Office for
Nuclear Regulation

New Reactors Division – Generic Design Assessment

Step 4 Assessment of Internal Hazards for the UK HPR1000 Reactor

Assessment Report ONR-NR-AR-21-012
Revision 0
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EXECUTIVE SUMMARY

This report presents the findings of my assessment of the Internal Hazards aspects of the generic UK HPR1000 design undertaken as part of the Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA). My assessment was carried out using the Pre-Construction Safety Report (PCSR) and supporting documentation submitted by the Requesting Party (RP).

The objective of my assessment was to make a judgement, from an Internal Hazards perspective, on whether the generic UK HPR1000 design could be built and operated in Great Britain, in a way that is acceptably safe and secure (subject to site specific assessment and licensing), as an input into ONR's overall decision on whether to grant a Design Acceptance Confirmation (DAC).

The scope of my GDA assessment was to review the safety aspects of the generic UK HPR1000 design by examining the claims, arguments, and supporting evidence in the safety case. My GDA Step 4 assessment built upon the work undertaken in GDA Steps 2 and 3 and enabled a judgement to be made on the adequacy of the internal hazard information contained within the PCSR and supporting documentation.

My assessment focussed on the following aspects of the generic UK HPR1000 safety case:

- Adequacy of the internal hazard claims, arguments and evidence detailed in the PCSR.
- Adequacy of the internal hazard methodologies and their application.
- Adequacy of plant layout.
- Adequacy of hazard identification & determination of design basis loading
- Adequacy of the identification of safety measures.

The conclusions from my assessment are:

- The RP has provided sufficient evidence to substantiate the claims and arguments detailed in the PCSR, for the sample areas assessed.
- I have concluded that the methodologies for each internal hazard are consistent with relevant good practice. Where I identified significant shortfalls, these have been raised and addressed by the RP for the highest risk areas. Although some shortfalls remain, these are judged not to undermine the conclusions of this report.
- The RP has provided adequate details of its hazard identification and screening processes to demonstrate that the key hazard areas have been identified and analysed.
- The generic UK HPR1000 design provides adequate segregation between the principal nuclear safety related divisions. This segregation is provided through claimed divisional barriers, the majority of which have been sufficiently substantiated through the assessment process. Where this has not been the case, I have been satisfied that the RP has undertaken sufficient analysis to demonstrate that this does not have a significant impact on nuclear safety, and that further work has been identified to address this at the detailed design stage.
- The generic UK HPR1000 design has adequately identified areas where exceptions to segregation exist. In these situations, I have been satisfied that the RP demonstrated the design to be largely tolerant of loss of the systems in these areas. Where this is not the case, I am content the RP has adequately

justified no significant impact to nuclear safety, and further work has been identified to address these at the detailed design stage.

- The RP has adequately reviewed the risks from hazards to High Integrity Components within the generic UK HPR1000 design.
- Based on the segregation of plant and adequacy of the analysis undertaken by the RP I am satisfied that, for the purposes of GDA, the RP has provided sufficient evidence to demonstrate that the layout of the plant and the divisional barriers are adequate.
- The RP has adequately identified those safety measures required to protect against internal hazards. However, the licensee needs to undertake further work at the detailed design stage to identify and fully substantiate all safety measures providing protection against internal hazards, particularly for defence in depth, and consolidate these within the hazard schedule.

These conclusions are based upon the following factors:

- A detailed and in-depth technical assessment, on a sampling basis, of the full scope of safety submissions at all levels of the hierarchy of the generic UK HPR1000 safety case documentation.
- Independent information, reviews and analysis of key aspects of the generic safety case undertaken by Technical Support Contractors (TSCs).
- Detailed technical interactions, comprising over 50 face to face meetings with the RP, alongside the assessment of the responses to the substantial number of Regulatory Queries (RQs) and the Regulatory Observations (ROs) raised during my assessment.

A number of matters remain outstanding, which I judge are appropriate for a licensee to consider and take forward to resolution in site-specific safety submissions. These matters do not undermine the generic UK HPR1000 design and safety submissions but are primarily concerned with the provision of site-specific safety case evidence, which will become available as the project progresses through the detailed design, construction, and commissioning stages. These matters have been captured in 23 Assessment Findings.

Based on my assessment undertaken in accordance with ONR’s procedures, the claims, arguments, and evidence laid down within the PCSR and supporting documentation submitted as part of the GDA process present an adequate safety case for the generic UK HPR1000 design. I recommend that from an internal hazards perspective a DAC may be granted.

LIST OF ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ALARP	As Low As Reasonably Practicable
ANSI	Design criteria for protection against the effects of compartment flooding in light water reactor plants
ANSYS	Finite Element Modelling Software
APG	Plant code for Steam Generator Blowdown System
AR	Assessment Report
ARE	Plant code for Main Feedwater Flow Cooling System
ARN	Autoridad Regulatoria Nuclear (Argentina)
ASCE	American Society of Civil Engineers
ASDS	Atmospheric Steam Dump System
ASG	Plant code for Emergency Feedwater System
ASP	Plant code for Secondary Passive Heat Removal System
AVS	Plant code for Annulus Ventilation System
BDA	Emergency Diesel Generator Building A
BNB	Emergency Diesel Generator Building B
BDC	Emergency Diesel Generator Building C
BDU	SBO Diesel Generator Building for Train A
BDV	SBO Diesel Generator Building for Train B
BEJ	Extra Cooling System and Fire-fighting Water Supply System Building
BEX	Equipment Access Building
BFX	Fuel Building
BLEVE	Boiling Liquid Expanding Vapour Explosion
BMS	Business Management System
BNX	Nuclear Auxiliary Building
BPX	Personnel Access Building
BRX	Reactor Building
BS	British Standards
BSI	British Standards Institution
BSA	Safeguard Building A
BSB	Safeguard Building B
BSC	Safeguard Building C
BSL	Basic Safety Level (in SAPs)
BSO	Basic Safety Objective (in SAPs)
BSX	Safeguard Buildings

BWX	Radioactive Waste Treatment Building
C&I	Control and Instrumentation
CAMPHOR	Analysis code used to simulate pressure and temperature
CCGCS	Containment Combustible Gas Control System
CCWS	Component Cooling Water System
CDRM	Control Rod Drive Mechanism
CFAST	Consolidated Model of Fire and Smoke Transport
CFD	Computational Fluid Dynamics
CGN	China General Nuclear Power Corporation Ltd
CHRS	Containment Heat Removal System
CRDS	Chemical Reagents Distribution System
CSBVS	Containment Sweeping and Blowdown Ventilation System
CVCS	Chemical and volume control system
DAC	Design Acceptance Confirmation
DBA	Design basis analysis
DBC (1 to 4)	Design Basis Conditions
DCL	Plant code for Main Control Room Air Conditioning System
DEC	Design Extension Condition
DEL	Plant code for Safety Chilled Water System
DG	Diesel Generator
DiD	Defence in Depth
DLF	Dynamic Load Factor
DR	Design Reference
DSEAR	Dangerous Substances and Explosive Atmosphere Regulations
DVL	Safeguard building ventilation system
DWDS (NI)	Nuclear island water distribution system
DWL	Fuel Building Controlled Area Ventilation System
EA	Environment Agency
EBE	Plant code for Containment Sweeping and Blowdown Ventilation System
EBS	Emergency Boration System
ECS	Extra Cooling System
EDE	Annulus Ventilation System
EDF-SA	Electricite de France
EDG	Emergency diesel generator
EDVS	Electrical Division of the Ventilation System
EFWS	Emergency Feedwater System
EHR	Plant code for Containment Heat removal system
EMC	Electromagnetic Compatibility

EMI	Electromagnetic Interference
ETC-F	French Technical Code for Fire Protection
ETS	Exception to segregation
EUF (CFES)	Plant Radiation Monitoring System
EUH (CCGCS)	Containment Combustible Gas Control System
FDS	Fire Dynamics Simulator
FE	Finite element (FEA finite element analysis)
FHSS	Fuel Handling and Storage System
FLASH-CAT	Flames Spread Over Horizontal Cable Trays
FLD	Fire Load Density
FPCTS	Fuel Pool Cooling and Treatment System
GDA	Generic Design Assessment
GNI	General Nuclear International Ltd
GNSL	General Nuclear System Ltd
HDS (HI)	Hydrogen Distribution System
HEAF	High Energy Arcing Fault
HEP	High Energy Piping
HEPF	High Energy Pipe Failure
HGL	Hot Gas Layer
HIC	High Integrity Components
HRR	Heat Release Rate
HP	High Pressure
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
IEC	Instrumentation, Electrical and Control
IET	Institute of Engineering and Technology
IH	Internal Hazards
IRWST	In-containment Refuelling Water Storage Tank
ISO	International Organisation for Standardisation
JPI [FWSNI]	Fire-fighting Water System for Nuclear Island
LEL	Lower Explosive Limit
LP	Low Pressure
LOCA	Loss of Coolant Accident
LOCUST	Analysis Code for Mass and Energy Release
LS-DYNA	Computational fluid dynamic modelling tool
MAGIC	Computational fire code (French)
MCL	Main Coolant Lines
MCP	Main Coolant Pump
MCR	Main Control Room

MCRACS	Main Control Room Air Conditioning System
MCS	Maintenance Cold Shutdown
MDEP	Multinational Design Evaluation Programme (within OECD-NEA)
MER	Mass and Energy Release
MFFCS	Main Feedwater Flow Cooling System
MJ	Megajoule
MOFIS	Systematic Modelling Solution to Fire Safety Design of Nuclear Power Plants’
MSDS	Main Steam and Drainage System
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
MSS	Main Steam System
MSSS	Main Steam Supply System
MSTM	Multiple-Stud Tensioning Machine
MW	Megawatts
NI	Nuclear Island
NNR	National Nuclear Regulator (South Africa)
NNSA	National Nuclear Safety Administration (China)
NPP	Nuclear Power Plant
NS/RIS-RHR	Normal Shutdown with Reactor Injection System/Residual Heat Removal
NS/SG	Normal Shutdown with Steam Generators
NSS	Nuclear Sampling System
NUREG	United States Nuclear Regulatory Commission Regulation Regulatory Report
OECD-NEA	Organisation for Economic Cooperation and Development
ONR	Office for Nuclear Regulation
PCSR	Pre-Construction Safety Report
PMC	Plant code for Fuel Handling and Storage System
PRMS	Plant Radiation Monitoring System
PSA	Probabilistic Safety Assessment
PTR	Plant code for Fuel Pool Cooling and Treatment System
PZR	Pressuriser
RBS	Plant code for Emergency Boration System
RCC-F	Design and construction rules for fire protection of PWR Nuclear Plants
RCC-M	Design and construction rules for mechanical components of PWR Nuclear Plants
RCD	Reactor Completely Discharge
RCP	Reactor Coolant Pump
RCS	Refuelling Cold Shutdown

RCV	Chemical and Volume Control System [CVCS]
RDS	Room datasheets
REN	Plant code for Nuclear Sampling System
RGP	Relevant Good Practice
RHR	Residual Heat Removal
RIS	Plant code for Safety Injection System [Safety Injection System]
RO	Regulatory Observation
RP	Requesting Party
RPE	Nuclear Island Vent and Drain System [VDS]
RPV	Reactor Pressure Vessel
RQ	Regulatory Query
RRI	Plant code for component cooling water system
RSS	Remote Shut down Station
SAPs	Safety Assessment Principles
SBCAVS	Fuel Building Controlled Area Ventilation System
SBO	Station Blackout
SBVS	Safeguard Building Ventilation System
SCWS	Safety Chilled Water System
SDOF	Single Degree of Freedom model
SED	Plant code for nuclear island water distribution system
SFP	Spent Fuel Pond
SFS	Safety Fire Compartments
SG	Steam Generators
SGBS	Steam Generator Blowdown System
SGH	Plant code for Hydrogen distribution system
SI	Structural Integrity
SIH	Plant code for Chemical Reagents Distribution System
SIS	Safety Injection System
SLB	Steam line break
SLT	Super limit temperature
SoDA	Statement of Design Availability
SPHRS	Secondary passive heat removal system
SSC	Structures, Systems and Components
SSE1 SSE2	Safety categorisation for structures with or without seismic classification
TAG	Technical Assessment Guide
TESG	Technical Expert Subgroup
TSC	Technical Support Contractor
UK	United Kingdom (of Great Britain and Northern Ireland)

US NRC	United States Nuclear Regulatory Commission
VDA	Plant code for atmospheric steam dump system
VPU	Plant code for Main Steam and Drainage System
VVP	Plant code for Main Steam System
WENRA	Western European Nuclear Regulators’ Association
ZFS	Safety fire cells

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1 INTRODUCTION

1.1 Background

1. This report presents my assessment conducted as part of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA) for the generic UK HPR1000 design within the topic of Internal Hazards (IH).

2. The generic UK HPR1000 is a pressurised water reactor (PWR) design proposed for deployment in the UK. General Nuclear System Ltd (GNSL) is a UK-registered company that was established to implement the GDA on the generic UK HPR1000 design on behalf of three joint requesting parties (RP), i.e. China General Nuclear Power Corporation (CGN), EDF SA and General Nuclear International Ltd (GNI).

3. GDA is a process undertaken jointly by the ONR and the Environment Agency. Information on the GDA process is provided in a series of documents published on the joint regulators' website (www.onr.org.uk/new-reactors/index.htm). The outcome from the GDA process sought by the RP is a Design Acceptance Confirmation (DAC) from ONR and a Statement of Design Acceptability (SoDA) from the Environment Agency.

4. The GDA for the generic UK HPR1000 design followed a step-wise approach in a claims-argument-evidence hierarchy which commenced in 2017. Major technical interactions started in Step 2 which focused on an examination of the main claims made by the RP for the generic UK HPR1000 design. In Step 3, the arguments which underpin those claims were examined. The Step 2 reports for individual technical areas, and the summary reports for Steps 2 and 3 are published on the joint regulators' website. The objective of Step 4 was to complete an in-depth assessment of the evidence presented by the RP to support and form the basis of the safety and security cases.

5. The full range of items that form part of my assessment is provided in ONR's GDA Guidance to Requesting Parties (Ref. 1). These include:

   - Consideration of issues identified during the earlier Step 2 and 3 assessments.
   - Judging the design against the Safety Assessment Principles (SAPs) (Ref. 2) and whether the proposed design ensures risks are As Low As Reasonably Practicable (ALARP).
   - Reviewing details of the RP's design controls and quality control arrangements to secure compliance with the design intent.
   - Establishing whether the system performance, safety classification, and reliability requirements are substantiated by a more detailed engineering design.
   - Assessing arrangements for ensuring and assuring that safety claims and assumptions will be realised in the final as-built design.
   - Resolution of identified nuclear safety and security issues or identifying paths for resolution.

