA:

- In collaboration with ONR’s MSQA inspector gain evidence that the RP is proposing adequate and proportionate QA arrangements for SSC within the Structural Integrity discipline.
- In collaboration with ONR’s fault studies and internal hazards inspectors, sample several non-HIC structures and components to establish that they are underpinned by adequate consequence analyses and that the resulting design and construction codes are appropriate.
- Review the application of the UK HPR1000 plant and Structural Integrity classification following the application of analysis methods developed for the UK HPR1000 design.
- Issue a RO requesting the RP to undertake further work to justify why, for UK HPR1000, classifying the MCL as HIC is ALARP.
- Where appropriate, seek the necessary assurances from the RP, through demonstrably robust, and proportionate ALARP justifications, to demonstrate all reasonably practicable engineered measures, which remove the need to make highest reliability claims, are incorporated into the UK HPR1000 design.

### 4.2.5 Conclusions

96. Based on the outcome of my Step 2, I have concluded that the RP’s approach to Structural Integrity classification will be suitable, and importantly, will allow the RP to identify those structures or components (including locations) that will require a higher Structural Integrity claim. In addition, the RP has recognised the interface between the UK HPR1000 plant categorisation of safety functions and classification of SSC scheme and the Structural Integrity classification.

97. The identification of candidate components requiring a higher Structural Integrity claim was completed by the RP towards the latter stages of GDA Step 2 based on a Structural Integrity classification procedure developed for the UK HPR1000. The rationale for the selection of all HIC candidates has not been fully reviewed as part of my Step 2 assessment, and the Structural Integrity classifications will be informed by the results of on-going direct and indirect consequence assessments. I will review these topics during GDA Step 3.

98. In particular, I will further establish the basis of the RP’s MCL HIC classification and expect an adequate ALARP justification to be provided. At this stage in GDA, this is an important shortfall. A RO is being prepared with my assessment report, to address this gap.

## 4.3 Applicable Codes and Standards

### Assessment - General

99. The classification of SSC reflects the importance to nuclear safety and the functional reliability, which then links the plant safety case to the engineering provisions, via the allocation of appropriate codes and standards (usually via an engineering schedule). ONR SAP ECS.3 states that SSC that are important to safety should be designed, manufactured, constructed, installed, commissioned

quality assured, maintained, tested and inspected to the appropriate codes and standards.

100. In Step 2 of GDA, I have sought to establish that the RP is proposing adequate design and construction codes commensurate with the importance of the SSC to nuclear safety. Indeed, the selection and implementation of appropriate design, manufacturing standards and inspection provisions to SSC is central to a demonstration the risks of failure are reduced to ALARP.

101. I raised RQ-UKHPR1000-0030 (Ref. 43) to establish the extent to which French, US and Chinese regulatory standards are intended to inform the selection of relevant codes and standards for the UK HPR1000. I also queried the basis for the RP's view that selection of relevant codes and standards for the UK HPR1000 pressure boundary was commensurate with the UK requirement of reducing risks ALARP.

102. The RP's response to RQ-UKHPR1000-0030 (Ref. 43) explained that the selection of codes and standards for SSC is based on IAEA SSG -30 (Ref. 21) and is informed by both the safety function class and design provision (or barrier class). In addition, standard class 1 and 2 SSCs are designed and constructed in accordance with nuclear specific codes and standards. For standard class 3 SSCs nuclear or appropriate non-nuclear codes and standards may be used. Nuclear pressure vessels and piping are designed to internationally accepted design codes and the RP has designed FCG3 to the French nuclear design code, RCC-M (Ref. 25). The use of Chinese codes and standards is limited to structures and components, which are non-safety classified i.e. do not deliver nuclear safety functions. Nonetheless, the RP is committed to reviewing some of the Chinese codes and standards to ensure equivalence with appropriate international equivalent codes. I note the RP's position, but need to establish whether for standard Class 3, the intent is to use nuclear codes or a combination of nuclear and non-nuclear codes with supplements. Notably, if non-nuclear codes with supplements are proposed then application of the nuclear exclusion under the Pressure Equipment Regulations will be an important consideration.

103. The PSR, (Ref. 2) along with the Structural Integrity classification document (Ref. 5), expand on the selection of codes and standards for the UK HPR1000 SSC within the Structural Integrity discipline. The French RCC-M code is proposed for the majority of SSCs with the allocation of the RCC-M classes 1-3 primarily governed by the plant safety class i.e. standard classes 1-3. The design requirements set by the RCC-M code were reviewed by ONR as part of the UK EPR$^{TM}$ GDA. ONR concluded that the design provisions were broadly the same as those for ASME III on a class- by- class basis, and are judged to be generally acceptable for nuclear pressure systems (Ref. 41). The design and construction provisions of RCC-M have since been implemented in the manufacture of the major vessels and piping for the UK EPR$^{TM}$ at Hinkley Point C (Ref. 42).

104. I am therefore broadly content with the proposed use of the RCC-M code and with the use of a graded approach to design and construction, with the Structural Integrity provisions proportionate to the importance to nuclear safety. In Step 3 of GDA, I will review the application of the RCC-M (and the RSE-M) code in the UK HPR1000 and informed by the experience from the UK EPR$^{TM}$ GDA identify specific areas where further work may be necessary to meet ONR's expectations.

105. In addition, several of the code editions proposed for the UK HP1000 major vessels and piping are up to 10 years old (RCC-M-2007 (design), RSE-M-2007, 2010 +2012 Addendum (ISI) and for the SG ASME III-2007 and 2008 Addendum (design). These code editions do not necessarily reflect current good practice. For example, RCC-M version 2018 incorporates good practice relating to forging manufacture based on the French ESPN order. The RP has committed to design SSC to the

current versions of the codes and standards taking cognisance of proven experience (Ref.43). In Step 3 of GDA, I will establish how the RP intends to meet the commitment to design and inspect to the current version of these codes and standards.

106. However, the development and application of the UK HPR1000 plant categorisation of safety functions and classification of SSC methodology needs to address ONR's expectations (Section 4.2.1). I will therefore sample the outputs from the allocation of design and construction classes for a range of the plant and Structural Integrity classes during Step 3 of GDA, and review the designation of the nuclear pressure vessel code class. This will focus on sampling SSCs more significant to nuclear safety, including structures and components that have previously warranted highest reliability claims e.g. RPV, Pressuriser, SG, MCL, MSL, RCP casing, RI etc. In addition, I may give some consideration to standard classes 2 and 3. In particular, if class 2 SSCs are designated HIC or for class 3 if non-nuclear codes with supplements, are claimed to be equivalent to nuclear standards i.e. RCC-M Class 3.

### Assessment - Steam Generator

107. The selection of the RCC-M code for SSCs within the Structural Integrity discipline for the UK HPR1000 follows the RPs experience in the application of RCC-M in FCG3 along with experience from other PWR designs built in China. However, for FCG3, the ASME III code (Ref. 24) is used for the design and construction of the SG, whereas ISI of the SG is to the French RSE-M code (Ref. 26). The RP intends to carry over this approach for the Structural Integrity provisions for the UK HPR1000 SG

108. The use of a combination of established nuclear design codes to underpin the Structural Integrity provisions for a pressure boundary component that forms a principal means of fulfilling nuclear safety functions is novel to ONR. The guidance at SAP ECS. 2 Paragraph 173 is relevant:

109. *'The combining of different codes and standards for a single aspect of a structure, system or component should be avoided. Where this cannot be avoided, the combining of the codes and standards should be justified and their mutual compatibility demonstrated.'*

110. In the case of the UK HPR1000 SG, I interpret a single aspect of structure, system or component to include the collection of Structural Integrity provisions (design, construction and in-service, rather than say design and construction, which are covered by the scope of the specific application of ASME III or RCC-M. In this context, and given that either ASME III/XI or RCC-M/RSE-M provide a sound basis for the Structural Integrity provisions and are readily available, the RP's proposal appeared inconsistent with meeting SAP ECS.2.

111. The main intent of avoiding a combination of codes and standards for a single aspect of a SSC is to avoid 'cherry picking' i.e. where selective and more lenient aspects of codes and standards are chosen with the resulting collective provisions potentially providing an inadequate basis to justify the integrity of the SSC compared to the holistic provisions offered in an established design, construction and inspection code e.g. ASME III/XI or RCC-M/RSE-M.

112. In RQ-UKHPR1000-0030 (Ref. 43), I sought further clarification of the basis of the proposal and that the RP's selection of codes and standards to underpin the Structural Integrity case for the UK HPR1000 SG pressure boundary were commensurate with reducing risks to ALARP.

113. The main reason for the selection of the ASME III code for design and construction was because the supplier (Canada BWXT) is familiar with the ASME code and has a proven record in designing, manufacturing and supplying the SGs in FCG3. In contrast, the RSE-M code is used for ISI (and the PSI 'fingerprint') of the SG during plant operation because the RSE-M code is the basis of the ISI policy for FCG3 (and the UK HR1000). This approach to ISI for the SG was held to meet the declared purpose of ISI; a preventative maintenance process to detect the onset of damage and loss of integrity, whilst utilising the operator's familiarity and experience in the application of the RSE-M ISI code for the UK HPR1000 plant.

114. In addition, the RP's proposals had drawn on the collective experience for the SGs in the Chinese Pressurised Water Reactor CPR-1000 PWR fleet of civil reactors in China, where a combination of US and French codes for the SG provisions is extensively used (Ref.43 and Ref. 44). The RP contends that the risks associated with using a combination of established nuclear design codes for the SG Structural Integrity provision were understood and mitigated.

115. In support of the application of this approach in FCG3, the RP undertook significant work, where the key differences between ASME III/XI and the RCC-M/RSE-M codes were identified. As a result in FCG3 the design and construction of the SG to ASME III was supplemented with additional requirements for design, manufacture (including implementation of the M140 provisions for forgings), testing and weld qualification from the RCC-M code.

116. I sought to understand why these additional measures, which effectively reduce relevant risks, were implemented by the RP for FCG3 in RQ-UKHPR1000-0109 (Ref. 45). The response indicated that this was to meet the requirements of the Chinese nuclear safety regulator, the National Nuclear Safety Administration. The position was therefore that by using ASME III, with supplements from RRC-M, the overall design and construction provisions are not only fully compliant with the intent of ASME III, but are broadly equivalent to RCC-M. Indeed, the full scope of the supplements to ASME III was more extensive than that first indicated and covered: design, material, procurement, manufacturing, welding, examinations, proof testing and PSI/ISI (Ref. 45). Indeed, in several cases the collective code provisions exceed those of the individual codes e.g. fingerprints for ISI are undertaken for both ASME XI and RSE-M which enhance the Structural Integrity demonstration.

117. I understand the rationale for the RP's selection of codes and standards for FCG3 is primarily driven by a world-wide shortage in SG design and manufacturing capability. There is no evidence to suggest the motivation is 'cherry picking'. On the contrary, although it could be argued that the SG is not fully compliant with either ASME or RCC-M/RSE-M, the collective Structural Integrity provisions for FCG3 appear to exceed those of the individual nuclear codes and standards. Nonetheless, there are risks associated with the management of responsibilities, QA provisions and the component interfaces (vessel to piping) and so alternative design options which would afford improved consistency, warrant further consideration.

118. Thus for the UK HPR1000 SG, I have sought a demonstration that the RP's proposals reduce relevant risks to ALARP. This is particularly important because the design code provisions will form the foundation for the SG Structural Integrity case. Indeed, the SG primary and secondary boundary is classified as HIC, and so the collective Structural Integrity provisions need to provide an adequate basis for the Structural Integrity case. I note, for example, that the SG secondary boundary is assigned to barrier safety class 2 under the FCG3 plant classification scheme. The RP's optioneering should also take cognisance of the need for additional measures to underpin the HIC classification, such as: QA provision, materials data, inspection data, design margins, load combinations, operation etc.

119. In my opinion there are benefits, detriments and risks with the proposed arrangement (FCG3) codes and standards option for the SG, and with alternative options that would afford improved consistency, for example, via the application of a single established design, construction and inspection code for the SG. These risks vary through the component life-cycle and with the design code option and need to be appropriately managed. For example, the SG designer is familiar with ASME code and not RCC-M; whilst the operator is familiar with ISI to RSE-M, but not ASME XI (Ref. 24).