6. The purpose of this report is therefore to summarise my assessment of the internal hazards (IH) topic which provides an input to the ONR decision on whether to grant a DAC, or otherwise. This assessment was focused on the submissions made by the RP throughout GDA, including those provided in response to the Regulatory Queries (RQs) and Regulatory Observations (ROs) I raised. Any ROs issued to the RP are published on the GDA's joint regulators' website, together with the corresponding resolution plans.

1.2 Scope of this Report

7. This report presents the findings of my assessment of the IH aspects of the generic UK HPR1000 design undertaken as part of GDA. I carried out my assessment using the Pre-construction Safety Report (PCSR) (Ref. 3) and supporting documentation submitted by the Requesting Party (RP). My assessment was focused on considering whether the generic safety case provides an adequate justification for the generic UK HPR1000 design, in line with the objectives for GDA.

1.3 Methodology

8. The methodology for my assessment follows ONR’s guidance on the mechanics of assessment, NS-TAST-GD-096 (Ref. 4).

9. My assessment was undertaken in accordance with the requirements of ONR‘s How2 Business Management System (BMS). ONR’s SAPs (Ref. 2), together with supporting Technical Assessment Guides (TAG), were used as the basis for my assessment. Further details are provided in Section 2. The outputs from my assessment are consistent with ONRs GDA Guidance to RPs (Ref. 1).

2 ASSESSMENT STRATEGY

10. The strategy for my assessment of the Internal Hazards (IH) aspects of the generic UK HPR1000 design and safety case is set out in this section. This identifies the scope of the assessment and the standards and criteria that have been applied.

2.1 Assessment Scope

11. A detailed description of my approach to this assessment can be found in assessment plan ONR-GDA-UKHPR1000-AP-19-002. Rev 0 (Ref. 5).

12. For IH, it is acknowledged that the hazard assessment is heavily influenced by the availability of detailed design information defining the generic UK HPR1000 design plant configuration. Therefore, it is expected that post GDA the design will be developed and optimised significantly during the detailed and site-specific stages to account for the numerous site and construction-specific factors that are not sufficiently mature at the time of GDA.

13. For GDA, the RP's analysis and substantiation are not taken to the full level of detail required to present a complete IH case. For IH, a pragmatic balance is struck; the aim is to ensure the level of detail is sufficient to demonstrate that the safety functions can be underpinned, and any risk areas can be understood, discussed, and associated design modifications or other improvements implemented or committed to.

14. The Step 4 generic design assessment process tests the RP's ability to articulate and apply its suite of methodologies demonstrating the competence and experience of its design team and the robustness of the design.

15. I recognise that because the IH safety case has been fixed on the design information associated with design reference (DR) 2.1 (Ref. 6), further evolution of the design during step 4 may impact the information provided for assessment. To address this, relevant modifications have been sampled when appropriate, noting that in some instances the required detailed design may not be available. However, notwithstanding the above, drawings and extracts from the RP's detailed design model were provided in formal submissions during Step 4 and these have been assessed accordingly as providing assurance with respect to the RP's processes and modifications.

16. I therefore considered all of the main submissions within the remit of my assessment scope, to various degrees of breadth and depth. I chose to concentrate my assessment on those aspects that I judged to have the greatest safety significance, or where the hazards appeared least well controlled. My assessment was also influenced by the claims made by the RP, my previous experience of similar systems for reactors and other nuclear facilities, and any identified gaps in the original submissions made by the RP. A particular focus of my assessment has also been the adequate resolution and close out of the RQs and ROs I raised through the GDA process.

2.2 Sampling Strategy

17. In line with ONR's guidance (Ref. 4), I chose a sample of the RP's submissions to undertake my assessment based on the following themes:

- Adequacy of the claims, arguments, and evidence detailed in the PCSR.
- Adequacy of the internal hazard methodologies and their application.
- Adequacy of plant layout.
- Adequacy of hazard identification & determination of design basis loading.
- Adequacy of safety measures.
- Demonstration that the risks to plant from internal hazards are as low as reasonably practicable (ALARP).

18. A detailed summary of the key aspects of the step 4 plan and how this has been addressed within the body of the report is contained in Appendix 4.

2.3 Out of Scope Items

19. The following items were outside the scope of my assessment.

- Beyond design basis accidents and severe accident analysis, as my IH assessment is limited to design basis accidents.
- Impact of hazards on design extension condition systems, as the intent is to obtain assurance through my assessment that IH do not lead to design extension conditions.
- Detailed substantiation of safety measures whose design needs to be finalised at the detailed design stage.
- Plant outside the nuclear island.

2.4 Standards and Criteria

20. The relevant standards and criteria adopted within this assessment are principally the ONR Safety Assessment Principles (SAPs) (Ref. 2) and Technical Assessment Guides (TAGs), relevant national and international standards, and relevant good practice informed from existing practices adopted on nuclear licensed sites in Great Britain. The key SAPs and any relevant TAGs, national and international standards and guidance are detailed within this section. Relevant good practice (RGP), where applicable, is cited within the body of the assessment.

2.4.1 Safety Assessment Principles

21. The SAPs (Ref. 2) constitute the regulatory principles against which ONR judges the adequacy of safety cases. The SAPs applicable to IH are included within Annex 1 of this report.

22. The key SAPs applied within my assessment were SAPs SC. 4, EKP.3 and EKP.5, ELO.4, ECS.2, ESS.18, EHA.1, EHA.2, EHA.3, EHA.6 and EHA.19.

2.4.2 Technical Assessment Guides

23. The following Technical Assessment Guides were used as part of this assessment:

- NS-TAST-GD-014, Internal hazards (Ref. 7).
- NS-TAST-GD-042, Validation of computer codes and calculation methods (Ref. 8).
- NS-TAST-GD-051, The purpose, scope, and content of safety cases (Ref. 9).
- NS-TAST-GD-056, Nuclear lifting operations (Ref. 10).
- NS-TAST-GD-096, Guidance on mechanics of assessment (Ref. 4).

2.4.3 National and International Standards and Guidance

24. The following standards and guidance were used as part of this assessment:

- IAEA SSR – 2/2 Safety of Nuclear Power Plants: Commissioning and Operation (Ref. 11).
- IAEA NS-G-2.1 - Fire Safety in the Operation of Nuclear Power Plants (Ref. 12).
- IAEA NS-G-1.7 – Protection against internal fires and explosions in the design of nuclear power plants (Ref. 13).
- IAEA NS-G-1.11- Protection against internal hazards other than fires and explosions in the design of nuclear power plants (Ref. 14).

- IAEA SSG-64 Protection against internal hazards in the design of nuclear power plants (Ref. 15).

2.5 Use of Technical Support Contractors

25. It is usual during GDA for ONR to use Technical Support Contractors (TSCs) to provide access to independent advice and experience, analysis techniques and models, and to enable ONR‘s inspectors to focus on regulatory decision making.

26. Table 1 below sets out the areas in which I used TSCs to support my assessment. I required this support to provide additional capacity and access to independent advice and experience.

Table 1: Work Packages Undertaken by the TSC

Number	Description
1	Provide specialist and independent technical review of the generic UK HPR1000 PCSR submissions and supporting documentation.
2	Provide specialist advice to ONR at technical meetings.
3	Specialist analysis of Mass energy release codes

27. Whilst the TSC undertook detailed technical reviews, this was done under my direction and close supervision. The regulatory judgment on the adequacy, or otherwise, of the generic UK HPR1000 safety case has been made exclusively by ONR. The following TSC reports have been used to inform my assessment:

- TSC independent review flooding (Ref. 16).
- TSC independent review fire (Ref. 17).
- TSC independent review missiles (Ref. 18).
- TSC independent review explosion (Ref. 19).
- TSC independent review high energy pipe failure (Ref. 20).
- TSC independent review dropped loads (Ref. 21).
- TSC independent review combined hazards (Ref. 22).
- TSC independent review RO-UKHPR1000-046 submissions (Ref. 23).
- TSC independent review CAMPHOR code review (Ref. 24).

2.6 Integration with Other Assessment Topics

28. GDA requires the submission of an adequate, coherent, and holistic generic safety case. Regulatory assessment cannot be carried out in isolation as there are often issues that span multiple disciplines. I have therefore worked closely with a number of other ONR inspectors to inform my assessment. The key interactions were:

- Civil Engineering – Substantiation of barriers and adequacy to support segregation claims.
- Structural Integrity – Determination of HIC and their withstand to hazards; IH considerations/ input into RO-UKHPR1000-08 (Justification of the Structural Integrity Classification of the Main Coolant Loop).
- External Hazards – Determination of combined hazards.
- Mechanical Engineering – Assurance for lifting methods and considerations in RO-UKHPR1000-14 (Spent Fuel Building – Design of Nuclear Lifting Operations to Demonstrate Relevant Risks are Reduced to ALARP).

- Fault Studies – Confirmation of Categorisation and Classification approaches in line with ONR expectations / Demonstration of diversity and redundancy of systems with regards to functional analysis.

2.7 Overseas Regulatory Interface

29. ONR has formal information exchange agreements with a number of international nuclear safety regulators and collaborates through the work of the International Atomic Energy Agency (IAEA) and the Organisation for Economic Co-operation and Development Nuclear Energy Agency (OECD-NEA). This enables us to utilise overseas regulatory assessments of reactor technologies, where they are relevant to the UK. It also enables the sharing of regulatory assessments, which can expedite assessment and helps promote consistency.

2.7.1 Multilateral Collaboration - Multinational Design Evaluation Programme

30. As part of my assessment, I participated in the Hazards Technical Expert Sub-Group (TESG) of the HPR1000 Multinational Design Evaluation Programme (MDEP). This TESG included national regulators from Argentina’s Autoridad Regulatoria Nuclear (ARN), China’s National Nuclear Safety Administration (NNSA) and South Africa’s National Nuclear Regulator (NNR).

31. Participation in this group provided insight into the design evolution of the HPR1000 following the Fukushima-Daiichi incident, and the safety systems included to enhance the design’s resilience against beyond design basis events, as well as the IH and hazard combinations considered in the design.

3 REQUESTING PARTY’S SAFETY CASE

3.1 Introduction to the Generic UK HPR1000 Design

32. The generic UK HPR1000 design is described in detail in the PCSR (Ref. 3). It is a three-loop PWR designed by CGN using the Chinese Hualong technology.

33. The generic UK HPR1000 design has evolved from reactors which have been constructed and operated in China since the late 1980s, including the M310 design used at Daya Bay and Ling’ao (Units 1 and 2), the CPR1000, the CPR1000$^+$ and the more recent ACPR1000. The first two units of CGN’s HPR1000, Fangchenggang Nuclear Power Plant (NPP) Units 3 (FCG3) and 4, are under construction in China and Unit 3 is the reference plant for the generic UK HPR1000 design.

34. The generic UK HPR1000 design is claimed to have a lifetime of at least 60 years and has a nominal electric output of 1,180 MW.

35. The reactor core of the generic UK HPR1000 design contains zirconium clad uranium dioxide (UO_2) fuel assemblies. Reactivity is controlled by a combination of control rods, soluble boron in the coolant, and burnable poisons within the fuel.

36. The core is contained within a steel Reactor Pressure Vessel (RPV) which is connected to the key primary circuit components, including the Reactor Coolant Pumps (RCPs), Steam Generators (SGs), pressuriser and associated piping, in the three-loop configuration.

37. The design also includes a number of auxiliary systems that allow normal operation of the plant, as well as active and passive safety systems to provide protection in the case of faults, all contained within a number of dedicated buildings.

3.2 The Generic UK HPR1000 Internal Hazards Safety Case

3.2.1 Overview of Key Buildings and Systems

38. In this section I provide an overview of the IH aspects of the generic UK HPR1000 safety case as provided by the RP during GDA. Details of the technical content of the documentation and my assessment of its adequacy are reported in the subsequent sections of this report.

39. The generic UK HPR1000 design philosophy as detailed in the PCSR (Ref. 3) is based on independence, diversity, and segregation. The design provides three divisions of systems, structures, and components for continued delivery of the fundamental safety functions (control of reactivity, removal of heat from the reactor and fuel store and confinement of radiological releases) under normal and fault conditions. For design basis IH, the generic UK HPR1000 design objective is to limit the effects from hazard loads to one division by robust divisional walls providing segregation.

40. The Nuclear Island (NI) includes the reactor building (BRX), three safeguard buildings (BSA, BSB and BSC), the nuclear auxiliary building (BNX), the nuclear fuel building (BFX), the emergency diesel generator buildings (BDA, BDB and BDC), the station blackout diesel generator for train A and B (BDU and BDV), the personnel access building (BPX) and the equipment access building. A generic site plan can be found in figure 1 below.

41. All the safety-relevant NI buildings are designed against external hazards including seismic loading, and aircraft impact. The following buildings are arranged on a common raft to protect against a design-basis earthquake: BRX, BSA, BSB and BSC, and the BFX. The other nuclear buildings are built on separate rafts.

42. Of the NI buildings listed above, the primary nuclear safety buildings are the BRX, BSA, BSB, BSC and BFX. These buildings contain the majority of the nuclear safety systems and radiological inventory on site.

43. The orientation of the BRX is shown in figure 1 below. The main function of the building is to; house the reactor; house the essential cooling systems (primary system) for the reactor, and; provide containment. The safeguards buildings are segregated into three divisions, with BSA on the west side of the BRX, BSB on the east, and BSC on the north side. The safeguard buildings are internally separated into mechanical, electrical and ventilation areas. The main control room is located centrally in the BSC. The BFX is arranged south of the BRX.