120. Furthermore, the interfaces and boundaries between the code jurisdictions i.e. vessel to piping, need careful consideration taking cognisance of relevant OPEX along with the different responsibilities and/or QA provisions, which are a potential source of errors and misunderstanding. There is also the potential for 'gaps' in the code provisions to leading to inadequate Structural Integrity provisions. Therefore, informed by the results of the RP's UK HPR1000 SG ALARP assessment covering codes and standards, I will address the RP's proposals for management of these interfaces in Step 3 of GDA.

121. In Step 2 of GDA, the RP has committed to undertaking a high-level review of several UK HPR1000 SG design code options with consideration of the benefits, detriments and risks (and their mitigation) using an ALARP optioneering approach. The RP has consulted UK expertise to develop the approach and to offer a multi-discipline independent view via an expert panel. The options considered include: the FCG3 option; design, construction and inspection to ASME III/XI; design, construction and inspect to RCC-M/RSE-M; and a complete re-design of the UK HPR1000 SG to RCC-M/RSE-M. In discussions it was evident that the RP has a well-developed design optioneering approach that has informed the codes and standards decision-making for the FGC3 SG. This is useful, though the criteria and judgements associated with ALARP optioneering are likely to differ from those employed in design optioneering.

122. The RP's 'SG High Level ALARP Assessment for SG Code' document is scheduled for delivery in August 2018 (i.e. beyond the cut-off date for ONR assessment work to be captured in GDA Step 2 reports) and so I will take the position forward prior to, and early in Step 3 of GDA. This needs to progress with some priority given that the RP has classified the SG as HIC and that there needs to be a sound foundation, through the collective Structural Integrity provisions, for the UK HPR1000 SG Structural Integrity case.

123. Overall, for Step 2 of GDA, the responses to my RQs have clarified the basis of the RP's proposed design and construction codes for the UK HPR1000 SG. The RP appears to have well-developed design optioneering processes and has applied this to the FCG3 SG design. In addition, there is emerging evidence that the FCG3 Structural Integrity provisions for the SG are founded on supplementing design to an established nuclear design code, namely ASME III, with additional measures to also achieve broad compliance with the French RCC-M code. The corollary is that irrespective of ONR's expectations for highest reliability, the Structural Integrity case for the SG is founded on provisions beyond basic compliance with an established nuclear design code. This notwithstanding, I expect a robust ALARP demonstration based on a balanced consideration of the benefits, detriments and risks associated with the proposed and alternative design code options. The extent of further regulatory scrutiny of this aspect of the design will be informed by the veracity of the RP's ALARP case for the selection of the SG design, construction and inspection codes.

### 4.3.1 Strengths

124. The RP's proposed use of the RCC-M/RSE-M code, in principle, provides an adequate basis for the Structural Integrity provisions for the UK HPR1000. In particular, these codes are internationally accepted and offer a graded approach to design, construction and inspection with the Structural Integrity provisions informed by the importance of the SSC to nuclear safety. During Step 2 of GDA, the RP committed to using the latest version of these codes in the design of the UK HP1000.

125. The RP recognises the linkage between the selection of code provisions and the nuclear safety classification and is committed to further work to confirm the adequacy of the proposed codes and standards following the development and application of the UK HPR1000 plant categorisation of safety functions and classification of SSC process to meet ONR's expectations.

126. The RP recognises the proposed use of a combination of established French and US nuclear design codes for the UK HPR1000 SG is novel to ONR. The RP also understands there are risks with this proposal that need to be identified and appropriately managed. These are particularly important because the RP has classified the UK HPR1000 SG as HIC, so there needs to be a sound foundation for the SG Structural Integrity case. The RP has accepted the need to provide a robust ALARP demonstration to show how the expectations of ECS.2 will be met. This includes consideration of the FCG3 approach along with alternative design code provisions that improve consistency as part of an optioneering approach based on a balanced consideration of the benefits, detriments and risks.

### 4.3.2 Items that Require Follow-up

127. During my GDA Step 2 assessment of applicable codes and standards, I have identified the following additional potential shortfalls that I will follow-up during Step 3 of GDA:

- Review the application of the RCC-M/RSE-M code in the UK HPR1000 and taking cognisance of previous experience in the application of the RCC-M/RSE-M codes, identify specific areas where further work may be necessary to meet ONR's expectations.
- Clarify how the RP intends to meet the commitment to design and inspect UK HPR1000 to the current version of the selected codes and standards.
- Clarify the basis for allocating the nuclear pressure vessel class and sample the outputs from the allocation of design and construction classes for a range of the plant and Structural Integrity classes for the UK HPR1000.
- Assess the RP's SG ALARP optioneering report covering codes and standards to establish that there is a sound basis for the SG Structural Integrity case and that the RP's proposals are commensurate with reducing risks to ALARP.
- Subject to the results of the RP's SG ALARP report covering codes and standards, review the RP's proposals for the management of the physical and managerial interfaces associated with the use of a combination of US and French design, construction and inspection codes for the UK HPR1000 SG.

### 4.3.3 Conclusions

128. Based on the outcome of my Step 2 assessment of applicable codes and standards, I have concluded that I am broadly content with the RP's proposed selection of codes and standards for the major vessels and piping in the UK HPR1000. In principle, I am satisfied that they provide an adequate basis for the Structural Integrity provisions. In practice, their application will be informed by the

development and application of a plant categorisation of safety functions and classification of SSC process to meet ONR's expectations.

129. The proposed use of a combination of established French and US nuclear design, construction and inspection codes for the UK HPR1000 SG is novel to ONR. The RP provided adequate responses to my initial queries and has developed an optioneering approach to show that the selection of codes and standards for the UK HPR1000 SG is commensurate with reducing relevant risks to ALARP. The SG optioneering report was not available to inform my Step 2 assessment report, but with delivery scheduled for August 2018, will be progressed with priority prior to and early in Step 3. I expect to see a robust ALARP demonstration based on a balanced consideration of the benefits, detriments and risks associated with the proposed and alternative design code options, with future regulatory action informed by the veracity of the RP's ALARP case.

## 4.4 Structural Integrity Safety Case Strategy

### 4.4.1 Assessment

130. ONR expects that safety cases to be complete, coherent, and traceable. One way to achieve this is with a clear trail from claims through to arguments and evidence (CAE) (SAP Paragraph 86, Ref 19). The rigour of the case presented should be proportionate to the importance of the SSC to nuclear safety. In addition, the safety case should be primarily written for the user(s) and should possess several qualities as described in Technical Assessment Guide 51; The Purpose, Scope, and Content of Safety Cases; (Ref. 20). At Step 2 of GDA, the generic safety case for the UK HPR1000 is at an early stage of development and so many aspects are incomplete and require work by the RP to progress through GDA. For Structural Integrity I have sought a basis or 'route map' for the development of soundly based and proportionate Structural Integrity cases. I have considered the RP's proposals for: structures and components not underpinned by a highest reliability claim i.e. SIC-1, SIC-2 and SIC-3; structures and components where highest reliability claims are invoked i.e. HIC; and the linkage to the overall plant safety case.

131. The RP's proposals were initially presented in a Safety Case Methodology for HIC Components using a CAE format (Ref. 9). This document focussed on the presentation of the safety case for HIC structures and components. Therefore the main concern related to the absence of information on the proposed content and structure of the Structural Integrity case for non-highest reliability structures and components. The RP subsequently issued a Safety Case Methodology for HIC and SIC Components (Ref. 17).

132. In Ref. 17 the RP confirmed that for the SIC-1 to SIC-3, the case would largely be based on design and manufacture to recognised nuclear and non-nuclear design codes. This notwithstanding, the need to also demonstrate relevant risks are reduced to ALARP was acknowledged, so for example certain SIC-1 structures and components may be supplemented with additional measures. I am broadly content that the RP's proposals will provide a sound basis to develop the Structural Integrity cases for non-highest reliability UK HPR1000 structures and components. In practice, this is subject to the implementation of a plant categorisation of safety functions and classification of SSC approach that accords with ONR's expectations and is founded on appropriate assessment methods.

133. A key point for the development of all Structural Integrity cases is that there is a clear link to the overall safety case for the UK HPR1000. I am not clear that the overall PSR Chapter 17 claim (Ref. 2): *"Appropriate methods will be adopted for the assessment of Structural Integrity of metallic components and structures",* fully reflects linkage to the PSR high-level safety objective (Ref. 2): "*The design and*

*intended construction and operation of the UK HPR1000 will protect the workers and the public by providing multiple levels of defence to fulfil the fundamental safety functions (reactivity control, fuel cooling and confinement of radioactive material), reducing the nuclear safety risks to a level that is low as reasonably practicable"*. I also understand that multiple levels of defence-in-depth includes conceptual aspects (along with physical protection and mitigation), to capture highest reliability claims.

134. On the basis of the scope of the RP's proposed arguments and evidence provided in the safety case methodology document (Ref. 9), I am satisfied that a route to providing more clear linkage between the Structural Integrity cases and the plant safety case can be developed, but will follow-up this up in Step 3 of GDA.

135. The ONR SAPs (SAP EMC.1 to EMC.3, Ref. 19) include specific expectations for the demonstration of highest reliability (HIC using the RP's terminology). Notably, SAP Paragraph 286 identifies the need for measures over and above the provisions of a recognised nuclear design and construction code. The RP is proposing a four-legged safety case based on the guidance provided by TAGSI, (Ref. 33). The approach is one of providing conceptual defence-in-depth through a multi-legged safety case comprising: design and manufacture; functional testing; failure analysis and forewarning of failure.

136. The TAGSI style presentation provides a basis for the safety case for highest reliability (HIC) structures and components. However, the TAGSI approach was developed to support the justification of existing plant, post the development and application of highest reliability concepts (Incredibility of Failure, (IoF)) to the UK's Sizewell B PWR plant. Indeed, the Sizewell B Structural Integrity case for the RPV and other IoF structures and components was founded on the recommendations of the Light Water Study Group (Ref.46), and scrutinised at the associated public inquiry. A key aspect of these recommendations involved the integration of fracture mechanics analyses with qualified inspection. In GDA, the integration of fracture mechanics analyses (defect tolerance assessment) with proposals for qualified inspection, which are underpinned by conservative material properties, supports an avoidance of fracture demonstration. I therefore view this as a fundamental demonstration which needs to be made for the UK HPR1000 design as it progresses through GDA.

137. In Ref. 9, the structure of the RP's proposed Structural Integrity case for UK HPR1000 is described using the TAGSI structure and a CAE format. However, limited information is presented relating to the role and development of an adequate avoidance of fracture demonstration. A subsequent update to the safety case methodology document provided further information, but the importance of the avoidance of fracture demonstration was still not prominent in the safety case architecture (Ref. 17). The RP has provided some evidence of the development of an approach to avoidance of fracture demonstration (Section 4.5). Nonetheless, I am not fully convinced that the RP understands the role and significance of the avoidance of fracture demonstration. For example, it is omitted from both the high-level safety objectives and the safety case route map (Ref. 17, Appendix A and B). Furthermore, during my coarse review of an early version of the draft PCSR (Ref. 47), I also noted it as a key omission. The need to develop an avoidance of fracture demonstration is a novel concept to the RP. It will be a significant undertaking and will form a fundamental part of the overall Structural Integrity case for the UK HPR1000.

138. I am mindful of the importance of the avoidance of fracture demonstration to the GDA. I consider this matter further along with the approach to the avoidance of fracture demonstration next (Section 4.5).

### 4.4.2 Strengths

139. During my GDA Step 2 assessment of the Structural Integrity Safety Case Strategy I have identified the following areas of strength:

- The RP is proposing a structure for the Structural Integrity case based on a CAE format, which is one way of meeting ONR's expectations for safety cases.
- The RP responded promptly to the need to outline the structure and content of the Structural Integrity safety case across the range of the proposed Structural Integrity classifications for the UK HPR1000.
- The RP has developed specific proposals to present the arguments and evidence to underpin highest reliability claims for structures and components that should meet ONR expectations, as GDA progresses.

### 4.4.3 Items that Require Follow-up

140. During my GDA Step 2 assessment of the Structural Integrity Safety Case Strategy, I have identified the following additional potential shortfall that I will follow-up during Step 3 of GDA:

- Clarify how linkage between the Structural Integrity case and the plant safety case will be captured in the planned strategy for the Structural Integrity case.

### 4.4.4 Conclusions

141. Based on the outcome of my Step 2 assessment of the Structural Integrity Safety Case Strategy, I have concluded that in the main, the RP is developing approaches that should allow the appropriate Structural Integrity levels to be demonstrated for UK HPR1000. I have reservations relating to the prominence given to the avoidance of fracture demonstration in the RP's safety case. This is an important shortfall in the information I have assessed to date, which I consider further below (Section 4.5)

## 4.5 Avoidance of Fracture

142. ONR's expectation for the highest reliability components is that the component or structure should be as defect free as possible and is demonstrated to be tolerant of defects (ONR SAPs EMC.1). In particular the limiting defect size needs to be shown to be larger than the defect size that can be reliably detected by the applied examination techniques. This is provided through an 'avoidance of fracture' demonstration.

143. The avoidance of fracture demonstration involves the integration of detailed fracture mechanics based DTAs, using verifiable material properties, to determine the limiting defect sizes for these components at the start of life taking into account any potential for through-life crack growth. The non-destructive examinations being proposed for the components then need to be shown to be able to reliably detect such start of life defects by a suitable margin (SAP EMC.28 and EMC.3, Ref.19). This demonstration is beyond the design code compliance required for these components.

### 4.5.1 Assessment

144. During Step 2, the RP provided the following documents in support of its proposed avoidance of fracture demonstration:

- A weld ranking procedure (Ref. 6) and the application of the weld ranking procedure (Ref. 8) which was used to describe how a sample of limiting HIC items will be selected for detailed treatment in GDA.

- Defect tolerance assessment process (Ref. 7), which describes the fracture mechanics methodology, and presents the overall concept of avoidance of fracture.
- A strategy and plan for NDT of HICs (Ref.10 ), along with the inspection qualification approach to be applied for HICs (Ref. 11).

145. My comments on the documentation along with the RP's overall approach to the avoidance of fracture demonstration are provided in the following sections.

### 4.5.1.1 SELECTION OF AREAS FOR CONSIDERATION IN GDA

146. For GDA, the RP is proposing to undertake detailed avoidance of fracture demonstrations on what it believes will be the limiting regions of HICs. Here, limiting regions are those for which the capability to reject defects of structural concern is considered to be the weakest. Previous GDAs have accepted that it is not necessary to provide an avoidance of fracture demonstration for every region of each highest reliability component during GDA; it is necessary to provide one for what are expected to be the limiting regions of the components, with any remaining demonstrations taking place after GDA has finished. Thus, I am satisfied with the RP's approach.

147. The majority of HIC regions are expected to be welds and the RP's approach for selecting welded regions is different from that used to select non-welded regions.

148. The RP provided its first version of the weld ranking procedure (Ref. 48), which describes the approach to identifying the limiting welds in HICs. From my assessment of this first version of the document, I sought clarification over the RP's terminology and as to whether the application of the procedure would lead to appropriate limiting cases. I therefore raised, RQ-UKHPR1000-0082 (Ref. 49), to which the RP responded in its revised version of the document (Ref. 6).

149. The RP's weld ranking procedure provides a structured approach to identifying the limiting regions by semi-qualitatively taking into account aspects related to the size of the limiting defect derived from DTA and the difficulty in detecting such a defect in order to identify those areas which are likely to be limiting in an avoidance of fracture demonstration.

150. The first step in the RP's ranking process is to group welds according to geometry, materials and welding type. In the next step, appropriate experts consider separately the parameters that influence the defect tolerance and the inspectability and in each case assign a rank as high, medium or low. The defect tolerance ranking is based upon a combination of expert judgement and inputs from the RCC-M code. Similarly, the inspectability ranking applies expert judgement and considers the component parameters including geometry, thickness, accessible surfaces and materials. The procedure then applies rules that define how the limiting case will be derived for the group; the premise being that an adequate demonstration of avoidance of fracture for this limiting case will bound the other welds in the group. Any areas where there is an apparent conflict are subject to a final expert review to make a judgement on the limiting case.

151. The RP provided an example of the ranking process for the welds of the RPV (Ref. 8) that helped me understand how the process will be applied in practice. I noted that the RPV nozzle to safe-end weld was classified as a HIC based on the indirect consequences of gross failure. It appears that the indirect consequences analysis for this weld would be similar to that of the adjacent safe-end to MCL and should be treated in a similar manner (see Section 4.2); I will take this forward into Step 3 of GDA.

152. Whilst there is inevitably an element of subjectivity in such a ranking process, I am satisfied that the approach should provide a suitable approach to identifying the limiting regions. As more detailed analysis is performed by the RP during Steps 3 and 4 of GDA, it is possible that the initial assessment of limiting cases may no longer be appropriate and the RP will need to address this as they progress through GDA.

153. Reference 7, states that any non-welded HICs will be considered in the defect tolerance assessment methodology. This document implies that all of the key non-welded areas, due to the likely small number of cases, will be subject to detailed analysis e.g. nozzle crotch corners.

154. Overall, I am satisfied that the RP's proposals provide a sound basis for selecting limiting areas of HICs for more detailed treatment later in GDA. Consideration of the limiting regions identified by the procedure for the detailed avoidance of fracture demonstrations, and whether they provide sufficient coverage of the HICs, will be addressed in the application of the procedure over the full range of HICs, during Step 3 of GDA.

#### 4.5.1.2 DEFECT TOLERANCE ASSESSMENT

155. The RP has recognised that more detailed defect tolerance assessments beyond the requirements of established design codes are needed for UK HPR1000 HIC structures and components. The RP has considered using the RSE-M code for DTA, but following a review they have proposed using the R6 defect assessment procedure (Ref. 23). The R6 defect assessment procedure is a well-established and validated procedure for assessing the integrity of structures containing defects, or postulated defects, and is routinely used by Licensees in Great Britain to support Structural Integrity aspects of nuclear safety cases. Furthermore, with the exception of the UK EPR$^{TM}$, it has been used for all previous GDAs. I am therefore satisfied with the choice of the R6 procedure for DTA. I will, however, sample the RP's application of these approaches later in GDA to gain assurance that appropriately conservative calculations are undertaken in practice.

156. Reference 7, presents the RP's defect tolerance assessment methodology. It covers the approach and key input parameters; selection of limiting locations, material property determination, classification of loadings and stresses, defect characterisation, analysis type, failure assessment curves and the determination of limiting and safety significant defects. There is also intent to show a defect size margin of at least two between the size of defect that can be reliability detected by qualified inspection and the limiting defect size taking into account through-life fatigue crack growth, which is consistent with the approaches established in previous GDAs.

157. In general, I am content that the RP is proposing an appropriately conservative approach. However, my Step 2 assessment identified a few areas requiring enhanced regulatory scrutiny. Firstly, the role of the DTA in underpinning the avoidance of fracture demonstration was not addressed in the initial defect tolerance assessment methodology (Ref. 51). I explained ONR's expectations to the RP and this was addressed in an update to the DTA methodology (Ref. 7). I also observed that the role of DTA and its integration with material properties and inspection qualification to support an avoidance of fracture demonstration is included in an appendix in the higher level safety case methodology document, though I judge that its importance is not fully captured (Section 4.4).

158. A second area of enhanced scrutiny was that there is provision to invoke crack initiation assessment in the fatigue crack growth calculations. This is not currently a feature of the R6 procedure and appears to relate to provisions within the RSE-M

code (Ref. 26). Notwithstanding, that under SAP EMC.34, ONR expects that verified and validated fracture mechanics methods are applied, the selected use of different codes in this situation does not meet the intent of SAP ECS. 2 Paragraph 173, (Section 4.3). I will progress this matter with the RP prior to Step 3 of GDA.

159. A final concern relates to the absence of any reference to the verification arrangements for using the R6 procedure to meet SAP EMC.34. The use of the R6 procedure is novel to the RP and I expect adequate arrangements for independent verification, supported by suitably qualified and experienced personnel. I judge this can be resolved satisfactorily and will progress to support Step 3 of GDA.

160. A key input for the DTA is the loadings on HIC structures or components. In a response to RQ-UKHPR1000- 0145 (Ref. 50), the RP confirmed this is detailed in their system and components loadings for defect assessment document, which in accordance with the Step 2 plan is scheduled for delivery late in Step 2 (Ref. 1). This later delivery date falls outside of the assessment window for my Step 2 assessment report. Considering the more detailed information contained in this report, this does not invalidate my conclusions at Step 2 of GDA and I will therefore progress this topic in Step 3 of GDA.

161. In addition, lower bound materials toughness properties are required in the DTAs for HIC structures and components. In its DTA methodology, the RP has chosen to use the initiation fracture toughness for loads experienced under normal operation and to invoke ductile tearing under infrequent loading conditions. This aligns with ONR's expectations under SAP EMC.34. However, limited evidence is presented to explain the understanding of the role of material properties in the overall avoidance of fracture demonstration. Indeed, for highest reliability, ONR's expectations for additional testing are over and above that required by recognised design codes e.g. RRC-M. Thus, in Step 3, I will need to establish the source and veracity of the material property data used in the DTA's e.g. the lower bound fracture toughness values. I will also need to establish there is a basis for underwriting the values used through the RP's proposals for additional fracture toughness testing on parent material and representative welds. Furthermore, I will need to review the RP's allowance for materials ageing, and where appropriate irradiation embrittlement, including consideration of the RP's proposals for materials surveillance.

#### 4.5.1.3 HIGH RELIABILITY NDT

162. PSR Chapter 17 (Ref. 2) does not describe clearly the relationship between the NDT and the overall Structural Integrity safety case for HICs. It is anticipated that, generally, the defects of structural concern that can grow in service or lead directly to failure will be planar and an important input to the inspection objectives will come from the fracture assessments (or defect tolerance assessments). In this context it is important that a suitable margin exists between the size of defect that could lead to failure and that which is reliably detected and rejected by the NDT (SAPs EMC. 28 and EMC.34).

163. I raised the following three related RQs to clarify the intent of the RP within and post GDA, regarding high reliability NDT for HICs:

- RQ-UKHPR1000-0057 sought the overall approach to high reliability NDT performed during manufacture (Ref. 52);
- RQ-UKHPR1000-0058, the qualification of manufacturing NDT (Ref. 53);
- RQ-UKHPR1000-0059, design for inspectability (Ref. 54).

164. The RP responded to RQ-UKHPR1000-0057 (Ref. 52), explaining it would provide a document describing their approach to high reliability NDT, prior to entry into Step

3 of GDA. The RP presented the outline contents of this document during a workshop held in China in May 2018, where I explained that these outline contents did not meet ONR's expectations. A further RQ, RQ-UKHPR1000-0113 (Ref.56), was issued as a follow-up. Since responding to RQ-UKHPR1000-0113, the RP has very recently issued their document for the NDT of HICs (Ref. 10). I was unable to perform a detailed assessment of Ref. 10, but I am able to make the following comments and observations for the purposes of my Step 2 report.

165. The RP's strategy comprises code-based and objective-based inspections, the latter applying beyond code NDT inspections that are developed specifically to detect and reject defects of structural concern and, in turn, these defects of structural concern are derived from a defect tolerance assessment.

166. The RP claims that, '*the inspectability for HIC and non-HIC components has been fully considered during the design of components and welds'* and in its response to RQ-UKHPR1000-0059 (Ref. 54) states that evidence of this approach will be provided at later stages of GDA. I will sample this evidence to establish confidence that the RP has taken reasonably practical measures to optimise the conditions for NDT.

167. I have noted the following points to follow-up in GDA Steps 3 and 4:

- The RP states that the NDT will be aligned with sound physical principles and based upon 'proven' NDT used in the Chinese HPR1000 (FCG3) and CPR 1000 plants.
- The eddy current inspection of the SG tubing will be performed according to ASME XI. I have discussed the issue of the application of the ASME and the French codes in Section 4.3.