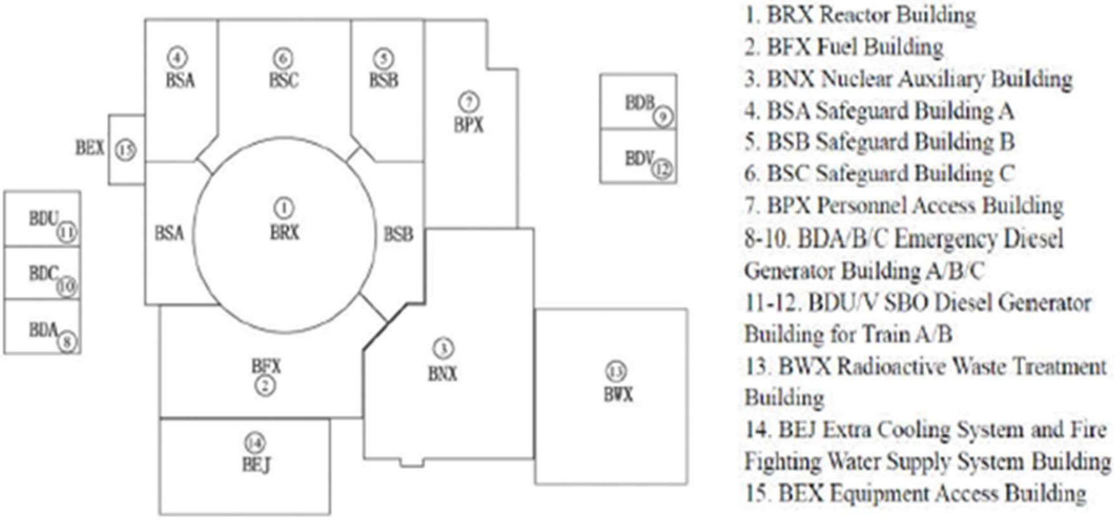

Figure 1: Plan of the generic UK HPR1000 building arrangements

44. The BRX consists of internal containment, external containment, and internal structures (concrete and steel). The internal region (BRA) and external containment are cylindrical concrete structures and are separated by the annulus region (BRB). The internal containment is pre-stressed and covered by a metallic leak-tight liner on the inner surface. The external containment is reinforced to withstand aircraft impact.

45. The principal safety function for the BRX internal structures is to provide containment and segregation between the various divisions. Internal structures are constructed of reinforced concrete.

46. The principal safety function for the reactor coolant system (primary system) is to transfer heat from the reactor core to the secondary system, and to produce steam for turbine operation.

47. The main parts of the primary systems are:

- The reactor pressure vessel (RPV).
- Three loops, each containing one reactor coolant pump, one steam generator, and main coolant lines (hot leg, cold leg, and cross leg).
- The pressuriser (PZR) which is connected to one of the three loops (via surge line), to maintain the pressure inside the reactor coolant system.

48. The secondary system transfers the heat from the primary loop to the main turbines. This is done through the three steam generators (SGs). The main systems are:

- The main steam lines (VVP [MSS]) – remove decay heat by transferring steam to the turbine generator set or the condenser. Each line consists of various valves and drain lines.
- The main feedwater flow control system (ARE [MFFCS]) - regulates feedwater flowrate for supplying the three SGs under normal conditions and performs the feedwater line isolation function under accident conditions.

49. In addition to the primary and secondary coolant systems several other SSCs maintain safety, these include:

- The safety injection system, RIS [SIS], injects borated water into the reactor coolant system (RCP [RCS]) to control the reactivity of the reactor under certain design basis faults and design extension conditions (DEC). In a LOCA, the RIS [SIS] contributes to water inventory compensation and residual heat removal for injecting borated water into the RCP [RCS] via 3 accumulators into the RCP cold leg.
- Fuel handling and storage system (PMC [FHSS]) maintains the integrity of the fuel cladding, cools the fuel assemblies, and maintains them in a sub-critical condition.
- The chemical and volume control system RCV [CVCS] performs the functions of reactivity control, volume control and chemical control.
- The containment combustible gas control system EUH [CCGCS] is designed to reduce hydrogen concentration in containment, ensuring that containment integrity and leak tightness can be maintained after a LOCA or under design extension conditions (DEC).
- The containment heat removal system EHR [CHRS] transfers residual heat from the in-containment refuelling water storage tank (IRWST) to the ultimate heat sink and limits the pressure of the containment with containment sprays under DEC.
- The secondary passive heat removal system ASP [SPHRS] is designed to provide decay heat removal during DEC-A accidents. The water tank of the ASP [SPHRS] is an annular concrete structure located around the top of the external containment.

3.2.2 Internal Hazards Safety Case Summary

3.2.2.1 Buildings in GDA Scope

50. The generic UK HPR1000 safety case aims to demonstrate that the threats to nuclear safety from IH are eliminated, protected against, or tolerable. The scope for generic UK HPR1000 GDA project is defined in the RP’s scope report (Ref. 25). This outlines the following buildings that are within the GDA scope:

- Emergency diesel generator buildings for trains A, B and C.
- Station black-out (SBO) diesel generator building for trains A and B.
- Equipment access building.
- Fuel building.
- Nuclear auxiliary building.
- Personnel access building.
- Reactor building.
- Safeguard buildings for trains A, B and C.
- Radioactive waste treatment building.
- Extra cooling system and fire-fighting water production building.

51. Areas of the nuclear site not included in the above list and generally outside the GDA scope have nevertheless been considered if they can generate significant hazard impacts on SSCs important to safety. An example are missiles from steam turbine disintegration.

3.2.2.2 Safety Case Structure

52. The generic UK HPR1000 safety case has a document hierarchy that is split to into four tiers as defined in the IH production strategy report (Ref. 26) and is shown in the table below. Within that document, an overview of the IH case is provided in Appendix 3.

Table 2: The generic UK HPR1000 safety case document hierarchy

Doc Tier	Description	Documents
1	One of the GDA main submissions, namely the PCSR. PCSR Chapter 19 is the main submission of the internal hazards safety case.	PCSR Chapter 19 (Ref. 3).
2	References directly supporting the PCSR.	The General Requirements of Protection Design against Internal and External Hazards (Ref. 27).
		Internal Hazard methodology reports for each hazard area and combined hazards, (multiple references see section 6).
		The Identification and Screening Process of Internal and External Hazards (Ref. 28).
		List of exception to segregation areas (Ref. 29).
		Internal and External Hazards Schedule Methodology (Ref. 30).
		Compliance Analysis of Codes and Standards for Internal Hazards (Ref. 31).
		Suitability Analysis of Codes and Standards in Internal Hazards (Ref. 32).
		A set of internal hazards safety assessment reports for sample buildings within scope of GDA, (multiple references see section 6).
		Hazard Barriers Substantiation Reports for buildings within scope of GDA, (multiple references see section 6).
		ALARP Demonstration Report for Internal Hazards (Ref. 33).
		RO action reports, (multiple references see section 6).
3	Safety case	Fire and flooding zoning drawings,

Doc Tier	Description	Documents
	documentation, which supports the Tier 2 document.	verification and validation reports for the model 'Systematic Modelling Solution to Fire Safety Design of Nuclear Power Plants' (MOFIS).
4	The process documents, including RQ responses, procedures, letters, and manuals.	

3.2.2.3 Design Reference for Internal Hazards Assessment

53. The design reference of the generic UK HPR1000 is presented within PCSR Chapter 19 (Ref. 3), which details the design basis used to inform the IHs assessment. It comprises the following:

- The internal hazards safety case, which was produced based on Design Reference (DR) version 2.0, as described in the generic UK HPR1000 Design Reference Report (Ref. 6).
- All the design changes between DR2.0 and DR2.1.
- Relevant modifications between DR2.1 and DR3.0.

3.2.2.4 Safety Case Objectives for Internal Hazards

54. The general requirements for protection design against internal and external hazards document (Ref. 27) highlights the RP's IH assessment principles and scope. The report states that, at a fundamental level, the purpose of the internal hazard assessment is to ensure that the safety functions needed to bring and maintain the plant to a safe state are adequately protected from hazards.

55. The RP describes its aim to deliver the above objective through the following design principles for hazards:

- The defence in depth concept should be applied in the design of hazards protection.
- Hazards should not result in the failure of any fundamental safety function of nuclear power plants.
- Priority should be given to barrier protection, and the integrity of the barrier against individual and combined hazards should be substantiated. Penetrations should be minimised as far as possible. The acceptability of any partial loss of barrier integrity should be evaluated.
- Conservative assumptions are used in the (RP's) deterministic assessment and single failure criterion.
- The habitability of the Main Control Room (MCR) should be maintained. The availability and the accessibility of the remote shutdown station should be ensured in case the MCR is unavailable.
- The protection design measures should ensure that there is no cliff-edge effect.
- The hazards safety assessment should demonstrate that the risk is reduced to As Low As Reasonably Practicable (ALARP).

56. The RP's assessment scope for the generic UK HPR1000 safety case is also defined in the general requirements report (Ref. 27) and the design condition list and acceptance criteria (Ref. 34). These documents state that the RP's internal hazards assessment is focused on those hazards that occur during normal operation (DBC-1) and anticipated operational occurrences (DBC-2). This therefore includes all operating

modes of the reactor: reactor in power (RP) mode, normal shutdown with steam generators (NS/SG) mode, normal shutdown with RIS-RHR (NS/RIS-RHR) mode, maintenance cold shutdown (MCS) mode, refueling cold shutdown (RCS), and reactor completely discharge (RCD) mode.

57. In relation to the scope the RP established the following requirements:

- Internal hazards should not cause Design Basis Condition (DBC)-3/DBC-4 or Design Extension Condition (DEC) events to the extent practicable. If this occurs, the delivery of the safety functions should still be ensured.
- Internal hazards shall not cause the failure of High Integrity Components (HIC).

3.2.2.5 RP's Internal Hazards Assessment and Screening Criteria

58. The RP has applied the above assessment criteria for each individual internal hazard, for the buildings within the GDA scope, in particular the safeguard buildings, reactor building and fuel building.

59. The PCSR states that according to their layout, buildings can be divided into segregation areas and exception to segregation areas. The implementation of segregation areas in the generic UK HPR1000 internal hazards topic area is based on the arrangement of redundant safety systems delivering the fundamental safety functions. Each division in the generic UK HPR1000 design is capable of delivering all of the required fundamental safety functions for the control of reactivity, removal of heat from the reactor and fuel store, and confinement of radiological releases.

60. The RP defined 'segregation areas' as those areas where divisional barriers provide segregation between redundant safety systems delivering the fundamental safety functions. The RP's aim was to ensure that the divisional barriers meet the safety functional requirements placed on them by internal hazards. For hazards impacting barriers in 'segregation areas' and areas where segregation is not provided, the RP's safety assessment strategy was to identify the most challenging hazard load on the barriers. This is a 'bounding case' approach. The RP selected hazards which it considered posed the maximum hazard loading, thus bounding other hazard scenarios.

61. The RP defined 'exception to segregation' areas as those areas where full segregation between redundant safety systems was not fully achievable. The 'exception to segregation' areas of the buildings within the assessment scope were identified and presented by the RP in the List of Segregation Areas and Exception to Segregation Areas, (Ref. 29). However, it should be noted that it is a broad classification. For example, there are concrete barriers (e.g. walls) which the RP considered can prevent redundant equipment from being damaged by an internal hazard. For the hazards with potential to impact more than one safety train in exception to segregation areas, the RP's safety assessment strategy was to assess them case-by-case without bounding case considerations.

62. Sub-section 19.6 of the PCSR (Ref. 3) defines the criteria for selection of the bounding case scenarios for internal hazards. These criteria are defined in three parts (A, B and C) and are reproduced below:

- **Criterion A**: selecting the cases which have the potential to generate the most challenging hazard loads (e.g. fire, flooding) to the divisional barriers. This criterion applies to the most challenging bounding load on divisional barriers that can be determined for a given building and hazard, including combined hazards.

- **Criterion B**: selecting the cases which have the potential to affect more than one train of SSCs important to safety and cause the loss of safety functions. This criterion applies when redundant SSCs are co-located and not fully segregated. If in some cases it is difficult to choose a single case which is the most challenging, all cases that meet this criterion are assessed.

- **Criterion C**: selecting the cases which have the potential to cause damage to HIC or candidate HIC. This criterion applies when there are hazard sources which could impact the HIC or candidate HIC in the building. For hazards impacting HIC, including segregation areas or exception to segregation areas, the safety assessment strategy is to assess them on a case-by-case basis without bounding.

63. The RP carried out safety analysis of the bounding cases through the application of various hazard assessment methodologies. Through the assessment, the RP intended to identify potential significant hazard risks and to demonstrate that the bounding analyses bounded the hazards identified, and to justify its SSC design and layout considerations.

3.2.2.6 RP’s General Safety Case Assessment Approach

64. For each internal hazard type, the RP developed a hazard analysis methodology which it then applied and documented in the safety assessment reports.

65. In general, the RP’s internal hazards safety assessment process includes the following steps: identification of internal hazard sources; consequence analysis, and; identification of safety measures and their substantiation. Within each assessment report the RP provided the analysis results which it in turn captured in a hazard schedule. The hazard schedule provided the summary of the RP’s assessments of all internal hazards, and links with hazard identification, safety measures, safety classification and the postulated initiating events.

66. Sub-sections 3.2.2.7-3.2.2.16 provide a summary of the internal hazards’ safety cases which the RP also summarised within the ALARP demonstration report (Ref. 33).

3.2.2.7 Internal Fire

67. For the Safeguards Building, the RP concluded that all significant risks from internal fire on nuclear safety functions had been identified, and it also identified measures for protection against internal fire, including the boundaries of fire compartments, cable wrapping and fire resistance casing. The RP self-identified one gap after internal fire safety assessment for Safeguard Buildings, which was related to seismic fire hazards impacting the MCR and implemented requirements on equipment qualification to eliminate the hazard.

68. Like the Safeguards building, in the Reactor Building the RP identified the measures for the protection against internal fire as follows: boundaries of fire compartments, cable wrapping, and fire resistance casing. Through barrier and equipment substantiation for the bounding cases, the RP concluded that barriers and HIC would withstand internal fires and the delivery of fundamental safety functions would not be impaired.

69. In the Fuel building the RP identified the following safety measures to protect against internal fire: fire compartment boundaries, cable wrapping, fire resistant board, and fire sealing. The RP studied the fire loading on the barriers and concluded that they would have withstand against the fire loads. For redundant SSCs, the RP concluded that fires would not impair delivery of fundamental safety functions.

70. For other buildings in scope of GDA the RP relies on the fire compartment boundaries and provided evidence to support that they would withstand the fires the RP considered most challenging.

3.2.2.8 Internal Explosion

71. For both the Safeguard and Reactor Buildings, the RP concluded that barriers and HIC equipment would withstand the internal explosion loads.

72. The RP acknowledged one gap in its explosion safety case for the Fuel Building, which was the need to consider the risk of continuous leakage of hydrogen. In this instance, the RP claimed that detectors and isolation valves would be provided to reduce the risks to ALARP. The RP also concluded that the building hazard barriers would withstand the corresponding internal explosion loads and no HIC would be impacted as there are none in this building.

73. For all other buildings in scope of GDA, the RP identified risks from internal explosion to nuclear safety functions and provided supporting evidence that the barriers would withstand the corresponding internal explosion loads.

3.2.2.9 Internal Flooding

74. For the Safeguard Building the RP identified the following safety measures for protection against internal flooding: the boundaries of internal flooding zones, watertight doors, and isolation.

75. In the case of the Reactor Building, the RP concluded that internal flooding would not compromise the delivery of fundamental safety functions, and the claimed measures are the boundaries of internal flooding zones (internal containment and external containment) and design measures such as gratings and engineered drainage routes.

76. The flooding safety assessment for the Fuel Building claimed the boundaries of internal flooding zones, watertight doors, and isolation as safety measures. The RP concluded through analysis that internal flooding in the building would not compromise the barriers nor the delivery of the fundamental safety functions.

77. In the internal flooding safety assessment for all other buildings in scope of GDA, the RP claimed the boundaries of internal flooding zones, watertight doors, and watertight sealings as safety measures.

3.2.2.10 High Energy Pipe Failures

78. For the Safeguard building, the RP's high energy pipe failure safety assessment stated that the significant risks had been identified. The RP provided evidence of barrier substantiation against the combined loads arising from this hazard, concluding that the consequences were tolerable.

79. For the Reactor Building the RP provided evidence in support of barrier and HIC equipment substantiation and concluded they would withstand the corresponding combined loads.

80. In the case of the Fuel Building, the RP provided evidence in support of barrier withstand against combined loads from hazards associated with high energy pipe failure.

81. For all other buildings in scope of GDA, the RP identified risks from high energy pipe failure and provided supporting evidence that the barriers would withstand the combined loads.

3.2.2.11 Dropped Loads

82. The RP's safety case for dropped loads hazards in the Safeguard and Reactor Buildings concluded that the foundation raft would withstand the dropped loads hazards identified. It also stated that dropped loads would not damage redundant SSCs in exception to segregation areas and the consequences of dropped load impacts on HIC were acceptable. According to the RP's safety case, however, the RPV would not withstand the highest drop of the RPV head assembly and therefore additional controls have been implemented, and a new lift path was proposed to mitigate this risk by reducing the potential drop height to within tolerable limits.

83. The RP's dropped loads case for the Fuel Building concluded that barriers could withstand the dropped loads effects for the scenarios identified and that redundant SSCs would not be affected. The RP reported a gap that was related to the drop height of the spent fuel cask. The RP addressed this through an optioneering approach and modified the lifting route to reduce the potential for significant drops and proposed the installation of impact limiters to reduce the loads to the cask to an allowable limit. There are no HIC in this building.

84. For all other buildings in scope of GDA, the RP identified risks from dropped loads and provided supporting evidence that the barriers would withstand the impact energy.

3.2.2.12 Internal Missiles

85. The RP's internal missiles case for the buildings in scope of GDA concluded that barriers would withstand internal missile loads identified, and that internal missiles would not cause the simultaneous failure of redundant SSCs important to safety.

3.2.2.13 Combined Hazards

86. The RP's combined hazards case for the Safeguard, Reactor and Fuel Building is based on the identification and substantiation of barriers against combined hazards for a series of bounding cases. Other buildings in scope of GDA contain single function nuclear safety systems (e.g. emergency diesel generators), or supporting systems, or fuel/waste storage and handling. The RP concluded that the effects of combined hazards for these buildings are generally similar to that for a single hazard, and the total loss of the SSCs in a building would be tolerable due to the provision of redundant SSCs in separate buildings.

3.2.2.14 Electromagnetic Interference

87. The RP provided a room-by-room analysis for the safeguard buildings to give confidence that adequate mitigation measures, Electromagnetic Compatibility (EMC) qualification criteria, and test specifications, can be defined at the site-specific design phase to protect the safety classified centralised I&C systems against electromagnetic interference (EMI) hazards. The RP also provided an assurance process for controlling internal EMI hazards through the safety life cycle of the plant showing how a substantiated EMC Safety Case would be developed at the end of the site-specific design.

3.2.2.15 Toxic and Corrosive Materials and Gases

88. For the buildings in scope of GDA, the RP presented evidence to support the assertion that toxic and corrosive materials do not threaten the safety functions of SSCs, or personnel in the MCR, based on separation distance. It also stated that there is no risk of toxic gases and corrosive materials impacting the Reactor Building.

3.2.2.16 Vehicle Impacts

89. The RP's vehicular transport impact safety assessment for buildings in the scope of GDA concluded that the exteriors of the buildings and the barriers between different divisions can withstand the corresponding vehicular transport impact loads.

3.2.2.17 Modifications Made during GDA

90. Through the course of the GDA the RP has implemented the following modifications to improve the design and safety case. These are also listed in the RP's ALARP summary (Ref. 33) and captured within each individual assessment report. The improvements are listed as:

- Implementation of cable wrappings to reduce fire loads.
- Implementation of Fire boards to protect other systems.
- Upgrading hydrogen detectors safety classification in the BFX.
- Upgrading hydrogen isolation valves safety classification.
- Modification of the RPV head assembly lifting path.
- Modification to the spent fuel delivery process.
- Modification of the steam generator blowdown system.
- Modification of the nuclear island firefighting water system.
- Modification to protect the main steam line in the safeguards building.
- Modification of layout to prevent impacts to high integrity components.
- Modification to protect high energy pipe penetrations.
- Modification to barrier to protect two main feedwater pipes.
- Modifications to reactor coolant pump design.

3.2.2.18 Summary

91. The generic UK HPR1000 PCSR chapter 19 (Ref. 3) presents the top-level safety case for internal hazards. The PCSR is underpinned by multiple documents as discussed above and these form the evidence provided in GDA.

92. The PCSR summarises the internal hazards case as follows:

- The protection design and safety assessment guarantee that the internal hazards do not compromise safety functions.
- In segregation areas, safety measures are identified, classified, and substantiated to ensure that the consequences of any internal hazard are limited to one train of the systems delivering the safety functions. This is ensured primarily by incorporating robust hazard barriers which are designed to withstand the loads from any individual design basis hazard (or credible combination thereof).
- Where there are exceptions to segregation, safety measures are also identified, classified, and substantiated to ensure that sufficient SSCs are available during and after an internal hazard, to deliver the safety functions.
- Internal hazards safety assessments for the BSA, BSB, BSC, BRX and BFX are carried out based on bounding cases to confirm that the safety functions for the UK HPR1000 are available under design basis internal hazards.

4 ONR ASSESSMENT

4.1 Structure of Assessment Undertaken

93. The scope of this report covers the subject area of internal hazards as defined in the ONR internal hazard technical assessment guide NS-TAST-GD-014 (Ref. 7). Internal hazards cover's all hazards to SSCs which originate within the site boundary but are external to the process.

94. Due to the wide scope of internal hazards, and to ensure that an effective assessment is undertaken, a sampling approach has been adopted. This approach is in line with relevant ONR guidance (Ref. 4). The areas sampled are based on the aspects highlighted in sub-section 2.2 and informed by the safety case structure as defined in section 3. The sampling for the step 4 internal hazards assessment has focused on the principal buildings required to maintain nuclear safety on the nuclear island; these are identified in the safety case as:

- Reactor building.
- Fuel building.
- Safeguard buildings.

95. As outlined in section 3 above, the generic UK HPR1000 design philosophy is based on independence, diversity, and segregation. This is principally delivered through three segregated divisions of systems, structures, and components. Each division is capable of delivering all of the required fundamental safety functions for the control of reactivity, removal of heat from the reactor and fuel store, and confinement of radiological releases. For design basis internal hazards, the generic UK HPR1000 design objective is to “limit the effects from the hazard loads to one division by robust divisional walls providing the segregating safety function”.

96. The RP aimed to demonstrate this key principle through the hazard analysis work that in turn should underpin the principal claims stated in the PCSR head document for internal hazards (Ref. 3). The PCSR claims and arguments have been assessed as part of earlier steps in the GDA process and were deemed adequate to outline the principal claims for a meaningful GDA assessment. As part of the step 4 assessment the substantiation of these claims have been assessed for each of the sample buildings and hazards.

97. For each of the sample buildings the following areas have been sampled for my assessment:

- Claims, arguments, and evidence to demonstrate that the divisional barriers can deliver segregation of multiple trains.
- Claims and evidence to demonstrate that the risks from internal hazard effects on exception to segregation areas are adequately managed.
- Claims and evidence to demonstrate that the risks from internal hazards on high integrity components (HIC) are adequately managed.

98. To deliver these objectives for each internal hazard the RP adopted a safety assessment strategy to identify all associated hazards that meet the following criteria:

- Criterion A: Internal Hazards that have the potential to result in damage to the claimed barriers to maintain nuclear safety.
- Criterion B: Internal Hazards that have the potential to affect more than one train of SSCs important to safety.
- Criterion C: Internal Hazards that have the potential to damage high integrity components (HIC).

99. This type of bounding approach is consistent with that applied during other GDAs (Ref. 35) and is considered appropriate for the stage in the design development expected for GDA. Therefore, I have reviewed the RP's safety case against these three criteria.

100. The specific actions to determine the adequacy of the RP's safety case are detailed in the ONR internal hazards step 4 assessment plan (Ref.5). These include assessment of:

- The PCSR and supporting documents to ensure the claims, arguments and evidence are adequately captured and justified.
- The justification, screening, selection and application of the bounding cases.
- The methodologies and application in the conservative analysis of internal hazards.
- Relevant analysis codes.
- The determination of the adequacy of plant layout.
- The robustness of the audit trail including the hazards schedule.
- The adequacy of the identified safety systems, structures, and components.
- The demonstration that the risks from internal hazards are as low as reasonably practicably (ALARP).

101. In addition to the actions detailed above, shortfalls identified within the ONR step 2 (Ref. 36) and step 3 reports (Ref. 37) have been included within the step 4 assessment scope. These are also included in the step 4 assessment plan (Ref. 5).

- The narrative including transparency, evidence and justification of the bounding scenarios selected.
- The application of the analysis methodologies including the requisite narrative, evidence, and transparency of all key assumptions.
- The consequence analysis for all initiating faults (including vehicle impact, EMI, toxic and corrosive materials and gases, and combined hazards).
- The demonstration of the adequacy of all safety measures for internal hazards.
- The withstand capability of HIC and other SSCs should be supported by the requisite evidence.

102. Review of the safety case assessment outcomes and any identified shortfalls have been sentenced in accordance with ONR guidance (Ref. 38).

103. The following sub-sections detail the assessment I have undertaken during GDA step 4. My assessment is structured around my sampling strategy outlined above, and covers the following technical topic areas:

- Barrier Substantiation.
- Fire.
- Explosion.
- Dropped loads.
- Internal missiles.
- High energy pipe failure.
- Combined hazards.
- Other hazards (including turbine disintegration).

4.2 Assessment of Barrier Substantiation Methodology

104. Barrier substantiation is a key foundation of the RP's safety case. Barrier withstand for both individual and combined hazards is a primary means to ensure divisional segregation and meet the RP's safety functional requirement of having at least one safety train available for any design basis accident. The derivation of the various hazard loadings is presented in detail in the specific hazard sections of this report

detailed below. This section provides an overview of the methodology adopted by the RP for the assessment of the barrier withstand against hazard loads.

105. The RP's analysis of the withstand of barriers against hazard loads as described in its methodology (Ref. 39), had been done in accordance with two principal standards, the American ACI-349M-13 (Ref. 40) for impact and dynamic loads, and BS EN1992 (Ref. 41), (Ref. 42) for fire. For fire resistance, I consider the application of BS EN1992 appropriate and valid for the fire curves detailed in ISO 834 (Ref. 43) and I have undertaken further assessment of this approach within the fire section of this report. For the assessment of hazard loads individually and in combination, the application of ACI-349M-13 is in line with my expectations, particularly for qualification of multi-hazard barriers, and satisfies SAP ECS.3.

106. The most dominant loads from internal hazards to barriers are dynamic loads. These can place large, localised loads on a barrier potentially resulting in localised failure. Large, distributed loads across a whole barrier are known as global loads, and the most challenging loads result from the combination of both dynamic and global loads.

107. The RP's approach to analysing the dynamic impact loads is documented within ACI-349M-13 Appendix F. The approach depends on the type of load and whether it requires the assessment of local effects as well as a global structural response. The standard distinguishes between types of dynamic loads by classifying them as either impactive load (involving a solid mass collision such as pipe whip) or impulsive (without a solid mass collision such as blast).

108. For the assessment of impactive loads, ACI-349M-13 does not provide an explicit methodology to determine localised effects; instead ACI-349M-13 states that suitable methods should be adopted. To determine the localised effects from pipe whip and missiles in the generic UK HPR1000 design, the RP has adopted methods defined within the R3 compendium of methods (Ref. 44).

109. I am satisfied that the approach within R3 provides an appropriate basis for predicting the potential for failure (spalling, scabbing etc.) of the barrier. I note that both missiles and pipe whip impacts are treated in the same way by the RP, this in my view provides a level of conservatism, particularly for the pipe whip analysis. Although ACI 349M-13 does not provide an explicit method to determine local effects, the standard does set out compliance criteria. ACI-349M-13 states that any safety significant walls should not fail through localised effects and a margin should be applied such that the thickness of the wall should be at least 20 percent greater than required. From my sampling of the RP's barrier analysis (Ref. 39) and response to RQ-UKHPR1000-1632 (Ref. 45), which I raised to query the approach for local impact analysis, it is my view that the RP has not fully achieved this standard criterion in all cases as several barriers have been shown to scab. This does not satisfy SAPs EKP.4, EKP.5, ECS.3 and ELO.4.

110. To address the shortfall described above I have raised the following Assessment Finding for the licensee to address as part of detailed design. It is my view that at detailed design the licensee can address this shortfall through various design choices, such as thickening barriers, moving pipework, adding restraints etc.

AF-UKHPR1000-0056: The licensee shall, as part of detailed design, demonstrate that the risks from barrier failure through scabbing are reduced to as low as reasonably practicable.

111. It should be noted that scabbing is a localised effect and can result in damage to equipment in adjacent compartments. The RP undertook assessment in these compartments to determine if SSCs could be damaged in response to queries raised in

RQ-UKHPR1000-1632 (Ref. 45). I have been satisfied that in the areas I have sampled, the RP has reviewed the adjacent compartment to determine if safety significant SSCs are located. In these instances, the RP confirmed that no safety significant SSCs were identified. This provided me with confidence that the scabbing hazard would not lead to further consequences in the areas sampled as detailed in the RP's response to RQ-UKHPR1000-1632 (Ref. 45). This approach is in line with ACI 349M-13 (Ref. 40).

112. The RP also undertook global assessment of such barriers and I am satisfied that the capacity of the barriers (in terms of their ability to deliver the required safety function for bearing load) has significant margin, thus I am satisfied that the majority of the challenges to the barriers remain at the localised level. This provides me with confidence that the structure maintains its structural safety function, but further work is required by the RP to eliminate the scabbing hazard. This satisfies requirements of SAPs EKP.2, EHA.2, and EHA.5.