168. The RP has committed to qualifying the end of manufacturing NDT using the ENIQ methodology as the framework. I consider ENIQ's approaches to be well founded, and capable of meeting ONR's expectations. The main elements of the methodology are to develop an inspection specification to define defect types and performance requirements, develop inspection techniques to meet the requirements of that specification, and then qualification of the inspection procedures and personnel through a combination of technical justifications and practical trials.

169. During a workshop in China in May 2018, the RP presented the contents of its document describing the implementation of full qualification that would be applied post GDA. I noted that this document was useful in describing the RP's process for full qualification but it did not include the RP's process for presenting evidence for the NDT capability within GDA. Consequently, I raised RQ-UKHPR1000-0110 (Ref. 55), asking the RP to outline this process. In response, the RP explained that, for the limiting HIC areas that were identified through its ranking process, an inspection specification would be produced describing the inspection objectives. An outline of the NDT techniques, along with limited evidence of the ability of these techniques to meet the inspection specification, would then be described in a reduced form of an ENIQ style technical justification. The RP confirmed that these technical justifications will be subject to review by an independent qualification body.

170. The RP recently issued the document proposing the methodology for full qualification of NDT (Ref. 11). I was unable to perform a detailed assessment of Ref. 11, however, for the purposes of my Step 2 report, from an initial review of this document I note the following points:

- The RP's proposals adopt the ENIQ methodology (Ref. 27) as the framework for qualifying the NDT. As stated above, I consider that the ENIQ methodology is well-founded and capable of meeting ONR’s expectations for assuring the high reliability of the NDT.

- The organisations and responsibilities for each of the qualification activities is described and aligns with my understanding of the application of the ENIQ methodology.
- The proposed arrangements for the qualification body provide options that I will consider during Step 3 of GDA.

#### 4.5.1.4 APPROACH TO DEMONSTRATION

171. The RP’s approach to demonstrating avoidance of fracture is covered in an Appendix to the Safety Case methodology (Ref. 17), but also described in its proposals for defect tolerance assessment (Ref. 7), and here it links the limiting defect size established from fracture mechanics to the size of defect that must be detected and rejected by NDT. The general approach is to determine the limiting defect size at the end of life and then applying a margin of at least two, which is then combined with the predicted fatigue crack growth through life to derive a defect size that must be rejected at start of life. I consider this ‘qualification examination defect size’ (QEDS) is an essential input to the NDT qualification which is used to confirm high reliability for detection and rejection of such defects.

172. Overall, ONR seeks a conservative approach for the avoidance of fracture demonstration. However, to achieve this it is necessary to strike appropriate balances between the three principal ingredients. For example, excessive conservatism in DTA can result in unrealistic demands for inspection qualification or in material properties e.g. fracture toughness. In GDA, ONR seeks an avoidance of fracture demonstration with an appropriately conservative fracture analyses, reliable and readily qualified manufacturing inspections, along with conservative and achievable material properties. This is a challenging expectation for RPs and requires the exercise of sound judgements, the development of integrated approaches and adequate arrangements for reconciliation within the Structural Integrity discipline.

173. In my opinion the RP is developing an understanding of these concepts, but I am not yet convinced that the RP has fully developed arrangements to achieve an integrated approach for their avoidance of fracture demonstration. For example, limited evidence was presented to explain the understanding of the role of material properties in the overall avoidance of fracture demonstration. Similarly, the RP presented some initial proposals to reconcile the DTA with NDT, but these were subsequently withdrawn in a subsequent updating of the DTA methodology. I am therefore unclear as to whether the RP is developing adequate processes to achieve an integrated approach for their fracture avoidance demonstration. In combination with my reservations about the prominence given to the avoidance of fracture demonstration in the safety case strategy (Section 4.4), I view this as a significant shortfall in the RP’s case, which warrants enhanced regulatory scrutiny as GDA progresses. A RO is being prepared in parallel with my assessment report, to address this gap.

### 4.5.2 Strengths

174. During my GDA Step 2 assessment of the Avoidance of Fracture, I have identified the following areas of strength:

- The proposals for demonstrating the avoidance of fracture provide for the individual factors an adequate foundation for confirming the Structural Integrity of HICs. In particular, two of the principal ingredients for this demonstration, a defect tolerance assessment and a NDT performance assessment, apply methodologies that are mature and have been applied in safety cases in Great Britain.

- A worked example for the RPV was helpful in my understanding of how the RP will select limiting regions for detailed assessment during GDA.
- The RP aided my assessment by providing prompt responses to RQs that gave commitments on its implementation of NDT assessments during Step 3 and Step 4 of GDA.

### 4.5.3 Items that Require Follow-up

175. My Step 2 assessment of the Avoidance of Fracture has identified the following matters for follow-up during later GDA steps:

- In my opinion, the RP has not clearly demonstrated an adequate understanding of the overall aims of demonstrating avoidance of fracture in underwriting the highest reliability claim for HICs. It isn't clear how the individual aspects of this crucial part of the Structural Integrity case, will fit together to provide an overall, demonstrably conservative safety justification for UK HPR1000. This is a novel concept to the RP, it will be a significant underrating, and will form a fundamental part of the overall Structural Integrity case for the design. The information I have assessed during Step 2 indicates the RP may not fully appreciate the importance of the avoidance of fracture demonstration and how to articulate this aspect of the UK HPR1000 safety case. This is an important shortfall in the information I have assessed to date, which needs to be given enhanced regulatory scrutiny as GDA progresses. A RO is being prepared in parallel with my assessment report to address this gap.
- The RP has, quite reasonably, developed a process for reducing the amount of detailed analysis which needs to be undertaken during GDA, by selecting areas that provide the greatest challenge to the avoidance of fracture case. Until the RP has finalised the Structural Integrity classification for the UK HPR1000 and completed its ranking analysis, it is not clear as to the extent of the detailed assessment that will be required. I will seek assurances from the RP at an early stage of Step 3 of GDA that the detailed assessment is appropriately prioritised and resourced.
- Discuss and resolve my concerns relating to the inclusion of crack initiation and the verification arrangements associated with RP's DTA approach.
- Review the source and veracity of the material property data used in the DTAs e.g. the lower bound fracture toughness values and establish there is a sound basis for underwriting the values through proposals for additional fracture toughness testing on parent material and representative welds.
- Review the RP's allowances for materials aging, and where appropriate irradiation embrittlement, including consideration of the RP's proposals for materials surveillance.
- I will sample the evidence to establish confidence that the RP has taken reasonably practical measures to optimise the conditions for NDT i.e. design for inspectability for both HIC and non-HIC SSC in Step 3.

### 4.5.4 Conclusions

176. Based on the outcome of my Step 2 assessment of the Avoidance of Fracture, I am satisfied that the RP's proposals for confining its detailed avoidance of fracture analyses to limiting cases is likely to provide a sufficient number of bounding cases within GDA such that, in principle, an overall claim for all HICs can be made.

177. The RP is developing an understanding of the expectations for the avoidance of fracture demonstration. This notwithstanding, the RP has not clearly demonstrated an adequate understanding of the significance of avoidance of fracture in underwriting the highest reliability claim for HICs. In addition, the RP needs to

further develop the understanding of the integration of the fracture analyses, qualified inspection and material properties that will underwrite such cases. I will issue an RO to progress this matter during Step 3.

## 4.6 Design Summaries for Major Components

### 4.6.1 Assessment

178. The RP has summarised the Structural Integrity aspects of the main metallic components in chapters 6 and 11 of the PSR (Refs. 3 and 30 respectively) and in two ‘scheme description’ documents; one for the reactor components (Ref. 34) and another for the balance of the main reactor loop equipment (Ref. 57).

179. I sought clarification of some specific points presented in earlier versions of the documents through RQ-UKHPR1000-0089 (Ref. 58). The responses to this query have been included in the latest versions.

180. In response, the RP explained that the scheme descriptions were summaries of the respective chapters of the PSR that highlighted the Structural Integrity aspects. The scheme descriptions were intended for use in Step 2 of GDA and will be superseded by the component safety reports that will support the PCSR.

181. The design documents, while being at a general level, were helpful in understanding the key design features. Overall, it appears that the nuclear steam supply system (NSSS) for the UKHPR1000 is of a standard PWR design and in its response to RQ-UKHPR1000-0089 (Ref. 58), the RP confirmed that there were no novel features.

182. I also questioned the RCC-M code classes for the SSC listed in the scheme description documents. The RP confirmed that with the exception of the MSL and accumulators the design and construction of the major vessels and piping is to RCC-M1 (or ASME III Class 1 for the SG). The RP proposes the lower RCC-M2 class for the MSL and accumulators, based on experience of PWR technologies in the GB, these can also be candidate components for highest reliability claims.

183. The response to RQ-UKHPR1000-0089 (Ref. 58) also lists the main material grades for the SSC listed in the scheme description documents. The UK HPR1000 design appears to use materials that are broadly similar to those I would expect for proven PWR technology. The RPV will be manufactured from low alloy steel, clad with stainless steel and with nickel-base alloys used in CRDM penetration regions. The MCL is manufactured from nitrogen controlled austenitic stainless steel forgings. The main steam lines are manufactured from carbon steel. Nuclear grade low carbon stainless steel will be used for the reactor internals along with niobium stabilised grades of nickel-base alloys. This information gives an appreciation that the design uses established materials that are generally suitable for their purpose, but that they are not necessarily immune from degradation. Indeed, a corollary of the use of low alloy steel vessels in combination with stainless steel MCL piping is that there is a need for several types of dissimilar metal weld, which require careful design, material selection and weld qualification to ensure Structural Integrity.

184. My view is that these materials are generally suitable for purpose based on FCG3, but in Step 3 of GDA I will carry out a more detailed review of the RP’s proposals including weld types and procedures, noting that ONR has specific expectations e.g. for the composition of RPV forgings. My assessment will also be informed by the RP’s recently issued materials section methodology report (Ref. 15), which I discuss in Section 4.7.

185. Notwithstanding the RP'S response to RQ-UKHPR1000-0089 (Ref. 58), I have noted some design features, presented below, that warrant follow-up activities as GDA progresses. These are in addition to those features that are discussed elsewhere in this report.

186. In taking these matters forward into the later stages of GDA, I expect the RP to justify that the designs and manufacturing routes selected, on balance, reduce relevant risks to ALARP.

#### 4.6.1.1 RPV FORGINGS

187. There is recent relevant experience relating to the international supply chain for large forgings. These include events at Doel 3, where hydrogen flaking were identified, and at Flamanville 3, where areas of carbon macro-segregation were identified. Notably, in 2014, mechanical tests performed on a RPV closure head representative of that of the Flamanville 3 EPR$^{TM}$ revealed the presence of a high carbon concentration in the central top part, leading to lower than expected fracture toughness values. The analyses carried out by EDF since 2015 on operating reactors concluded that certain steam generator (SG) channel heads, manufactured by Areva Creusot Forge (ACF) and Japan Casting and Forging Corporation (JCFC) had areas having high carbon content (Ref. 63).

188. For the UK HPR1000, the proposed RPV closure head is a removable flanged forged hemispherical design, consisting of a head flange and an upper dome, welded together by a circumferential weld. The use of a non-integral RPV closure head design in the UK HPR1000 is therefore likely to be more amenable to the achievement of adequate material properties. Nonetheless, this is a large thick section forging and there needs to be a demonstrably sound basis for the achievement of adequate material properties. Similar considerations may apply to the RPV bottom dome.

189. In addition, in the UK HPR1000, the RPV shell in the vicinity of the core comprises a single piece forging. This is beneficial as this avoids placing a weld in a region where neutron irradiation is high and degradation of the weld properties (through radiation embrittlement) is at its highest (SAP EMC.10). However, the recent international experience has highlighted the difficulties of manufacturing large forgings which are free of defects or carbon macro-segregation (Ref. 63). this may result in the need for additional measures for the qualification of forgings beyond the provisions in established nuclear design and construction codes. The elimination of a weld in the 'beltline' region of the UKHPR1000 is achieved through using a larger core shell forging than most other PWRs and I will explore, in later stages of the GDA, how the forging process excludes excessive levels of carbon.

190. A corollary is that a balance may need to be struck between minimising the numbers and lengths of weld (SAP EMC.9), and achieving adequate material properties in large RPV thick section forgings (SAP EMC.13). This is also a relevant consideration in the design of the pressuriser, SG and MCL.

#### 4.6.1.2 RPV NOZZLE TO SHELL WELDS

191. Reference 34 shows that the main inlet and outlet nozzles of the RPV are welded into a nozzle shell forging. I note that this has been traditionally standard practice for PWR designs but it may be possible to integrate the nozzles in the PRV forging thereby removing eight large diameter nozzle to shell welds. The RP's decision relating to the RPV main inlet and outlet nozzle design is also influenced by the balance in achieving adequate material properties in thick section forgings. I will explore this matter further during Steps 3 and 4 of GDA.

#### 4.6.1.3 PRESSURIZER NOZZLE TO SHELL WELDS AND FORGINGS

192. I note that the lines going in to the pressurizer and the man-way are attached to the pressuriser shell through set-in nozzle welds. There may be an opportunity to remove some of these welds by integrating them into the pressurizer. I will request the RP to explore this further with a view to arriving at a design that is demonstrably ALARP.

193. In addition, the pressuriser includes large thick section forgings. I am aware that recent international experience has highlighted the difficulties of manufacturing large forgings free of carbon macro-segregation. I will explore this matter further during Steps 3 and 4 of GDA.

#### 4.6.1.4 STEAM GENERATOR FORGINGS

194. I note that the SG includes large thick section forgings e.g. the primary head and tubesheet. The primary head includes integral main inlet and outlet nozzle designs, which eliminates the need for set-in or set-on inlet and outlet nozzle welds. Nevertheless, I am aware that recent international experience has highlighted the difficulties of manufacturing large forgings free of carbon macro-segregation. Thus informed by the resolution of the SG codes and standards question, I will explore this matter further during Steps 3 and 4 of GDA.

#### 4.6.1.5 MAIN COOLANT LINE FORGINGS

195. The main coolant line of the UKHPR1000 comprises a series of austenitic stainless steel forgings welded together, which uses as few forgings as possible to reduce the number of welds. Furthermore, large diameter branches (for lines having a nominal bore of >150mm) are integrated into the main coolant line, thereby removing a welded connection. I welcome the approach of minimising the number of welds in this manner; however, I note that recent experience from one forgemaster has revealed difficulties in controlling the grain size and mechanical properties for large austenitic steel forgings. I will consider the ability to manufacture forgings of appropriate properties at later stages of GDA.

#### 4.6.1.6 REACTOR COOLANT PUMP CASING AND MAIN STEAM LINE VALVE BODY MANUFCATURE

196. The RCP casing and flywheel are HIC candidates (Table 1). I will follow-up the basis of the Structural Integrity class at Step 3. In addition, the RCP casings are manufactured from either cast or forged stainless steel. ONR has a preference for the use of forged components where reasonably practicable. This is because of the potential for difficulties in the achievement of adequate material properties and the justification of weld repairs, with their attendant residual stresses. Indeed, experience from previous GDAs along with operating plant in Great Britain indicates that the position can be particularly challenging, if cast materials are used for highest reliability components e.g. RCP casings and valve bodies. This is because the combination of an appropriately conservative fracture analyses, underpinned by conservative and validated material properties and the achievement of high reliability NDT are expected to underpin the avoidance of fracture demonstration. In Step 3, I will follow-up the RP’s manufacturing proposals for the RCP casings and valve bodies to establish that these are commensurate with reducing risks ALARP.

#### 4.6.1.7 TEN YEAR HYDROSTATIC PROOF TESTS

197. In its response to RQ-UKHPR1000-0089 (Ref. 58), the RP confirmed its intent that the 10yr requalification of the primary circuit as specified by the RSE-M code will be applied for the UK HPR1000. This requalification includes a full hydrostatic proof

test under similar conditions as for the initial proof test prior to entering service. ONR's TAG on the integrity of metal components (Ref. 20) states:

> *The reassurance provided by a further hydrostatic proof test performed after operation has started may only be of limited value for plant where degradation mechanisms may have eroded any margins derived from the original proof tests and tests do not represent all loading conditions. Further proof tests in service are not usually feasible given the radiological consequences if failure occurred during such a test. It may also introduce additional damage to the plant in the form of stable tearing at pre-existing crack-like defects that may undermine the proof test argument.*

198. In summary, the hydrostatic proof test performed at 10yr intervals may be of limited value to the Structural Integrity case when balanced against the increased radiological risk of performing such a test and the potential for introducing damage, for example, tearing or increased fatigue crack growth. I will follow this up at later stages of the GDA.

### 4.6.2 Strengths

199. The design information presented hitherto gives a basis for confidence that the design of the major vessels and piping in UKHPR1000 are likely to comply with modern PWR standards. In addition, the UK HPR1000 design incorporates some design features that I judge to be beneficial to Structural Integrity e.g. the absence of a weld in the RPV in the vicinity of the core where neutron irradiation is high; and the use of integral inlet and outlet nozzles in the SG primary head.

### 4.6.3 Items that Require Follow-up

200. During my GDA Step 2 assessment of design summaries for the main metallic components, I have identified the following matters for follow-up during later GDA steps:

- Some specific Structural Integrity matters relating to the design of the major vessels, casings and piping that warrant follow up activities as a matter of priority.
- These Structural Integrity matters involve the need to adequately address significant ALARP considerations in the UK HPR1000 design and safety case, specifically associated with the design of the RPV, pressuriser, SG, MCL and RCP. Taking cognisance of recent OPEX, this may involve the need for complex balances between minimising the number and length of welds, whilst retaining adequate material properties in thick section forgings.

201. As a matter of priority, I will raise RQs on these topics to gain further information from the RP to clarify the extent of any such work that has already been performed for the FCG3 Reference Plant, and/or their plans for these aspects of the UK HPR1000 design and safety case, during GDA.

202. It is also important to note that as GDA progresses, I expect to focus on additional items as more detail of the design is made available, e.g. the type, location and welding processes proposed for a sample of the dissimilar metal welds in the RPV, pressuriser, and SG.

### 4.6.4 Conclusions

203. Based on the outcome of my Step 2 assessment of design summaries for the main metallic components, I conclude the following with regard to Structural Integrity:

- Subject to further detailed assessments during Steps 3 and 4 of GDA, the design appears capable of compliance with the expectations in ONR relevant SAPs for metal structures and components.
- There are some features of the UK HPR1000 where I will seek a further understanding as to whether potential design changes are reasonably practicable, to demonstrate relevant risks are reduced to ALARP.
- As a matter of priority, as GDA progresses, I will explore some of the design concepts in the light of recent operational experience. In particular, for the RPV pressuriser, SG, MCL and RCP.

## 4.7 Material Selection Principles and Degradation Mechanisms

### 4.7.1 Assessment

204. In the PSR (Ref. 2) the RP makes implicit claims relating to the identification and management of any through-life degradation mechanisms that could potentially affect the delivery of the SSC safety functions, and hence the achievement of a 60 year design life for example:

> *"Based on the requirements of RCC-M, the material selection for the HPR1000 (FCG3) metallic components and structures has considered the behaviour and function of the equipment in the manufacturing, operation, inspection and maintenance stages, selected existing proven materials with good engineering experience, and avoided damage occurred in manufacture and installation, so that the Structural Integrity of components has been ensured,." (Section 17.3.3, Ref. 2).*

> *"The compatibility with reactor coolant has been considered in the structural material selection." (Section 17.3.3, Ref. 2).*

205. The RP's processes and principles for material selection need to be in place to support progression through GDA. This is because the identification, elimination or management of the risks relating to through-life degradation mechanisms are prominent nuclear safety considerations intrinsically linked to the plant design, environmental conditions, and judicious material selection. The specific SAPs relevant to the issue include EMC.13 (Materials) and EAD.1 to EAD.4 (Ageing and Degradation) and ECS.1 to ECS.3 (Safety Classification and Standards).

206. The FCG3 design is based on proven PWR technology and the UK HPR1000 design appears to use materials that are generally suitable for purpose, based on FCG3 (Section 4.6). Nonetheless, they are not immune from through-life degradation mechanisms.

207. RQ-UKHPR1000-0016 (Ref 59) was raised by ONR's reactor chemistry inspector and primarily sought clarification on specific topics relating to reactor chemistry and materials selection. The importance of risk balancing across the disciplines was highlighted. The RP's response did not fully address the principles of materials selection or the role and scope of OPEX (Ref. 59).

208. In RQ-UKHPR1000-0081 (Ref 60), I therefore sought clarification on several points: the basis of the claim for the Structural Integrity of SSCs over the 60 year design life; the principles for material selection; the scope of the consideration of through-life degradation mechanisms; and the scope and sources of OPEX that will inform the understanding of the through-life degradation mechanisms for the UK HPR1000.

209. The basis of the claim for Structural Integrity over the 60 year design life is that SSCs will be designed with adequate margins against through-life degradation, particularly for major structures and components that are difficult or not practicable

to replace. The approach involves elimination of degradation where reasonably practicable using proven materials and elsewhere to minimise susceptibility and establish control of degradation.

210. A comprehensive listing of the key principles to underwrite the proposed approach was provided. Key principles included judicious material selection, proportionality, consideration of the full range of environmental conditions, identification of ageing and degradation mechanisms, manufacturability, evaluation of OPEX, radiological dose. In addition, the RP also acknowledges that this could involve going beyond the provisions of relevant design and construction codes. These key principles were subsequently captured in a material selection methodology (Ref. 15). I have not formally assessed this document, from a Structural Integrity perspective during Step 2. My assessment of this topic has focused on the RP's response to relevant RQs.

211. The RP also explained that a report covering in-service ageing and degradation mechanisms and their mitigation is scheduled for submission to ONR for formal assessment during Step 3 of GDA. They claim this will provide for safety significant SSC a comprehensive review of relevant aging and degradation mechanisms including their: causes, risks, and remedial measures. The key degradation mechanisms included those I would expect for PWR technology: intergranular stress corrosion cracking; irradiation-assisted stress corrosion cracking (IASCC); erosion (and flow accelerated corrosion); boric acid corrosion; thermal aging; fatigue and irradiation embrittlement. In addition, the material selections for safety significant SSC in the UK HPR1000 will be underpinned by material selection reports for specific SSC during Step 4 of GDA.

212. In addition, from the response to RQ-UKHPR1000-0081 the RP appears to have access to a diverse range of OPEX and feedback from domestic and worldwide sources. It claims this is evaluated in a systematic way with consideration of the causes and potential risks and if appropriate, the implementation of proven measures to either eliminate or mitigate the through-life degradation threats.

213. Structural integrity is the lead discipline for the material selection decisions for the UK HPR1000, responsible for coordinating and communicating ONR's overall consolidated assessment position for this topic. Nevertheless, material selection decisions are important to other technical disciplines e.g. reactor chemistry, mechanical engineering, radiological protection and radioactive wastes (including the EA). The assessment of material selection will therefore broaden as GDA progresses, for example use of Ni based alloys in CRDM adaptor tubes, and internals, use of cobalt etc. Thus, to manage the risks across the disciplines, a multi-discipline approach is needed both to develop and assess the safety case. The RP committed to adopting a multi-discipline approach and in Step 3, in collaboration with other ONR technical disciplines, I will sample the application of this approach.

214. For my assessment of the RP's material selection decisions, I consider it informative to undertake an independent review of Structural Integrity related PWR operating experience post completion of the UK EPR$^{TM}$ and AP1000 GDAs. The large scope and higher priority assessment activities associated with the Step 2 Structural Integrity assessment work has limited progress with this review.

215. In general, I am satisfied with the RP's response to my queries relating to materials selections and through-life degradation mechanisms for the purposes of Step 2, where in the absence of any fundamental design shortfalls, the focus is on establishing the processes and methodologies to support GDA progression. Notably, the RP is committed to implementing principles for material selection which should meet the expectations captured in SAPs EAD.1 to EAD.4. However, in Step

3, I will sample the application of these principles for a selection of SSCs of safety significance to confirm that, in practice, ONR's expectations are met.