113. For impulsive loads ACI-349M-13 highlights three approaches to determine the structural response. All three methods are analysed against a ductility criterion to ensure that the maximum deformation does not result in the loss of intended function of the structural member nor impair the safety-related function of other SSCs. The three methods proposed are:

- Calculation of a dynamic load factor (multiplying a dynamic load by a factor to equate it to a static load in relation to the structures natural frequency).
- Using impulse, momentum, and energy balance.
- Performing a time history dynamic analysis.

114. ACI-349M-13 (Like R3) states that for most cases the application of these methods can be based on a single degree of freedom model (SDOF). In my opinion this is an adequate approach by the RP for the generic UK HPR1000 design and from my experience is routinely used for such impact analysis to determine impacts to concrete structures. The RP identified the individual hazard loads that can impact barriers in accordance with its own bounding case philosophy (Ref. 39), and these are intended to determine the largest loads that can impact a claimed barrier. I am satisfied that the approach provides confidence that the most challenging loads can be identified and analysed by the RP. The RP captured the determination of these hazard loads within the associated IH reports covering; explosion; fire; flooding; missiles; dropped loads; high energy pipe failure (HEPF), including overpressure, high temp, jet impingement, blast, and pipe whip, and; vehicle impact, which are reported within the relevant sections of this assessment report.

115. Where load combinations are required such as for HEPF, ACI 349M-13 provides a clear objective for the design of structural concrete and the required strength when subject to the largest combined loading. For undertaking load combinations, ACI 349M-13 Appendix C outlines a methodology to determine the required strength of the structural concrete. For high energy pipe failures, ACI 349M-13 presents several equations defining the various loadings to which the structure/barrier would be exposed. Each element is weighted accordingly, and it is expected that an appropriate loading factor is applied unless an appropriate time history analysis is performed to justify otherwise. I am satisfied that this approach is in line with ONR expectations and SAPs AV.2 and AV.4.

116. The RP's approach to barrier substantiation is presented within its structural analysis and design method statement (Ref. 39). All buildings have identified design basis targets to which their compliance is assessed. These are detailed within the RP's basis of design documents (Ref. 46) (Ref. 47) (Ref. 48).

117. The design method statement (Ref. 39) confirms that ACI 349M-13 is the principal standard to determine the barrier withstand. The RP confirms the use of the relevant formula for load combinations relating to HEPF. The approach taken by the RP can be summarised as:

- The high temperature, overpressure, jet impingement, blast, and pipe whip caused by HEPF are combined for the structural analysis and barrier substantiation.
- The equivalent static loadings from high temperature, overpressure, jet impingement and blast on the structure are calculated within the ANSYS finite element model, while the pipe whip is evaluated by the R3 method.
- The total deflection considering the combination of high temperature, overpressure, jet impingement, blast and pipe whip is checked according to the limitation provided in the ACI349M-13.

118. I am satisfied that the approach undertaken by the RP for the combination of loads is aligned with the approach defined in ACI349M-13. I am satisfied that the approach taken by the RP in the conversion of temperature, overpressure, jet impingement and blast to static loads using a dynamic load factor (DLF) is appropriate given that these loads are likely to remain in the elastic zone for the barrier element. Pipe whip is not included as this is determined to generate a load that can induce plastic deformation. This again I judge to be a reasonable assumption.

119. I have discussed the RP's approach to barrier substantiation with the ONR Civil Engineering inspector who stated that the RP's approach for barrier substantiation, as described above, is adequate (Ref. 49). However, the shortfall against scabbing is recognised and should be addressed as part of detailed design as per IH AF-UKHPR1000-0056.

120. In summary, I am satisfied that the approach the RP has adopted to determine barrier withstands is in line with ONR expectations, in particular SAP ECS.3. The approach assesses both individual hazard loads and hazard loads in combination. This therefore provides confidence that the methodology applied for barrier substantiation is adequate for GDA.

4.3 Hazard Assessment – Fire

4.3.1 Principal Claims from the Generic UK HPR1000 Fire Safety Case

121. The generic UK HPR1000 fire safety case for the principal sample buildings (BRX, BFX and BSA/BSB/BSC) is comprised of the following documents:

- The Internal fire methodology report (Ref. 50).
- The internal fire zoning diagrams for the reactor building (Ref. 51).
- The internal fire zoning diagrams for the fuel building (Ref. 52).
- The internal fire zoning diagrams for the safeguards building (Ref. 53).
- The Internal fire safety assessment report for the reactor building (Ref. 54).
- The Internal fire safety assessment report for the fuel building (Ref. 55).
- The Internal fire safety assessment report for the safeguard buildings (Ref. 56).
- Regulatory Observation RO-UKHPR1000-053 Report (Ref. 57).
- Regulatory Observation RO-UKHPR1000-054 Report (Ref. 58).
- Regulatory Observation RO-UKHPR1000-055 Report (Ref. 59).

122. The principal claims for the fire safety case for the generic UK HPR1000 design are defined within the pre-construction safety case report (PCSR) Chapter 19 Internal Hazards (Ref. 3). These principal claims are stated as:

- Sub-claim 3.2.2.SC19.2.1: The internal fire sources are sufficiently identified.

  - Argument 3.2.2.SC19.2.1-A1 (Fire): The combustible materials are sufficiently identified, including their location and their fire loads.

- Sub-claim 3.2.2.SC19.2.2: The safety measures to mitigate the consequences of internal fire are identified and properly classified.

  - Argument 3.2.2.SC19.2.2-A1 (Fire): In segregation areas, safety measures are identified to ensure that the consequences of any internal fire are limited to one train of the systems delivering the safety functions through use of barriers.
  - Argument 3.2.2.SC19.2.2-A2 (Fire): Where there are exceptions to segregation, safety measures are identified to ensure that sufficient SSCs are available, during and after an internal fire, to deliver the safety functions.
  - Argument 3.2.2.SC19.2.2-A3 (Fire): An internal fire does not cause unacceptable damage to HIC.
  - Argument 3.2.2.SC19.2.2-A4 (Fire): The safety measures to mitigate the consequences of internal fire are classified in accordance with the methodology of safety categorisation and classification.

- Sub-claim 3.2.2.SC19.2.3: The safety measures for internal fire are sufficiently substantiated.

  - Argument 3.2.2.SC19.2.3-A1 (Fire): The safety measures to mitigate the consequences of internal fire in segregation areas are sufficiently substantiated.
  - Argument 3.2.2.SC19.2.3-A2 (Fire): The safety measures to mitigate the consequences of internal fire in exception to segregation areas are sufficiently substantiated.
  - Argument 3.2.2.SC19.2.3-A3 (Fire): Functional fire-resistant cases and cable wrappings can effectively protect SSCs important to safety in some areas where the multiple trains are in the same division.

4.3.2 Fire Methodology Assessment

123. This section presents the findings of my assessment of the RP’s fire methodology applied for the assessment of fire hazards within the generic UK HPR1000 design. The assessment of this methodology by ONR focused on ensuring that appropriate methods were defined for the following aspects:

- Layout design.
- Identification of fire sources.
- Identification of safety classified SSCs.
- Fire characterisation.
- Identification of safety measures.

124. The assessment has been undertaken in line with ONRs expectations in the SAPs (Ref. 2), and with relevant international standards for safety in the design of nuclear power plant including IAEA (Ref. 15), (Ref. 13) and WENRA safety reference levels (Ref. 60).

125. All the standards above are based upon a generalised approach for the management of fire hazards, including:

- Prevention of fire hazards, including by choice of materials.
- Avoidance of potential ignition sources, where practicable.

- Minimising the effects of fires if they do start, by redundancy, diversity, and physical separation, including segregation between redundant trains of equipment.

126. The fire methodology report (Ref. 50) outlines the key design principles for the plant's fire protection design and aims to demonstrate that the consequences of a fire should not:

- Prevent the performance of safety functions.
- Cause the loss of any equipment, or equipment item whose loss would lead to Design Basis Conditions (DBC)-3, DBC-4, and Design Extension Condition (DEC).
- Compromise the segregation / separation between different divisions.

127. To achieve the above principles the safety case describes the approaches used in defining the generic UK HPR1000 layout to reduce the risks from fire. These principles are captured within the General Requirements of Protection Design against Internal and External Hazards report (Ref. 61) and include:

- Use of non-combustible materials where possible.
- Avoiding localised accumulations of combustible materials where possible.
- Physical separation and segregation of the three divisions by providing Class 1 barriers between redundant trains, including walls, ceilings, floors, and all barrier penetrations.
- The creation of Safety Fire Compartments (SFS) and Safety Fire Cells (ZFS).
- Provision of additional Defence in Depth (DiD) safety measures where required, including fixed fire-fighting systems, smoke control systems, and fire-resistant cable wrappings.

128. I have assessed these principles taking account of relevant good practice and SAPs ELO.4 and EHA.16 and judge that they are adequate for the purpose of informing the RP's fire safety analysis and design decisions.

129. To implement these nuclear fire design principles, the generic UK HPR1000 design utilised ETC-F 2010 (Ref. 62) as the principal design guide for fire layout design.

130. ETC-F is a nuclear-specific French guide used in the design of pressurised water reactors. During the time between the start of GDA entry and Step 4, the ETC-F 2010 standard used as the basis of the generic UK HPR1000 design has been replaced by RCC-F 2017 (Ref. 63), which also has now been replaced by RCC-F 2020 (Ref. 64). The withdrawal of the 2010 standard was identified by ONR at previous GDA steps and raised within RQ-UKHPR1000-0125 (Ref. 65). In response, the RP undertook a comparison analysis. This identified several areas for further consideration but none that the RP considered as sufficiently significant to undermine the use of ETC-F 2010 for GDA. Noting that the standard RCC-F 2017 has now been superseded by RCC-F 2020 (Ref. 64), any further fire analysis at detailed design stage should adopt the new RCC-F 2020 standard or latest equivalent. This will be progressed as part of normal regulatory business.

131. I recognised that the ETC-F 2010 (Ref. 62) takes cognisance of key aspects of UK fire protection standards which are also explicitly listed within the standard. However, although the standard aligns with general fire protection principles, in my opinion it does not fully align with ONR's expectations for fire analysis.

132. I consider that by starting with the challenge of the maximum fire event, a deterministic safety case can be constructed which illustrates the safety features on which the design depends, and their importance (Ref. 7).

133. ETC-F 2010 allows for crediting fire prevention measures in determining the worst-case fire consequences. For example, if a cable system has protective wrapping, the standard allows such cables not to be included within the fire loading for assessment of the design of the fire area. However, this approach does not inform the categorisation of the protective wrapping as a nuclear safety measure. Furthermore, the choice of the technology to protect the cables should be justified. The RP's approach therefore does not satisfy SAPs EHA.3, FA.1, FA.7 and FA.8. I judge this a safety case shortfall and I raise the following Assessment Finding.

AF-UKHPR1000-0057: The licensee shall, as part of the detailed design, refine and implement the internal fire hazards analysis methodology demonstrating that the shortfalls identified in GDA have been addressed. This should include, but not be limited to:

- Full compartment burnout.
- Conservative combinations of fire load density, heat release rates and vulnerable structures, systems, and components.
- Conservative ventilation conditions including but not limited to open access doors and hatches.
- Sensitivity analysis is conducted to identify and address potential cliff edge effects.
- Models used for fire analysis are within their valid ranges.
- Justification of the spatial separation and management of fire loads.
- Optioneering is undertaken to demonstrate that all reasonably practicable measures to reduce risks have been analysed.
- The identification and capture of safety requirements for structures, systems, and components.
- Justification of the structures, systems, and components classification.
- Justification of the codes and standards used to substantiate the structures, systems, and components.

134. The generic UK HPR1000 fire analysis methodology required the safety case to identify the type and quantity of combustible materials in each room within a defined ‘fire area’. Based on the type and quantity of combustible materials and taking account of the area in the room, the RP's methodology expects a fire load density (FLD) to be derived. Furthermore, for the purposes of GDA and when determining the bounding fire scenarios for divisional barrier substantiation, the RP's approach was to only consider rooms adjacent to barriers.

135. It is my view that the FLD approach defined in the RP's methodology provides a reasonable scoping overview of potential fire challenges. However, since it is not accompanied by assessment of the potential effects from a fire in other locations, there is lack of visibility as to whether fires in other rooms may give different insights than those covered by the bounding case analyses. In my judgement the current safety case approach does not fully demonstrate that the risks from fires and fire spread have been fully captured. This does not satisfy SAPs EHA.1, EHA.19 and EHA.3. This should be addressed by the licensee at detailed design and is captured in Assessment Finding AF-UKHPR1000-0057, as it will be influenced by licensee choices such as the location of combustible materials.

136. The RP's fire safety evaluation methodology is based on the approach by BS ISO 18195:2019 (Ref. 66). In-line with this approach, the severity of a fire in a room is represented by establishing a bounding temperature/time curve, which is defined as the room fire curve. This curve is compared to the fire-resistant performance of fire

barriers that is typically represented based on the standardised temperature/ time curve (ISO 834 (Ref. 43) / EN1363:2013 (Ref. 67). The latter is called the fire-resistant performance curve. The RP's design intent is to demonstrate that in the fire room there are no temperatures above the standard fire curve, and that elevated temperatures above 200 °C do not occur for longer than the time the relevant barrier is rated to.

137. I consider that the approach adopted by the RP is appropriate and sufficiently conservative. However, to ensure that the analysis is conservative, the assumptions made to underpin the analysis need to be bounding. One key input in a fire model is the determination of the fire heat release rate (HRR). I therefore sampled the methodology to assess how HRRs were addressed and, specifically, how ventilation effects were considered to make a conservative determination of the HRR curve.

138. Ventilation effects can increase the HRR in comparison to an open fire but can also limit the HRR to that from an oxygen limited environment. The RP's fire modelling assumptions are highlighted within the fire methodology (Ref. 50), and this asks for "all possible ventilation configurations" to be considered, "i.e. non fire-resistant doors are assumed to be openings…".

139. Although the RP's fire methodology acknowledged the importance of ventilation, I have found that it does not provide clear guidance on how the analysis should manage the ventilation conditions within the fire compartment. This is an essential element to consider for sensitivity analysis and determining cliff edge effects.

140. Relevant good practice as described within the Eurocode BS EN 1991-1-2:2002 (Ref. 41) and BS 7974 (Ref. 68) for naturally ventilated fires requires simulations to avoid under-ventilated fire conditions as they may result in lower temperatures, inaccurate conditions, and non-conservative results. The approach in the RGP above requires that a ventilation-controlled limit is defined for the maximum HRR, ensuring that the worst-case conditions based on the ventilation conditions is derived. For nuclear power plants ventilation is normally provided by mechanical ventilation and therefore the impact to fire growth should also be considered as described within BS ISO 18195:2019 (Ref. 66).