### 4.7.2 Strengths

216. During my GDA Step 2 assessment of the material selection principles and degradation mechanisms I have identified the following areas of strength:

- The RP responded positively and constructively to my request to provide early visibility of the principles for material selection and the processes for the identification of threats from through-life degradation mechanisms.
- The RP accepts that, to manage the risks of through-life degradation, additional measures beyond the provisions of established relevant nuclear codes and standards may be necessary.
- The RP appears to have access to a wide range of OPEX sources along with established processes for the systematic evaluation of information to either eliminate or reduce the risks from through-life degradation mechanisms.
- The RP committed to adopting a multi-discipline approach to inform the material selection decisions for the UK HPR1000.

### 4.7.3 Items that Require Follow-up

217. During my GDA Step 2 assessment of the material selection principles and degradation mechanisms, I have identified the following additional potential shortfalls that I will follow-up during Step 3 of GDA:

- In collaboration with ONR's reactor chemistry inspector, from a Structural Integrity perspective, assess the RP's material selection methodology to ensure it captures the key principles outlined by the RP at Step 2.
- In collaboration with other ONR technical disciplines, sample the output from the application of the RP's material selection approach for a selection of SSCs of safety significance.
- Complete an independent review of Structural Integrity related PWR operating experience post completion of the UK EPR$^{TM}$ and AP1000 GDAs.

### 4.7.4 Conclusions

218. Based on the outcome of my Step 2 assessment of the Material Selection Principles and Degradation Mechanisms, I am satisfied that the RP is developing appropriate principles and is intending to adopt a multi-disciplinary approach. The RP appears to have an established OPEX evaluation process and is committed to adopting measures beyond the provisions of design and construction codes where appropriate to reduce risk.

## 4.8 ALARP Considerations for Structural Integrity

### 4.8.1 Assessment

219. A legal duty in Great Britain is that duty holders reduce risks to workers and the public so far as is reasonably practicable (SFAIRP). Note that SFAIRP is the legal term and for the purposes of this assessment report the synonymous term ALARP is used. In GDA, the RP needs to provide evidence to demonstrate that a chosen design or does, or is capable of reducing risks to ALARP. This is particularly important at the design stage where there is the best opportunity to reduce risks.

220. The RP's approach to Structural Integrity classification will identify those structures and components which need a highest reliability claim (i.e. HIC) to infer that the likelihood of gross failure is so low that it can be discounted and that suitable

approaches will be developed to justify such claims (Section 4.1). This is an onerous route to a safety justification with measures beyond normal practice expected (SAP EMC. 1 to EMC.3, Ref. 19). A corollary is that there needs to be a robust demonstration that risks are reduced to ALARP. In addition, the design of other SSCs is also important, with respect to demonstrating risks are reduced to ALARP, but on a proportionate basis. However, the RP's approach to ALARP in a Structural Integrity context was not evident from their safety case methodology (Ref. 9).

221. I therefore issued RQ-UKHPR1000-0090 (Ref. 61) to gain clarification of how the RP intended to demonstrate that risks are reduced to ALARP, in particular, for HIC and how the ALARP justifications would be presented in the RP's Structural Integrity case.

222. The RP confirmed that within the Structural Integrity discipline several measures would be applied to demonstrate that the risk of failure is reduced to ALARP through establishing:

- a systematic method to determine and allocate an appropriate classification to SSCs, so that the appropriate and reasonable design, manufacturing and operating codes and standards can be applied commensurate with their safety and Structural Integrity class.
- a safety case methodology based on multi-legged approach, which is in line with good practice for guiding designers to develop system and comprehensive arguments to enhance the reliability of SSCs.
- an ALARP methodology, which will be applied to minimise the risk of component failure to a level that is ALARP through measures such as structure scheme optimisation investigation, material selection and manufacturing process, and taking into account of previous RGP and OPEX.

223. In addition, for HIC, the RP committed to ensuring that structures and component design meets appropriate standards, based on: good practice and OPEX; the application of additional measures to meet ONR's expectations; and the consideration and implementation of design improvements where reasonably practicable (Ref. 61).

224. For HIC and some significant SIC-1 components, the component safety reports to be developed in Step 3 of GDA, will include information to support the ALARP justifications, such as codes and standards selections (optioneering for the SG), balancing minimising welds and maximum forging dimensions, material selections etc.

225. I also note from the RP's response to my queries relating to the selection of the codes and standards for the SG, that the RP appears to have access and has consulted UK expertise in developing the approach for the SG ALARP optioneering relating to codes and standards (Ref. 43). In addition, the RP appears to have well-developed design optimisation processes, which although based on different assessment criteria, provide a basis for confidence that the RP can develop effective approaches for Structural Integrity (Section 4.3).

226. I am broadly content that the RP is developing a reasonable understanding of ONR's expectations with respect to reducing risks to ALARP, in a Structural Integrity context. I observe however that the importance of the avoidance of fracture demonstration for HIC structures and components is not fully and consistently reflected in every GDA submission. In Step 3, I will review the safety demonstrations for a range of SSC classifications, with the emphasis on HIC, to establish that in practice the RP is delivering the commitments made in the response to RQ-UKHPR1000-0090 (Ref. 61).

227. During Step 2, the RP also provided an ALARP methodology (Ref. 16). I have not formally assessed this document as part of my Step 2 assessment report for Structural Integrity. ONR's overall assessment of ALARP is being coordinated by the Project Technical Inspector and is reported in ONR-GDA-UKHPR1000-020 (Ref. 62).

### 4.8.2 Strengths

228. I have identified the following strengths in the RP's proposals relating to ALARP considerations for Structural Integrity:

- The RP has accepted the need to demonstrate risks are reduced ALARP within the Structural Integrity context, in particular, for structures and components underpinned by highest reliability claims.
- The RP committed to considering and implementing additional measures for Structural Integrity to reduce risk, where reasonably practicable.
- The RP appears to have a well-developed design optimisation process which could inform the development of effective ALARP methodologies.
- The RP appears to have access to UK expertise experienced in the development and implementation of ALARP optioneering approaches.

### 4.8.3 Items that Require Follow-up

229. During my GDA Step 2 assessment of ALARP considerations for Structural Integrity, I have identified the following additional potential shortfall that I will follow-up during Step 3 of GDA:

- Sample the Structural Integrity cases for a range of SSC classifications, with the emphasis on HIC, to establish that in practice the RP is delivering the commitments to demonstrate relevant risks are reduced to ALARP.

### 4.8.4 Conclusions

230. Based on the outcome of my Step 2 assessment of ALARP considerations for Structural Integrity, I have concluded that I am broadly content that the RP is developing a reasonable understanding of ONR's expectations with respect to reducing risks to ALARP in a Structural Integrity context.

## 4.9 Out of Scope Items

231. The following items have been left outside the scope of my GDA Step 2 assessment of the UK HPR1000 Structural Integrity.

- The documents describing the approach to achieving high reliability NDT (Refs. 10, 11). These documents arrived towards the end of Step 2. I have undertaken a coarse assessment for the purposes of Step 2, and will perform a more detailed assessment during Step 3.
- The Step 2 assessment plan included a deliverable, scheduled for late in Step 2, describing the system and component loadings for defect assessment. Due to the late delivery I will assess this report during Step 3.
- The materials selection methodology (Ref. 15) arrived late in Step 2, and I have not assessed this document from a Structural Integrity perspective. I will undertake this assessment during Step 3.

232. It should be noted that the above omissions do not invalidate the conclusions from my GDA Step 2 assessment. During my GDA Step 3 assessment I will follow-up the above out-of-scope items as appropriate; I will capture this within my GDA Step 3 assessment plan.

## 4.10 Comparison with Standards, Guidance and Relevant Good Practice

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

- SAPs: The approach proposed by the RP in relation to Structural Integrity appears consistent with ONR's expectations as identified in the relevant SAPs. Notably, the RP is proposing an approach to identify and justify the highest reliability components in accordance with EMC.1 to EMC.3. Table 1 provides further details.
- TAGs: The approach proposed by the RP is consistent with the TAG on the Integrity of Metal Components and Structures.

## 4.11 Interactions with Other Regulators

234. During GDA Step 2, I interacted with the EA in relation to the RP's proposals for categorisation of safety functions and the classification of SSC. The interaction was useful in understanding the other regulator's areas of interest and priorities. I also made the EA aware of the need for multi-discipline working in the assessment of the RP's approach to material selection. Similarly this interaction informed a view on the areas of mutual interest. These interactions will continue in GDA Step 3.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

235. During Step 2 of GDA, the RP submitted a PSR and other supporting references, which outline a preliminary nuclear safety case for the UK HPR1000. These documents have been reviewed by ONR. The PSR together with its supporting references present an approach to assuring the Structural Integrity of the principal reactor structures and components that, overall, I consider appropriate and adequate at this stage of the GDA.

236. During Step 2 of GDA I have targeted my assessment at the content of the PSR and its references that are of most relevance to the area of Structural Integrity and most significant to nuclear safety; 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:

237. I am satisfied that the approach taken and the claims made by the RP in demonstrating the Structural Integrity of the UK HPR1000 are adequate for Step 2 of the GDA. This judgment is derived from my assessment of the RP's submissions where I have concluded:

- The RP recognises the importance of the Structural Integrity discipline to nuclear safety through a dedicated chapter in the generic safety case.
- The RP is proposing a systematic approach, informed by failure modes and effects analysis (FMEA) and specific underlying assumptions, to identify the integrity claims needed to support the overall safety case including those components requiring a claim that the likelihood of gross failure is so low that it can be discounted i.e. highest reliability.
- The RP is proposing codes and standards for structures and components that offer a graded approach to design, construction and inspection with the Structural Integrity provisions informed by the importance to nuclear safety.
- The safety case strategy includes proposals for the beyond design code compliance justification for HICs.
- The RP is developing an understanding of the means for demonstrating the 'avoidance of fracture' of HICs that aligns with ONR's SAPs. This includes the application of defect tolerance assessment using the R6 fracture mechanics methodology and proposals to qualify the manufacturing non-destructive testing (NDT) using the ENIQ methodology.
- The design summaries show that the main metallic structures and components of the reactor plant are generally based on conventional Pressurised Water Reactor (PWR) technology, giving a basis for confidence that the UK HPR1000 is likely to comply with modern PWR standards. There are also some design features that I judge to be beneficial to Structural Integrity.
- The RP has identified some key principles for material selection, outlined an approach to identify and mitigate through-life threats, and using a multi-discipline approach, committed where appropriate, to implement measures beyond code to reduce risk.
- The RP committed to consider and implement additional measures for Structural Integrity to reduce risk where reasonably practicable, in particular for highest reliability structures and components.
- I have identified a number of shortfalls during my assessment, which are captured in Section 4 of this report. I will follow up these matters during Step 3 of GDA.

238. Overall, during my GDA Step 2 assessment, I have not identified any fundamental safety shortfalls in the area of Structural Integrity that might prevent the issue of a design acceptance confirmation (DAC) for the UK HPR1000 design.

## 5.2 Recommendations

239. 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 Structural Integrity assessment plan for the UK HPR1000.
- Recommendation 3: All the relevant out-of-scope items identified in sub-section 4.7 of this report should be included in ONR’s GDA Step 3 Structural Integrity assessment plan for the UK HPR1000.

# 6 REFERENCES

1. Generic Design Assessment of GNS's UK HPR1000 - Step 2 Assessment Plan for Structural Integrity ONR-GDA-UKHPR1000-AP-17-018 Revision 0. November 2017. TRIM 2017/353361.

2. UKHPR1000 GDA Project. Preliminary Safety Report Chapter 17 Structural Integrity. HPR/GDA/PSR/0017 Revision 0, October 2017. TRIM 2017/401380.

3. UKHPR1000 GDA Project. Preliminary Safety Report Chapter 6 Reactor Coolant System. HPR/GDA/PSR/0006 Revision 0, October 2017. TRIM 2017/401355.

4. Generic Design Assessment for UK HPR1000, Methodology of Safety Categorisation and Classification, GH X 00100 062 DOZJ 03 GN, Rev. B, 5 June 2018. TRIM 2018/199731.

5. Generic Design Assessment for UK HPR1000, Methodology and Requirements of Structural Integrity Classification, GH X 30000 002 DOZJ 03 GN, Rev. D, 3 April 2018. TRIM 2018/128015

6. Generic Design Assessment for UK HPR1000: Weld Ranking Procedure: GH X 0010 004 DPCH 03 GN, Revision D. 29 May 2018. TRIM 2018/184883.

7. Generic Design Assessment for UK HPR1000, Defect Tolerance Assessment Methodology for HIC Components, GH X 00100 066 DPLX 03 GN, Rev. C, 14 June 2018. TRIM 2018/211826.

8. Generic Design Assessment for UK HPR1000: Application of Weld Ranking Procedure: GH X 0010 005 DPCH 03 GN, Revision B. 29 May 2018. TRIM 2018/184857.

9. Generic Design Assessment for UK HPR1000, Safety Case Methodology for HIC Component, GH X 00100 009 DPFJ 03 GN, Rev. C, 20 April 2018. TRIM 2018/146093.

10. Generic Design Assessment for UK HPR1000: Strategy and Plan of Non-Destructive Testing for High Integrity Component. GH X 0010 107 DPCH 03 GN, Revision C. 07 June 2018. TRIM 2018/199955.

11. Generic Design Assessment for UK HPR1000: Inspection Qualification for High Integrity Component: GH X 0010 028 DPCH 03 GN, Revision B. 07 June 2018. TRIM 2018/193735.

12. Generic Design Assessment for UK HPR1000, Equipment Structural Integrity List, GH X 30000 003 DOZJ 03 GN, Rev. D, 29 May 2018. TRIM 2018/184876.

13. Generic Design Assessment for UK HPR1000, The Scheme Description of Reactor Components, GH X 00100 008 DPFJ 03 GN, Rev. C, 29 May 2018. TRIM 2018/182035.

14. Generic Design Assessment for UK HPR1000, The Scheme Description of Reactor Main Loop Equipment, GH X 00100 101 DPZS 03 GN, Rev. E, 5 June 2018. TRIM 2018/193731.

15. Generic Design Assessment for UK HPR1000, Material Selection Methodology, GH X 00100 006 DPCH 03 GN, Rev. B, 6 June 2018. TRIM 2018/211845.

16. Generic Design Assessment for UK HPR1000, ALARP Methodology, GH X 00100 051 DOZJ 03 GN, Rev. B, 28 April 2018. TRIM 2018/181415.

17. Generic Design Assessment for UK HPR1000, Safety Case Methodology for HIC and SIC Components, GH X 00100 001 DPFJ 44 DS, Rev. A, 29 May 2018. TRIM 2018/182038.

18. ONR HOW2 Guide NS-PER-GD-014 Revision 6 - Purpose and Scope of Permissioning. November 2019. http://www.onr.org.uk/operational/assessment/index.htm

19. Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0. November 2014. http://www.onr.org.uk/saps/saps2014.pdf

20. Structural Integrity NS-TAST-GD-016 Revision 5. ONR. March 2017.
    Guidance on the Demonstration of ALARP NS-TAST-GD-005 Revision 9. ONR. March 2018.
    Categorisation of Safety Functions and Classification of Structures Systems and Components NS-TAST-GD-094 Revision 0. ONR. November 2015.

    The Purpose, Scope and Content of Safety Cases NS-TAST-GD-051 Revision 4. ONR. July 2016.

    http://www.onr.org.uk/operational/tech_asst_guides/index.htm

21. IAEA, Safety Classification of Structures, Systems and Components in Nuclear Power Plants, No.SSG-30, May 2014. www.iaea.org.

22. Safety Reference Levels for existing reactors WENRA September 2014, Reactor Harmonisation Working Group report on Safety of new NPP designs WENRA March 2013, http://www.wenra.org/

23. R6 – Assessment of the Integrity of Structures Containing Defects, Revision 4, EDF Energy Nuclear Generation Ltd.

24. The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Sections III and XI.

25. RCC-M. Design and Construction Rules for Mechanical Components of PWR Nuclear Islands. 2007 Edition. Published by the French Association for Design, Construction and In-Service Inspection Rules for Nuclear Island Components – AFCEN, Paris.

26. RSE-M. In-Service Inspection Rules for Mechanical Components of PWR Nuclear Islands, RSE-M, 2010 edition+2012 addendum, 2010, 2012, AFCEN.

27. European Methodology for Qualification of Non-Destructive Testing. Third Issue. ENIQ Report No. 31 EUR 22906 EN. August 2007.

28. ENIQ Recommended Practice 2. Strategy and Recommended Contents for Technical Justifications, Issue 2. ENIQ Report No.39. EUR 24111EN-2010. June 2010.

29. UKHPR1000 GDA Project. Preliminary Safety Report Chapter 4 General Safety and Design Principles. HPR/GDA/PSR/0004 Revision 0, October 2017. TRIM 2017/401351.

30. UKHPR1000 GDA Project. Preliminary Safety Report Chapter 11 Steam and Power Conversion Systems. HPR/GDA/PSR/0011 Revision 0, October 2017. TRIM 2017/401362.

31. GNS UK HPR1000 - Schedule of Regulatory Queries raised during Step 2. ONR. TRIM Ref. 2018/315144

32. RQ-UKHPR1000-0083 Structural Integrity Classification Procedure. TRIM 2018/183365.

33. R. Bullough, F. M. Burdekin, O. J. V. Chapman, V. R. Green, D. P. G. Lidbury, J. N. Swingler, R. Wilson. The Demonstration of Incredibility of Failure in Structural Integrity Safety Cases, International Journal of Pressure Vessels and Piping 78, pages 539-552, 2001.

34. Generic Design Assessment for UK HPR1000, The Scheme Description of Reactor Components, GH X 00100 008 DPFJ 03 GN, Rev. B, 11 December 2017. TRIM 2018/41264.

35. UKHPR1000 GDA Project. Preliminary Safety Report Chapter 1 Introduction. HPR/GDA/PSR/0001 Revision 0, October 2017. TRIM 2017/401345.

36. New Nuclear reactors: Generic Design Assessment Guidance to Requesting Parties. ONR-GDA-GS-001 Revision 3 September 2016.

37. RQ-UKHPR1000-0007 Structural Integrity Classification and the UK HPR1000 Safety Case – Underlying Assumptions. TRIM 2017/469062.

38. GDA Step 2 Assessment of Internal Hazards of the UK HPR1000 Reactor, ONR-GDA-UKHPR1000-AR-18-003 Revision 0, August 2018. TRIM 2018/208486.

39. RQ-UKHPR1000-0102 HPR1000 (FCG3) Application of Leak Before Break Concept. TRIM 2018/192675.

40. RQ-UKHPR1000-0115 HPR1000 Queries on preclusion of high energy pipe failure locations from consequences analysis. TRIM 2018/232334.

41. Step 4 Structural Integrity Assessment of the EDF and AREVA UK EPR$^{TM}$ Reactor. ONR-GDA-AR-11-027. Revision 0. 14 November 2011. TRIM 2010/581504.

42. PCSR3 reference to RCC-M and RSE-M.

43. RQ-UKHPR1000-0030 Proposed Design and Construction Codes in the UK HPR1000 Structural Integrity Case. TRIM 2018/40105.

44. RQ-UKHPR1000-0030 Proposed Design and Construction Codes in the UK HPR1000 Structural Integrity Case. TRIM 2018/87899.

45. RQ-UKHPR1000-0109 UK HPR1000 Steam Generator Design, Construction and Inspection Codes. TRIM 2018/198542.

46. Light Water Reactor Study Group on Pressure Vessel Integrity: Assessment of the Integrity of Pressure Water Reactors Pressure Vessels; second report, sections 6-11. March 1982.

47. Generic Design Assessment for UK HPR1000: Pre-Construction Safety Report. Chapter 17. Structural Integrity. GH X 00620 017 KPGB 02 GN. Revision B. TRIM 2018/105310.

48. Generic Design Assessment for UK HPR1000: Weld Ranking Procedure: GH X 0010 004 DPCH 03 GN, Revision C. 2 April 2018. TRIM 2018/128050.

49. RQ-UKHPR1000-0082 UK HPR1000 Weld Ranking Procedure. TRIM 2018/183363.

50. RQ- UKHPR-0145. Loadings for Defect Tolerance Assessment. TRIM 2018/228190.

51. Generic Design Assessment for UK HPR1000, Defect Tolerance Assessment Methodology for HIC Components, GH X 00100 066 DPLX 03 GN, Rev. B, 4 May 2018. TRIM 2018/159742.

52. RQ-UKHPR1000-0057 Plan for High Reliability NDT of High Integrity Components in the UK HP1000 Reactor. TRIM 2018/122772.

53. RQ-UKHPR1000-0058 Inspection Qualification Strategy for the NDT of High Integrity Components for the UK HP1000 Reactor. TRIM 2018/122774.

54. RQ-UKHPR1000-0059 Access for Non Destructive Testing & 'Design for Inspectability' for the UK HP1000 Reactor. TRIM 2018/122781.

55. RQ-UKHPR1000-0110 Demonstration of Effectiveness for the Manufacturing NDT of High Integrity Components in the UK HPR1000. TRIM 2018/198543.

56. RQ-UKHPR1000-0113 A Strategy and Plan for High Reliability NDT of High Integrity Components in the UK HPR1000. TRIM 2018/206219.

57. Generic Design Assessment for UK HPR1000, The Scheme Description of Reactor Main Loop Equipment, GH X 00100 101 DPZS 03 GN, Rev. C, 10 January 2018. TRIM 2018/41274.

58. RQ-UKHPR1000-0089 4 May 2018, UKHPR Design and Structural Integrity. TRIM 2018/183368.

59. RQ-UKHPR1000-0016 Justifying Materials Selection Decisions for UK HPR1000 TRIM 2018/31041.

60. RQ-UKHPR1000-0081 - Through-Life Degradation Mechanisms and Materials Selection TRIM 2018/183362.

61. RQ-UKHPR1000-0090 UK HPR1000 ALARP and Structural Integrity TRIM 2018/183367.

62. ONR-GDA-UKHPR1000-AR-18-020, Summary of the Step 2 Assessment of the UK HPR1000 Reactor, TRIM 2018/238474

63. WENRA Recommendation in connection with macro-segregation anomalies found in French reactors, dated 30 May 2018. http://www.wenra.org/archives/wenra-recommendation-connection-macro-segregation-/

64. UKHPR1000 GDA Project. Preliminary Safety Report Chapter 12 Design Basis Conditions Analysis. HPR/GDA/PSR/0012 Revision 0, October 2017. TRIM 2017/40136.