141. It is my expectation that adequate sensitivity analysis is undertaken to ensure that there are no cliff edge effects and conservative analysis is required to be undertaken to determine the bounding fire conditions (Ref. 7). All potential impacts to ventilation conditions should be assessed and their impacts determined. The RP's methodology does not fully align with these expectations and therefore does not satisfy SAP AV.6 and EHA.7 and is captured in Assessment Finding AF-UKHPR1000-0057.

142. Overall, I judge that the adoption of the ETC-F 2010 standard provides an adequate basis for the generic UK HPR1000 design for GDA. The design requirements discussed above, which include the identification and analysis of fire effects, provide confidence that the generic UK HPR1000 fire design principles apply relevant good practice. This is evidenced through the application of both fire compartmentation, divisional segregation, and fire zoning.

143. The most significant shortfall that I have identified in the methodology related to the assessment of the 'compartment burnout' where safety measures are credited without recognising their required safety functions through classification. The purpose of undertaking an unmitigated full compartment burnout is to determine the significance of the unmitigated fire to SSCs to inform both the requirements for the safety system and to ensure they are adequately safety classified to provide the required reliability. My Assessment Finding AF-UKHPR1000-0057 captures where I expect the licensee to address the shortfalls when compared to relevant good practice.

4.3.3 Fire Analysis Tools

144. The RP has adopted the following fire analysis tools as part of its fire hazard analysis:

- MOFIS-Z.
- MOFIS-C.
- Fire Dynamics Simulator (FDS).

145. From my experience I am satisfied that the use of FDS (Ref. 69) is well documented and validated within the UK nuclear industry. Therefore, I judged that further assessment of the validation and verification of FDS as a tool to inform the generic UK HPR1000 fire analysis was not required.

146. In contrast to the use of FDS, the RP has also used two in-house codes called MOFIS to characterise fire effects. Because these are not codes with which ONR has previous experience, I judged it necessary to undertake assessment of their applicability within the context of the cases modelled for the generic UK HPR1000 design. In support of this assessment the RP submitted the verification and validation documents for both the codes (Ref. 70), (Ref. 71) which I sampled.

4.3.3.1 MOFIS-C

147. My assessment of the validation report for MOFIS-C (Ref. 70) identified that the analysis code is a standalone model that had been adapted from the US NRC FLASH CAT model (NUREG 7010) (Ref. 72), (Ref. 73). Its purpose is to provide a HRR input for use within the MOFIS-Z zone model. The supplied verification document (Ref. 70) showed that the principal equations and data inputs had been taken from NUREG 7010. These equations are well verified and in my view are appropriate for the intended application, thereby satisfying SAPs AV.1 and AV.2.

148. I noted that there are a few indications from the results presented in the validation and verification report (Ref. 70) that additional functionality had been built into the MOFIS-C model. However, it was unclear to me how the additional features interacted with the overall model and how that differed from the verified FLASH CAT model (Ref. 72). This aspect is not fully discussed within the MOFIS-C verification report (Ref. 70). I consider this a minor shortfall in the documented evidence, as it does not wholly satisfy the intent of SAP AV.5, which may be addressed at the detailed design stage as I judge that these differences are not significant.

149. The MOFIS-C validation report provides evidence of benchmarking against several experiments to verify the performance of the model and its ability to predict accurate HRR for cable fires. I am satisfied that the experiments listed by the RP are appropriate and consistent with the source document, NUREG 7010 (Ref. 72) and provide a useful validation source. Additional references were presented including some early PRISME data sets (Ref. 74) that provide up to date experimental work on cable fires.

150. From my assessment sampling I have noted that the RP's experimental comparisons do not always replicate the behaviour observed in the experiment, and that the reasoning behind these variations is not clearly discussed within the supplied documentation. Furthermore, the RP did not provide a direct comparison with the FLASH-CAT model with like for like inputs to demonstrate that the MOFIS-C model conforms to the model that it is based upon. This does not satisfy SAP AV.5 relating to adequacy of documentation

151. I recognise that modelling cable fires is a complex problem. HRR is a key parameter in fire codes to determine fire effects. Therefore, it is important that the RP understands the limitations of its code and recognises where other HRR data sources should be

used. As stated in sub-section 4.4.2 of this report, it is important that the ventilation parameters are appropriately selected and conservatively modelled.

152. My assessment of the code found that the results from the RP's validation and verification work demonstrated that the code had a wide variation in results, in some cases as much as 30% over and under prediction depending on the cable orientation and location. Overall, the RP validation report stated that on average, based on its benchmarking results, MOFIS-C under predicts HRR by 4.4%.

153. In my view the potentially wide variation of HRR, particularly the bias towards underpredictions in the HRR, could lead to cliff edge-type effects. The RP has recognised this by requiring various assumptions to minimise the potential cliff edge effects, which are as follows:

- The plastic mass fraction of cables is set to 1. This principally means that the copper element of the cable is considered combustible. This adds additional fire load to the assessment and results. I consider this a conservative assumption.
- The assessment sets the Char yield to 0. This means that no residual material can remain meaning that all material should be consumed within the fire. I also consider this a conservative assumption.

154. Overall, I judge that the approach adopted by the RP to address the bias of underprediction provides some confidence that the outputs of MOFIS-C are unlikely to provide a significantly underpredicted HRR, principally because the approach adopted artificially increases the fire load and duration. This in my view should enable a HRR to be established that is unlikely to under predict results and I therefore consider that for the purposes of GDA this is an adequate approach. This satisfies SAPs AV.1 and AV.4.

4.3.3.2 MOFIS-Z

155. MOFIS-Z is an in-house implementation of the models that form the basis of the CFAST programme (Ref. 75) . CFAST is a two-zone fire model designed to model multi-compartments fires, simulating the distribution of both smoke and temperature. I have experience of assessing CFAST in a UK context and I consider this as an industry standard application, and I am satisfied that it is adequately validated within its given areas of application. Like CFAST, MOFIS-Z is a multi-room two-zone model.

156. Specific guidance on the aspects to consider in the analysis of fires using zone models is defined in PD ISO/TS 13447:2013 (Ref. 76). The standard highlights the limitations of two-zone models and the importance of ensuring appropriate ventilation regimes and defining the HRR. I have used this standard to inform my assessment.

157. The MOFIS-Z programme is based on rectilinear geometry, but the model has limitations for rooms with severe aspect ratios such as long hallways and tall shafts. I note that MOFIS-Z, like CFAST and FDS have no sub-models for ventilation-controlled HRR/MLR, therefore the HRR inputs need to be established before being used within the application.

158. My assessment of the MOFIS-Z report (Ref. 71) identified that the key assumptions, models, and approximations used in CFAST had been adopted in the MOFIS-Z model. From my assessment it appears that the only variation from the CFAST tool is related to the model used to approximate heat transfer into ceilings. However, from my sampling of the MOFIS-Z validation report (Ref. 71), I was satisfied that there was adequate evidence to demonstrate that the predicted fire behaviours are consistent with specific expected theoretical results within validation ranges. This, in my opinion,

provides some confidence that the models as implemented in MOFIS-Z are behaving as intended, thereby satisfying SAP's AV.1, AV.2 and AV.3.

159. I also sampled some of the benchmarking analysis undertaken by the RP against similar two-zone fire codes (CFAST and the French code MAGIC). The RP compared model results against a total of 20 experiments. The RP results showed that the MOFIS-Z programme behaves consistently with both CFAST and MAGIC. This provided me with further confidence that the various models had been appropriately implemented, thereby satisfying SAP's AV.4 and AV.5.

160. I sampled the RP's findings regarding the uncertainty of the best estimate calculations relating to the MOFIS-Z model's behaviour against known experimental results. The RP plotted a series of bias factors and standard deviations. I noted that these values are different to those presented in the CFAST validation work. This therefore indicates to me that there is some variation between the behaviour of MOFIS-Z compared with CFAST.

161. The RP's MOFIS-Z report (Ref. 71) indicated that, on average, MOFIS-Z over-predicts the hot gas layer temperature by between 5.4% to 22.3% depending on the compartment configuration. In addition, I note that the RP adopted conservative assumptions with respect to the oxygen levels. The value of the lower oxygen limit is set at 0. This means that combustion is modelled as continuing until the oxygen is completely depleted. I note that for most materials such as plastics, fire requires oxygen concentrations of more than 15%-18% to be sustained. Therefore, in my opinion applying this approach provides a conservative assumption.

162. From my sampling of the evidence underpinning the MOFIS-Z, model, I am satisfied that the model provides a usable and conservative result to inform fire analysis work. Due to the potential variations in HRR and ventilation conditions it is my view informed by relevant good practice (Ref. 76) and SAP AV.6, that the RP should ensure that adequate sensitivity analysis is undertaken to understand how changes in these parameters could impact the modelling results. From my assessment of the methodology the importance of this approach is not fully captured and therefore SAP AV.6 is not fully satisfied. I judge this is a minor shortfall, recognising confidence has been gained from some compensatory conservative assumptions.

163. Overall, I am satisfied that the RP has provided sufficient justification that its use of both MOFIS-C and MOFIS-Z for fire analysis is acceptable for the purposes of GDA. This is primarily on the basis that the modelling assumptions and approaches adopted will provide an adequate estimation of the fire effects within a compartment that is within the valid ranges of the models.

4.3.4 Assessment of Reactor Building Fire Safety Case

164. The BRX is divided into two distinct areas, the BRA (internal to the inner containment boundary) and the BRB (annulus between the internal and external containment boundaries). Both areas are divided further into a series of fire safety cells (ZFS). The BRA is predominantly split into three fire safety cells to provide separation of the corresponding three safety trains A, B and C.

165. The BRB annulus is divided into different fire safety cells by fire resistant boards to provide spatial segregation of equipment and systems of each trains. In total there are seven ZFS within the BRX. In addition to the ZFS, there are fire detection measures and a fixed firefighting system.

4.3.4.1 Bounding Cases for Barrier Assessment (Criterion A)

166. The BRX fire analysis report (Ref. 54) identifies two bounding cases that were stated to represent the most significant challenges to divisional barrier claims. These scenarios were:

- IH-IF-BRX-01 - A cable fire with the largest fire load in BRB which can bound other fire scenarios in BRB.
- IH-IF-BRX-02 - A cable fire with the largest fire load in BRA impacting the barrier between different safety trains which can bound other fire scenarios in BRA.

167. Due to the BRX being split into two distinct regions BRA and BRB, I have elected to assess and sample each region individually to determine the adequacy of the RP's bounding case selection.

168. For each of the bounding cases I have assessed the application of the fire methodology and justification of the two bounding cases described above. In sampling these, I have focused on the evidence underpinning the identification and screening process.

169. My review of the fire assessment report (Ref. 54) found that the report did not provide adequate evidence to underpin the bounding cases and the hazard assessment process, resulting in a shortfall against SAPs SC.4, EHA.1 and EHA.6. To address this shortfall and to obtain sufficient evidence that the cases were truly bounding, I selected them as sample areas within RO-UKHPR1000-053. Further details on the background of RO-UKHPR1000-053 can be found in sub-section 4.11 of this report.

170. The RO-UKHPR1000-053 report (Ref. 57) provided detailed information to underpin my areas of concern within the main BRX fire assessment report (Ref. 54). The narrative within RO-UKHPR1000-053 is also supported by detailed room data sheets (Ref. 77) and detailed design drawings (Ref. 78). I therefore used the outputs of the RO-UKHPR1000-053 report and the BRX fire analysis report (Ref. 54) together to inform my assessment.

4.3.4.2 Bounding Cases for Barrier Assessment (Criterion A) – BRA

171. As part of the RO-UKHPR1000-053 work, I sampled five locations for detailed evidence to confirm that the claimed bounding case in the BRA (IH-IF-BRX-02) was fully bounding. The rooms that I selected for sampling were:

- BRA3730ZRM - Set down area and operating floor. The room is located at the +17.5m elevation in the reactor building. The room is under the dome of the containment and was selected as it contains three loops in the same space.
- BRA3104ZRM, BRA3105ZRM and BRA3106ZRM – These three rooms contain the main coolant pumps for the three associated trains and are located at +11.6m. These rooms were selected as the pumps and support systems contain a significant inventory of oil.
- BRA2632ZRM – Located within the annular space and loop 2 of the BRA. It is located at the +6.5m elevation in the Reactor Building. This room was selected as it is connected to the bounding case room BRA2631ZRM.

<u>Sampled Room BRA3730ZRM</u>

172. My assessment of BRA3730ZRM found that the RP's evidence for the screening and hazard identification in this location demonstrated that the cable distribution and total combustible loading would not present a significant fire hazard to challenge the designated fire zones providing segregation of the three individual loops. As a result, I

was satisfied that the fire load could be bounded by IH-IF-BRX-02 for criterion A purposes.

173. However, my review of the layout (Ref. 78) identified that a cable tray was in the locality of one of the main steam lines (VVP1110TY). As the main steam line is a HIC, further analysis was required by the RP to demonstrate that this did not present a significant safety risk. This additional work was reported in the RO-UKHPR1000-053 report (Ref. 57). The report highlighted that, due to the openness of the compartment, the global temperatures within the space could be discounted due to the HGL being well-dispersed and local fire effects would be dominant. Given the arrangement and layout, I judge that these assumptions are appropriate.

174. I sampled the local fire effects assessment (Ref. 57) and noted that the RP adopted a simple fire dynamics approach to determine the radiative heat flux to the pipe and its temperature increase. Despite this being a simplistic approach, I am satisfied for the purposes of GDA that it is acceptable for this scenario.

175. The RP's analysis takes its success criteria from BS EN1993-1-2 2005 (Ref. 79) for the withstand of stainless steel under heat loads. The standard highlights that the metal reaches 50% strength loss (loss of proof strength) at 600ºC and 40% strength loss at 400ºC.

176. It is my view that these success criteria are based on the specific steels detailed in the standard. From my sampling I found that the RP does not clarify the specific steel for the actual component and how this is bounded by the standard. As a result, these generic temperature targets in my opinion do not provide an adequate basis on which to make a judgement. The analysis results indicate that the pipe would be exposed to a fire temperature of approximately 300ºC, which the RP claims to be acceptable. In addition, I have found that the RP's simple assessment has limited sensitivity analysis to show how sensitive the temperature predictions are to changes in various assumptions. This again could impact the predicted temperatures.