**Table 2**: Relevant Safety Assessment Principles Considered During the Assessment

| SAP No and Title | Description | Interpretation | Comment |
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| SC.4 | The regulatory assessment of safety cases. Safety case characteristics | A safety case should be accurate, objective and demonstrably complete for its intended purpose | Considered in Sections: 4.1, 4.3, 4.4 and 4.5.<br>During Step 2, the RP presented the high level Structural Integrity claims for the safety case in the PSR. The RP presented a Structural Integrity safety case strategy that included both HIC and non-HICs. The safety case for HICs applies a multi-legged approach based on that developed by TAGSI. I considered this as an adequate basis for further development of the safety case.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment of the PCSR as it is developed during Stages 3 and 4. Note several points relating to compliance with the SAPs relevant to Structural Integrity are identified below as follow-up items in the next stages of GDA. These comments therefore need to be considered in the context of GDA Step 2, which is essentially a high level review of the design fundamentals along with key claims from a Structural Integrity perspective. |
| EKP.3 | Engineering principles: key principles. Defence in depth. | Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression | Considered in Sections: 4.1, 4.3, 4.4 and 4.5.<br>The RP has provided an approach for HICs that applies a multi-legged conceptual defence approach. I consider with development of the avoidance of fracture demonstration this provides an adequate basis for underpinning a claim to discount gross failure of HICs. The application of a defence in depth approach is inherent to the codes specified by the RP, which is dependent on the classification of SSC to meet ONR's expectations.<br>It is not clear as to whether reasonably practicable measures have been taken to mitigate the consequences of postulated gross failures for some SSCs.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 |

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| | | | and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.1 | Integrity of metal components and structures: highest reliability components and structures.<br>Safety case and assessment | The safety case should be especially robust and the corresponding assessment suitably demanding, in order that an engineering judgement can be made for two key requirements:<br>a) the metal component or structure should be as defect-free as possible;<br>b) the metal component or structure should be tolerant of defects. | Considered in Sections: 4.1, 4.2, 4.3, 4.4, 4.5, 4.8<br>The RP has made an important step in recognising the need to demonstrate highest reliability through component specific DTAs and the development of provision for high reliability NDT including inspection qualification. The methods selected for these activities align with UK relevant good practice.<br>There was no clear link between the avoidance fracture demonstration and high level safety case claims, nor a full understanding of the integration of DTA, material properties and inspection qualification. The SAP was not met. An RO will be raised to progress through Steps 3 and 4. |
| EMC.2 | Integrity of metal components and structures: highest reliability components and structures.<br>Use of scientific and technical issues | The safety case and its assessment should include a comprehensive examination of relevant scientific and technical issues, taking account of precedent when available. | Considered in Sections: 4.1, 4.2, 4.3, 4.4, 4.5, 4.8<br>The RP has indicated areas where multidisciplinary working is necessary (fault studies, internal, external hazards and chemistry) is required. In general terms, the RP has understood ONR's expectations regarding the need to provide a multi-legged structural integrity case for HIC, including additional measures to reduce risk, and the role of LBB.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.3 | Integrity of metal components and structures: highest reliability components and structures: Evidence | Evidence should be provided to demonstrate that the necessary level of integrity has been achieved for the most demanding situations. | Considered in Sections: 4.1, 4.5, 4.8<br>This has been appropriately treated at a high level during Step 2 and the evidence will be tested through my sample assessment of submissions during Steps 3 and 4.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |

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| EMC.4 | Integrity of metal components and structures: general. Procedural control | Design, manufacture and installation activities should be subject to procedural control. | Considered in general terms in Section 4, and in particular in Sections: 4.3.<br>The RP has identified the codes and standards that will be used for design and manufacture that is appropriate for Step 2. These codes are recognised nuclear codes that have been used previously within GB.<br>The approach defines measures to control the design manufacture and installation that are commensurate with the safety classification.<br>The RP codes to be used for the SG have not been fully developed; the reference design applies a combination of ASME and RSE-M codes. There are some points relating to the selection of codes and standards for the lower Structural Integrity classes to progress.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.5 | Integrity of metal components and structures: general. Defects | It should be demonstrated that safety-related components and structures are both free from significant defects and are tolerant of defects. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, 4.5<br>The RP's submissions, as planned, have focussed on the methods that will be applied to demonstrate highest reliability for HICs. The methods for defect tolerance and demonstrating the freedom from defects for non-HIC are partly provided by the codes specified for the UK HPR1000.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated considering non-HICs. |
| EMC.6 | Integrity of metal components and structures: general. Defects | During manufacture and throughout the operational life the existence of defects of concern should be able to be established by appropriate means. | |
| EMC.7 | Integrity of metal components and structures: design. Loadings | For safety-related components and structures, the schedule of design loadings (including combinations of loadings), together with conservative estimates of their frequency of occurrence should be used as the basis for design against normal operating, plant | Considered only in general terms in Section 4.<br>Prescribing the use of the RCC-M (and ASME III) as the basis for determining loads is considered appropriate for Step 2. I will work with ONR inspectors from fault studies, internal hazards and |

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| | | transient, testing, fault and internal or external hazard conditions. | external hazards during Steps 3 and 4 to perform a sample assessment of the loadings used for the UK HPR1000.<br>The SAP has not been fully explored at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.8 | Integrity of metal components and structures: design.<br>Requirements for examination | Geometry and access arrangements should have regard to the requirements for examination. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.5, 4.6<br>The RP has made claims that plant is designed to facilitate NDT wherever possible. This is an appropriate design intent for Step 2; I will seek evidence to support this claim through Steps 3 and 4. |
| EMC.9 | Integrity of metal components and structures: design. Product form | The choice of product form of metal components or their constituent parts should have regard to enabling examination and to minimising the number and length of welds in the component. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.5, and 4.6.<br>There are some areas where it may be possible to change the product form and/or the number of welds. A balance between minimising the number of welds and achieving inspectability in thick section forgings may also need to be struck e.g. for the MCL.<br>The SAP has not been demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.10 | Integrity of metal components and structures: design.<br>Weld positions | The positioning of welds should have regard to high-stress locations and adverse environments. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, 4.5, 4.6<br>It is noted that the UK HPR1000 has no weld in the beltline region of the RPV. This is judged to be beneficial. It is not clear at the conclusion of Step 2 as to how widely this principle has been considered.<br>The SAP is not fully met and I will undertake a sample assessment during Steps 3 and 4 to judge whether high stress locations and adverse environments have been considered in the location of welds. |

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| EMC.11 | Integrity of metal components and structures: design.<br>Failure modes | Failure modes should be gradual and predictable. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, 4.5<br>The control of operating conditions to reduce risks of brittle fracture features in design code provisions.<br>The RP's is also aware of ONR's expectations with regard to invoking stable tearing in DTAs for highest reliability. These aspects were considered at a high level in Step 2, and will be followed-up at Steps 3 and 4. |
| EMC.12 | Integrity of metal components and structures: design.<br>Brittle behaviour | Designs in which components of a metal pressure boundary could exhibit brittle behaviour should be avoided. | |
| EMC.13 | Integrity of metal components and structures: manufacture and installation.<br>Materials | Materials employed in manufacture and installation should be shown to be suitable for the purpose of enabling an adequate design to be manufactured, operated, examined and maintained throughout the life of the facility. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, 4.5, and 4.7. There may be a need for an appropriate balance between minimising the number and length of welds and achieving adequate properties in thick section forgings to be struck (see EMC.9).<br>The RP has also recognised the need to consider measures, additional to the code, for HICs. The RP has also recognised that materials selection is a multidisciplinary task.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.17 | Integrity of metal components and structures: manufacture and installation.<br>Examination during manufacture | Provision should be made for examination during manufacture and installation to demonstrate the required standard of workmanship has been achieved. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, 4.5<br>In general this is covered in design and construction code provisions. The RP has however recognised that for SSC e.g. RPV Internals there may be a need for additional measures beyond code to reduce the risk of through-life degradation. I will perform sample assessments during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.21 | Integrity of metal components and structures: operation.<br>Safe operating envelope | Throughout their operating life, safety-related components and structures should be operated and | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, and 4.5. The operating rules and limits and conditions are a |

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| | | controlled within defined limits consistent with the safe operating envelope defined in the safety case. | feature of the design codes. The RP needs to show that the these controls reduce risk ALARP (see EMC.11 and EMC.12). Will follow-up in Step 3 and 4. |
| EMC.23 | Integrity of metal components and structures: operation. Ductile behaviour | For metal pressure vessels and circuits, particularly ferritic steel items, the operating regime should ensure that they display ductile behaviour when significantly stressed. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.4, 4.5<br>See the comments for EMC. 11, 12 and 21. Will follow-up in the next stages of GDA. |
| EMC.24 | Integrity of metal components and structures: monitoring. Operation | Facility operations should be monitored and recorded to demonstrate compliance with the operating limits and to allow review against the safe operating envelope defined in the safety case. | |
| EMC.27 | Integrity of metal components and structures: pre- and in-service examination and testing. Examination | Provision should be made for examination that is reliably capable of demonstrating that the component or structure is manufactured to the required standard and is fit for purpose at all times during service. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.5.<br>The RP's submissions, as planned, have focussed on the methods that will be applied for HICs. These provide a basis for confidence commensurate with the aims of Step 2.<br>More widely, the RCC-M (and ASME III) code describes methods along with acceptance criteria for establishing the existence of defects of concern during manufacture.<br>The application of the RSE-M code defines methods for in-service inspection and maintenance that are aimed at detecting defects during service.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.28 | Integrity of metal components and structures: pre- and in-service examination and testing. Margins | An adequate margin should exist between the nature of defects of concern and the capability of the examination to detect and characterise a defect. | |
| EMC.29 | Integrity of metal components and structures: pre- and in-service examination and testing. Redundancy and diversity | Examination of components and structures should be sufficiently redundant and diverse. | |
| EMC.30 | Integrity of metal components and structures: pre- and in-service examination and testing. Control | Personnel, equipment and procedures should be qualified to an extent consistent with the overall safety case and the contribution of examination to the Structural Integrity aspect of the safety case. | Considered in general terms in Section 4, and in particular in Section 4.5.<br>The RP has defined the approach it will use to qualify NDT systems (procedures, equipment and personnel), mainly in the context of HICs. Provisions |

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| | | | are included in the appropriate codes specified by the RP for demonstrating the capability of NDT systems.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.32 | Integrity of metal components and structures: analysis.<br>Stress analysis | Stress analysis (including when displacements are the limiting parameter) should be carried out as necessary to support substantiation of the design and should demonstrate the component has an adequate life, taking into account time-dependent degradation processes. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.5.<br>The RP submissions included a high level description of the approach for HICs. Provisions are made in the appropriate codes specified by the RP for undertaking stress analysis.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.33 | Integrity of metal components and structures: analysis.<br>Use of data | The data used in analyses and acceptance criteria should be clearly conservative, taking account of uncertainties in the data and the contribution to the safety case. | Considered in general terms in Section 4, particular in Sections: 4.3, 4.5.<br>The RP's submissions relating to DTA contain some information on input data for HICs. The codes specified by the RP define the inputs and acceptance criteria that can be applied to non-HICs.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EMC.34 | Integrity of metal components and structures: analysis.<br>Defect sizes | Where high reliability is required for components and structures and where otherwise appropriate, the sizes of crack-like defects of structural concern should be calculated using verified and validated fracture mechanics methods with verified application. | Considered in general terms in Section 4, and in particular in Sections: 4.3, 4.5<br>The RP has specified the use of the R6 methodology for determining the sizes of structural significant defects; I judge this to be appropriate.<br>The inclusion of the RSE-M treatment of fatigue crack initiation appears to be in conflict with the application of R6 and I will need to explore this further.<br>The RP is also developing an understanding of the |

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| | | | linkage between defect tolerance assessment, inspection qualification and material properties for HIC structures and components.<br>The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |
| EAD.1 | Ageing and degradation.<br>Safe working life | The safe working life of structures, systems and components that are important to safety should be evaluated and defined at the design stage. | Considered in general terms in Section 4, and in particular in Section 4.7.<br>The RP has developed principles for material selection using a multidiscipline approach.<br>The also RP has committed to undertake a comprehensive review of ageing and degradation mechanisms during Step 3.<br>The SAP has not been fully demonstrated at Step 2; I will perform assess the RP's approach during Step 3 and further sample available evidence during Step 4 to judge whether the SAP has been adequately demonstrated. |
| EAD.2 | Ageing and degradation.<br>Lifetime margins | Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components that are important to safety. | |
| EAD.3 | Ageing and degradation.<br>Periodic measurement of material properties | Where material properties could change with time and affect safety, provision should be made for periodic measurement of the properties. | |
| EAD.4 | Ageing and degradation.<br>Periodic measurement of parameters | Where parameters relevant to the design of plant could change with time and affect safety, provision should be made for their periodic measurement. | |
| ECS.1 | Safety classification and standards.<br>Safety categorisation | The safety functions to be delivered within the facility, both during normal operation and in the event of a fault or accident, should be categorised based on their significance with regard to safety. | Considered in Sections: 4.1, 4.2, 4.3, 4.5<br>The RP has outlined a methodology for deriving Structural Integrity class and recognised the need for a specific class for components where gross failure is discounted (HICs). The RP has not been able to complete a Structural Integrity classification as the full plant categorisation and classification was not completed within the Step 2 assessment period.<br>The RP has, during Step 2, produced an initial list of HIC candidates. I will perform a sample assessment |
| ECS.2 | Safety classification and standards.<br>Safety classification of structures, systems and components | Structures, systems and components that have to deliver safety functions should be identified and classified on the basis of those functions and their significance with regard to safety. | |

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| ECS.3 | Safety classification and standards. Standards | Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate standards. | of the complete categorisation and Structural Integrity classification basis as the GDA progresses. The SAP has not been fully demonstrated at Step 2; I will perform a sample assessment during Steps 3 and 4 to judge whether the SAP has been adequately demonstrated. |