177. A key finding from my assessment is that the RP claimed BS EN1993-1-2 (Ref. 79) as the nominal basis for assessment. The main steam lines have been designed to different codes namely the 'prevention of damages in mechanical components' RCC-M codes (Ref. 80). It is my expectation that the analysis undertaken should be in line with the relevant codes against which the components have been designed. The RCC-M codes include provision for an assessment of heat loads and therefore relevant analysis should be undertaken to substantiate the pipework. Furthermore, at present no safety factors have been applied or any sensitivity analysis undertaken to demonstrate that the conclusions drawn are robust.

178. I accept that this analysis has not considered some factors that may reduce the fire load impact, the most relevant of which is the main steam lines' insulation. Given the output of the analysis, I judge it to be unlikely that the fire would cause significant damage to the pipe as the temperatures are below failure criteria which are likely to be applicable, but this needs to be adequately substantiated using appropriate codes and standards. I therefore judge that this is a shortfall against SAPs FA.8, ESS.1, ESS.2, EKP.4 and EKP.5 which I have captured as part of Assessment Finding AF-UKHPR1000-0057.

179. Noting the above, it is important that the RP's safety case demonstrates that the risks from fire to SSCs have been reduced to ALARP. From my assessment of this sample area, I have not been satisfied that the RP has assessed all options to reduce the risks to the main steam lines further, either through implementation of a barrier or simply by moving the cables away from the pipe. This is a shortfall which is also related to Assessment Finding AF-UKHPR1000-0057.

Sampled Rooms BRA3104ZRM, BRA3105ZRM and BRA3106ZRM

180. From my sampling of rooms BRA3104ZRM, BRA3105ZRM and BRA3106ZRM, I was not satisfied that adequate evidence or justification was provided to demonstrate why oil fires in these rooms were bounded by the cable fire in IH-IF-BRX-02. To get further clarity on the RP's hazard analysis and screening approaches, I raised RQ-UKHPR1000-1036 (Ref. 81) and, RQ-UKHPR1000-1341 (Ref. 82). I also selected these areas as sample areas for RO-UKHPR1000-053 (Ref. 57), as I deemed the gap to be potentially significant. This was primarily because the characteristics of an oil fire are significantly and fundamentally different to those of a cable fire. Each of the identified rooms contains a large lubricating oil inventory to serve the reactor coolant pump (RCP) and flywheel. This inventory is split into two oil casings, the upper one contains the largest quantity of oil and the lower contains the remaining oil.

181. In response to my queries, the RP undertook further analysis. With a potential oil pool fire over an area of 29m^2 (the size of the allocated bunded area), it estimated the heat release rate to be over 50000kW, and the resulting temperatures would exceed 800ºC due to flame impingement. The RP's analysis (Ref. 57) concluded that the impact from this fire to the RCP pump casing was deemed significant and therefore the RCP pump could not be substantiated against such a fire load.

182. Further analysis of the oil fire was also conducted by the RP using FDS to determine the impact to the other SSCs and the civil structure forming the compartment. I judge the use of FDS to be appropriate due to the complexity of the analysis. I noted that the RP presented little information on sensitivity studies to determine any cliff edge effects and the only sensitivity study provided by the RP was that of mesh sizes.

183. However, I acknowledge that for large analysis problems such as this, there is a balance between accuracy of results (such as impacts to temperatures & heat fluxes) and simulation run times. Overall, I was satisfied that the RP provided adequate information to underpin its decision on mesh size and due to the methods adopted (taking the largest oil inventory heat flux as the bounding case) the conclusions and approach to the simulation appears reasonable. The results from the analysis indicate that the impacts to the steam generators (53ºC at their surface) and compartment walls (400ºC at their surface) are tolerable and will not result in loss of containment or damage to other SSCs. Based on the FDS approach presented and spatial separation within the compartment, I consider these conclusions plausible. However, this scenario is not presented within the barrier substantiation report (Ref. 83) and should be assessed in line with the appropriate fire loading profile. I consider this a minor shortfall in the documented evidence, as it does not wholly satisfy the intent of SAPs SC.2, EKP.5 and EHA.6, which may be addressed at the detailed design stage.

184. Based on the analysis, the main challenge is to the RCP pump. It is worth recognising that the use of lubricating oil for the RCP cannot be avoided as it provides a safety function for the RCP to prevent the pump seizing, therefore its use cannot be readily eliminated. However, it is my expectation that measures should be identified to mitigate the impact of the fire loads to the RCP pump. In line with this expectation the RP has undertaken design reviews and proposed modifications to address the shortfalls identified. These proposed modifications include:

- the placement of additional metal plates at weak points (welded joints), to prevent leakage.
- An alarm system to detect oil leaks, with an alarm signal sent to the main control room (MCR) should a leakage be detected.
- Additional localised bunding has also been added for the upper oil tank. Should a leak still occur, the additional bunding has sufficient volume to collect all the oil in the upper tank. The proposed new bunding is located at the top of the

RCP assembly and therefore any fire within the bunding would be directed away from the RCP and eliminate the potential for flame impingement.

185. I have sampled the proposed modifications, and, in my view, they appear to address the hazard through mitigation by retaining the oil at source, rather than allowing it to pool in the lower bunding area, and this therefore reduces the risks from the fire hazard. It should also be noted that there are limited ignition sources in the vicinity and a fire suppression system providing additional defence in depth.

186. Overall, I judge that the RP has presented an adequate case for GDA on the management of the oil fire risks in the BRA. The RP has committed to implement the identified modifications at the detailed design stage, and to ensure that this shortfall is addressed, I raise the following Assessment Finding in line with SAPs EHA.5, EHA.17, EKP.4 and EKP.5:

AF-UKHPR1000-0058: The licensee shall, as part of detailed design, demonstrate that risks to SSCs from internal oil fires have been reduced to as low as reasonably practicable. This should include but not be limited to the reactor coolant pumps, the steam generators and the main coolant lines.

Sampled Room BRA2632ZRM

187. I have assessed the additional information for sample area BRA2632ZRM provided in the RP's response to RO-UKHPR1000-053 (Ref. 57), (Ref. 77), (Ref. 78). I have been satisfied that the combustible loading and the RP's accompanying narrative provided sufficient justification that room BRA2632ZRM is adequately bounded by the identified bounding case IH-IF-BRX-02 (BRA2331ZRM). This satisfied my sample query and ONR SAPs EHA.6 and EHA.19.

IH-IF-BRX-02 (Room BRA2631ZRM) – Bounding Case

188. The IH-IF-BRX-02 scenario is the bounding case identified for the BRA in the BRX. The scenario was defined by the RP as a cable fire in BRA2631ZRM that could impact the barrier between different trains. The RP undertook screening for the bounding case using the criterion of the 'largest fire load' in a room. From my review of the data provided, I was satisfied that this location contained the largest quantity of combustible solid material.

189. However, my assessment of the RP's analysis for this scenario identified that the RP only assessed one of the seven cable layers and therefore the heat release rate is only based on a portion of the total inventory. This is the result of the methodology adopted by the RP. The RP stated that because every second cable tray is protected by cable wrappings only one cable would present the fire source. As highlighted in the methodology section, I judge that this is not fully in line with ONR expectations. The basis of this shortfall has been discussed earlier in the methodology (sub-section 4.3.2) and is captured in Assessment Finding AF-UKHPR1000-0057. This shortfall in my view challenges the overall case presented. I therefore sampled this scenario to judge the potential risk to nuclear safety. The scenario is illustrated in figure 2 below.

190. It can be seen in figure 2 that room BRA2631ZRM which is located at level +6.5m of the BRX is adjacent to barrier BRA2607VB. The bounding scenario IH-IF-BRX-02 is concerned with the impact to barrier BRA2614VB (highlighted in yellow) as this forms a divisional boundary.

191. Figure 2 also shows that there is spatial separation between room BRA2631ZRM and BRA2614VB; additionally, the wall BRA2607VB provides shielding from localised heat

effects. In the analysis, the RP assumed that the target barrier BRA2614VB is in the location of BRA2607VB, which the RP deemed a 'Virtual Wall'. No account has been taken in the analysis for the additional wall BRA2607VB.

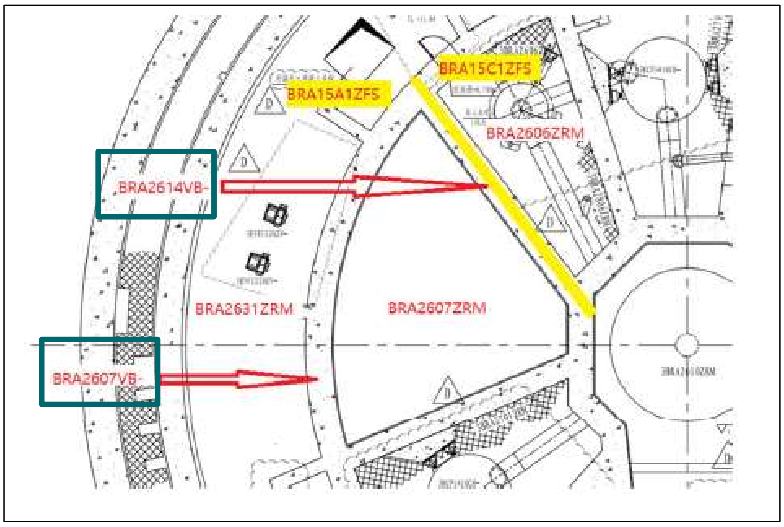

Figure 2: Position of Identified barriers in relation to BRA2631ZRM

192. I note that the SSCs and combustibles in proximity to this room (and for which fire spread may be possible) belong to the same division, therefore, I accept that despite any fire spread within this area, the other two redundant trains should remain unaffected. The RP confirmed (Ref. 57) that there are no HIC in this room or in the other two connecting rooms BRA2632ZRM and BRA2633ZRM located at either side of BRA2631ZRM. Virtual boundaries connect these three rooms and the distance between combustibles in different divisions is stated to be more than 6m for BRA2631ZRM at the closest point (Ref. 57).

193. To provide some additional confidence in the fire zones, the RP undertook a FDS assessment (Ref. 57). Given the size, geometries, and constraints, I was satisfied that FDS is an appropriate tool for this assessment and that it meets expectations in ONR SAPs EHA.6 and AV.1. Noting the curvature of the rooms in this scenario, the RP's analysis simplified the volume as a cuboid. I do not consider this a major issue as I am content that the RP's simplification provides an adequate representation of the volume within which the fire effects are contained, and therefore I do not consider this to significantly impact the RP's analysis results.

194. The RP's modelling adopted a fire power of 1.2MW which I noted was larger than the fire loading originally used by the RP to define the bounding case. This updated fire power was used by the RP to analyse the impact of the fire's heat flux to targets to determine if there was a potential for fire spread. The RP's analysis showed that the targets would be exposed to relatively low heat fluxes, below the ignition criteria, and therefore fire spread was unlikely.

195. I have assessed the RP's modelling results and I am satisfied that the approach provides me with confidence that a fire within BRA2631ZRM would be contained within the designated fire zone and the likelihood of fire spread is low. The RP's FDS analysis results are limited in scope and do not, however, provide compartment temperatures or localised temperatures on the walls with the increased fire powers.

196. Because the bounding case IH-IF-BRX-02 was not based on a full compartment burnout, any additional safety measures to reduce the risks ALARP have not been

identified. Although I consider that the risk to the barrier is low, a shortfall remains against SAPs AV.5, AV.2, FA.1, FA.3, FA.7 and EHA.1 and should be addressed by the licensee through Assessment Finding AF-UKHPR1000-0057.

197. The RP's analysis of the claimed barrier for this scenario is presented in the BRX barrier substantiation report (Ref. 83). The report stated that, based on the design load, barrier BRA2614VB meets the desired 2-hour performance requirement.

198. The RP's barrier substantiation is based on the defined ISO 834 fire performance curve (Ref. 43) and the structural requirements set out in BS EN 1992-1-2:2004 (Ref. 42). The RP stated that in all cases, the concrete barrier is thicker than the standard requirement of 220mm, and the concrete cover of the steel reinforcement is greater than the required 35mm and therefore satisfies the 2-hour standard requirement. I note that the BRX barrier analysis (Ref. 83) stated that the thickness of the claimed barrier was 1.0m. This provides me with some confidence that sufficient margin exists such that any additional analysis undertaken to address the shortfalls is unlikely to result in challenges to the RP's conclusions.

199. Through the additional evidence provided, I have been satisfied that the identified bounding case contains the largest fire load within the BRA. However, I have concluded that the RP did not assess the full impact of the largest fire load, this is because fire protection measures were credited.

200. Although this shortfall presents a challenge to the case, I acknowledge that the RP has demonstrated that the risks from fire can be reduced by implementing suitable fire protection measures (such as cable wraps) and this has been committed to through the RP's safety case. But the significance and importance of these measures (in terms of classification of SSCs and categorisation of safety functions) should be determined based on the unmitigated fire, and I have therefore captured the shortfall in Assessment finding AF-UKHPR1000-0057 as detailed above.

Summary for BRA

201. In summary, and in addition to the above for the BRA, I have sampled several rooms which were claimed by the RP as being bounded by the bounding case. The rooms sampled included locations that contained oil sources. The RP identified that oil fire was not bounded by the bounding case and therefore undertook additional analysis to address this which I have assessed.

202. My assessment also took account of the additional information provided as response to RO-UKHPR1000-053 (Ref. 57). I am satisfied that the additional analysis undertaken by the RP for assessment of the RCP oil fires in the sample area was adequate. The RP proposed, but did not implement, several modifications to reduce the fire risks to the RCP. The modifications in my opinion are feasible and provide an additional layer of defence in depth. I have raised Assessment Finding AF-UKHPR1000-0058 to ensure that the substantiation of these modifications is tracked at detailed design.

203. Overall, I am satisfied that the scenarios assessed within my assessment of the BRA present challenges contained within one division. The plant is based on a three-division layout and as a result I am content that the shortfalls identified do not undermine the principal safety claims of the plant.

4.3.4.3 Bounding Cases for Barrier Assessment (Criterion A) – BRB

204. The following section provides my assessment of the BRB. The RP's fire safety case identified a cable fire in room BRB2601ZRM that impacted the barrier between two different safety trains (scenario IH-IF-BRX-01). This scenario was claimed by the RP to

bound all other fire scenarios within the BRB. The bounding case was selected by the RP based on the area in the BRB that contained the largest fire load.

205. I identified four additional locations in the BRB for my sample, to obtain the evidence to justify how IH-IF-BRX-01 bounded the sample rooms as claimed within the fire analysis report (Ref. 54). The rooms I identified were:

- BRB2101ZRM (+1.2m) – This location was chosen as it contains significant fire loading close to a divisional boundary.
- BRB3012ZRM (+11m) – This location was chosen as it was identified that quantities of cables ran in proximity of two main feedwater pipes.
- BRB3101ZRM (+11m) - Location indicates multiple cable trays next to another feedwater pipe.
- BRB3702ZRM (+17.5m) – Location chosen as cables are located near two main steam line pipes.

Sampled Room BRB2101ZRM

206. I selected room BRB2101ZRM based on the room's fire load and the fact that it is close to a divisional boundary. Unlike the scenario IH-IF-BRX-01 in BRB2601ZRM, there is no encasement of cables. The fire protection board segregating the divisions runs vertically parallel to the cable trays. As a result, the cables sit within a large open area, allowing the hot gas from any fire to disperse within the BRB area. The RP considered ventilation in this region to be such that it would sustain full burnout of the combustibles. I judge this to be an appropriate assumption. The RP's analysis therefore focused on the local effects to the barrier and on radiative heat flux. I am satisfied that this is an acceptable approach.

207. The RP assessed the fire effects of the cable located closest to the barrier. It should be noted that within the BRB, the barriers are described as fire-resistant boards, and I note than no specific design or manufacturer had been provided.

208. The RP stated that the distance between the cable tray and the board is 2m. The RP calculated the thermal radiation using the methods defined in NUREG 1805 (Ref. 84). I recognise that this is a standard approach which is appropriate for this application.

209. The temperature at the fire-resistant board as calculated by the RP was approximately 293°C. The RP claimed that the fire-resistant boards provide a 2-hour fire resistance against the ISO 834 performance curve (Ref. 43). I am satisfied based on this temperature that the safety functional requirements for the fire board are adequate, however no fire durations are provided, thus if the fire could extend beyond the 2-hour duration the barriers currently in place would not be adequate. This is a minor shortfall against SAPs EKP.4, EKP.5, ECS.1 and ECS.2 which I consider can be addressed through justification or design choices at detailed design.

Sampled Rooms BRB3102ZRM and BRB3101ZRM

210. Both sample areas BRB3102ZRM and BRB3101ZRM are located on the same elevation and both locations contain cables and the main feed water pipes. In both scenarios the RP demonstrated that the cables are located above the feedwater pipes (Ref. 78). Because the two scenarios are similar, I assessed them together, and I selected BRB3102ZRM as the bounding case because the cables are in closer proximity to the feed water pipe than within BRB3102ZRM.

211. The safety case (Ref. 57) states that the main feedwater pipes are encased within a mechanical penetration that transits through the BRB into the safeguards building,

therefore the impact of the fire to both the pipework and the mechanical penetrations should be considered.

212. I noted that the cables are not located directly below the pipes and therefore the RP took the decision to only consider thermal radiation from the cables adjacent to the pipes. The RP's safety case also highlighted that the cables are encased within a steel casing. However, for the purposes of this assessment the steel casing covering the cables were not accounted for. I judge that these are reasonable judgements and do not undermine the intent of the analysis. As described in the previous sections, the RP adopted the same approach using NUREG 1805 (Ref. 84) to calculate the radiative heat flux, but for this case the RP has also undertaken additional modelling using FDS.

213. In reviewing the input parameters within the RO-UKHPR1000-053 report (Ref. 57), I observed that the two methods (analytical following NUREG 1805 vs. CFD using FDS) resulted in differing estimates for thermal radiation values to which the main feed water pipes (ARE) could be exposed. The report did not provide details on the failure criteria for the pipe, the penetration and associated welds, the safety margins or potential mitigation measures. I raised these with the RP within RQ-UKHPR1000-1723 (Ref. 85). The RPs response to RQ-UKHPR1000-1723 provided the following clarification:

- The ARE pipes are double-walled (inner and outer coaxial pipes) with a layer of insulation in the interspace.
- A conservative failure criterion of 400°C is assumed for the ARE pipe on either the inner or outer pipe elements. This equates to a reduction in steel strength of 30% with the ARE pipe (based on thermal degradation for stainless steel in BS EN1993-1-2) which is assumed to have a utilisation factor of less than 0.7.
- The predicted temperatures are based on a 10kW/m^2 average received flux, equivalent to a 383°C encompassing fire using the Stefan-Boltzmann equation and considering a steady state (energy balance) condition on the pipe.
- The mechanical property of welds within the pipe is required to be not less than the mechanical property of parent metal, according to the design codes and relevant welding material specifications.
- The ARE pipes carry water at 228°C and a velocity of 6m/s. The heat capacity of the flowing water is not considered in the analysis but would provide considerable cooling against the effects of fire to the inner pipe.

214. Given the above information, I am satisfied that the cables are in favourable positions above the main feed water lines and the impact of fire is likely to be low. This is principally because the pipes will not be exposed to direct flame impingement and are insulated. I also recognise that the pipework is designed to operate at high temperatures and has a continual water flow, therefore the pipe should not significantly heat up.

215. However, I noted that the RP has claimed BS EN1993-1-2 as the nominal basis for its assessment. My assessment identified that the main feedwater pipes are designed to different codes, namely the prevention of damages in mechanical components RCC-M codes (Ref. 80). It is my opinion that the analysis undertaken should be in line with the code against which the component has been designed and the RCC-M codes indeed provide for assessment against heat loads. Therefore, I consider that the RP should have undertaken analysis with the code used to substantiate the pipe work. Furthermore, the RP has so far not applied safety factors or undertaken sensitivity analysis to demonstrate that the conclusions are robust. This does not satisfy SAPs ECS.3 and SC.5. I have already captured this shortfall in Assessment Finding AF-UKHPR1000-0057 which also applies here.

216. Furthermore, I have found no evidence of the RP's optioneering to reduce the risks further by, for example, providing additional barriers to further segregate the pipework from cables, or looking for alternative cable routing options. Therefore, this does not

satisfy SAPs EKP.3. It is my understanding that the detailed layout of cables had not been finalised for the generic UK HPR1000 design and is out of scope of GDA as confirmed in RQ-UKHPR1000-0785 (Ref. 86). However, RQ-UKHPR1000-0785 highlighted that cable planning will be undertaken in accordance with the nuclear island cable routing guidelines (Ref. 87). I have assessed these guidelines and found that they highlight the requirement for cable placement to account for internal and external hazards. I am satisfied that further review will be undertaken by the licensee as part of normal business at detailed design, and this should offer choices for cable routes that reduce risks.

217. Given the evidence reviewed, I judge that it is unlikely that the fire scenario presents a significant risk to the current plant layout. However, it does warrant further assessment at detailed design in line with SAP's EHA.1, EHA.5, and EHA.6 and this is captured as part of AF-UKHPR1000-0057.

Sampled Room BRB3702ZRM

218. I sampled location BRB3702ZRM (Ref. 52) as this is an area which contains large quantities of cables near the main steam lines. The scenario is very similar to the main feedwater scenario discussed above. However, a significant difference is that the cable trays are directly below the main steam line pipes (VPP); these pipes would therefore sit within the fire plume and be exposed to greater temperatures.

219. To analyse this scenario, the RP adopted a two-stage approach. The first stage was to adopt FDS to define the heat flux from the cable fire. This result was then used in a computational fluid dynamics (CFD) model, using Star-CCM+, to determine the pipe temperatures. I am satisfied that the analysis methods adopted by the RP combining the outputs of the FDS model and the CFD tool to predict the degree of heating of a component/target is an adequate approach.

220. Due to the complexities of modelling this fire scenario, I raised RQ-UKHPR1000-1723 (Ref. 85) to gain an understanding of the user choices for defining the heat flux, as the approach taken should account for the non-uniformity of the convective heat transfer from the plume. This is likely to be important in a scenario where the target sits above the fire source.

221. I assessed the RP's response to RQ-UKHPR1000-1723 (Ref. 85). I was satisfied that the response provided adequate justification of its approach for the determination of the heat flux, arguing that it provided a balance between the various options that can be used in the model. I was also satisfied that the RP provided suitable arguments regarding the peak values calculated and the adoption of the average value for the effects on the VPP pipes. Utilising the results from the FDS model, the RP undertook CFD modelling based on the geometry and construction of the VPP pipes. However, I note that the explicit details on the material properties used in the analysis were not presented, nor how they compare to the actual pipe.

222. The RP's CFD modelling results indicated that the outer wall of the pipe reached 355ºC after 2 hours, and that it reached 375ºC after 3 hours. I note that there are non-insulated sections in the design of the penetration, and that they have not been assessed within the modelling. I raised this in RQ-UKHPR1000-1723 and the RP responded qualitatively, claiming that the sections would transfer the heat away. In my view such claims have not been fully substantiated.

223. The RP's success criteria for pipe integrity uses the same basic criteria as those in the previous ARE pipe assessment, namely the application of BS EN1993-1-2 and the 400ºC target. As a result, I make the same observation, i.e. the need to ensure that the pipes are assessed against the relevant design standard which is, as for the ARE pipes, the RCC-M code.

224. The conclusions of the analysis using the CFD modelling indicated that the temperature increase of the main steam line (VVP) is sufficiently low that the steam line integrity can be assured when compared to the generic assessment criteria defined in BS EN1993-1-2.

225. Also, as in the previous cases, I note that the RP has not provided an adequate assessment of options to reduce or eliminate the risk from cable fires further, such as putting additional barriers in place or moving the cable. As the main steam lines are HIC, they also fall within the scope of RO-UKHPR1000-046 (Ref. 88) requiring demonstration that the risks of hazards to the HIC are ALARP. Sub-section 4.12.5 provides the findings of RO-UKHPR1000-046. However, for this case, the principal findings have been presented here as it was part of the RO-UKHPR1000-053 sample area. I have reviewed the findings from the associated RO-UKHPR1000-046 reports (Ref. 89), (Ref. 88) and I am satisfied that the reports confirm the conclusions that the fire loads on the pipe will not result in loss of steam line integrity. Therefore, I am content that a consistent case has been presented and satisfies SAP EHA.1, EHA.3 and EHA.6.

226. Based on the arguments, approach, and analysis results, I am satisfied that sufficient evidence has been presented to demonstrate the main steam line is likely to maintain its integrity. However, I judge that this needs to be adequately substantiated in accordance with the appropriate codes and standards at detailed design. I therefore highlight this as a safety case gap in line with SAP ECS.3, and Assessment finding AF-UKHPR1000-0057 applies here also.

Bounding Case IH-IF-BRX-01 (Room BRB2601ZRM)

227. The bounding case IH-IF-BRX-01 was identified by the RP in the BRX fire analysis report (Ref. 54) as the scenario where the largest fire load (in location BRB2601ZRM) sits next to a divisional fire barrier. In this instance the fire barrier is defined as a ‘fire board’.

228. My assessment of the bounding case identified that the approach and methods adopted by the RP did not appear appropriate for the scenario. The methods adopted did not account for the complexity of the scenario, and in my view would not provide adequate analysis results which is a shortfall against SAP AV.2. To obtain further clarity on the justification of the methods adopted I raised RQ-UKHPR1000-1036 (Ref. 81). In response to my query, the RP recognised that the initial approach and analysis methods were not adequate for the scenario. Therefore, I requested further analysis to be undertaken by the RP as part of RO-UKHPR1000-053 (Ref. 57) for this scenario.

229. The additional analysis undertaken by the RP as part of RO-UKHPR1000-053 confirmed that the temperatures at the board were higher than calculated by hand calculations presented in the fire analysis report (Ref. 54). I also noted that the full fire duration exceeded the standard rating of 120 min. However, the CFD simulations only assessed the temperatures up to the 2-hour period. In my opinion this leaves a gap in the substantiation of the fire board. Furthermore, I noted that the fire load in room BRB2601ZRM is stated to be 174,488 MJ in the fire analysis report (Ref. 54). This fire load quantity was used as the principal screening criteria that identified it as the ‘bounding’ case selection. However, the integral heat release from the FDS input implies that the actual fire load used in the analysis was 27,500 MJ. This is only about 1/6th of the available fire load.

230. I have already discussed in the previous sections that the RP did not consider full compartment burnout in the barrier assessment due to the RP’s analysis crediting fire safety measures. I raised this issue in RQ-UKHPR1000-1723 (Ref. 85). In response, the RP stated its intent to use a fire-resistant board with a higher fire rating than

120min. However, a final solution had not been presented. In this instance I judge that there is a gap in the demonstration that the divisional barrier provides the appropriate withstand, and this does not satisfy SAPs EKP.4, EKP.5, EKP.3 and EHA.3. This shortfall is addressed through Assessment Finding AF-UKHPR1000-0057, with the expectation that the licensee will demonstrate that the barriers are adequate to meet the performance requirements.

Summary for BRB

231. In summary my assessment of the sample areas in the BRB, and of the adequacy of the bounding cases as described above, has identified several shortfalls in the RP's approach in defining bounding cases.

232. For the actual assessment of the bounding case IH-IF-BRX-02, insufficient evidence has been provided in the safety case to substantiate the 2-hour claim on the barrier. This presents a gap in the safety case that I expect to be addressed by the licensee at detailed design.

233. Given the approach taken by the RP, I am satisfied that suitable measures can be implemented, however the analysis needs to provide a conservative basis to inform the required engineering measures. This is a shortfall against SAPs FA.1, EHA.1 and EHA.19 and is captured within Assessment Finding AF-UKHPR1000-0057.

4.3.4.4 Exception to Segregation (Criterion B)

234. Criterion B internal fires have the potential to affect more than one train of SSCs important to safety. Exceptions to segregation areas are identified in the 'List of Segregation Areas and Exception to Segregation Areas' report (Ref. 29) which provides the locations for detailed assessment.

235. The RP has undertaken review of these areas and identified 11 cases for analysis in its fire analysis report (Ref. 54). For each of these cases the RP undertook functional analysis to determine if a common mode failure of the identified systems is acceptable. The basis of the RP's analysis is to assume conservatively that both systems are lost. The results of the RP's functional analysis indicated that for 9 of the scenarios identified, there were sufficient redundant systems that resulted in no impact to nuclear safety. The remaining two scenarios required further analysis; these scenarios were:

- IH-IF-BRX-08 – This scenario relates to room BRA2633ZRM that contains multiple trains of the pressurisers pressure and level measurement sensors. A fire in this room could impact all the safety systems.
- IH-IF-BRX-13 - This scenario relates to a fire in room BRA2631ZRM that could impact the various SSCs, and cables located in BRA2632ZRM and BRZ2633ZRM.

236. I therefore focused my sample assessment on these two bounding cases.

Bounding Case IH-IF-BRX-08

237. My assessment of the analysis presented in the BRX fire assessment report (Ref. 54) for IH-IF-BRX-08 identified that the analysis for the PZR level measurement sensors had been omitted from the report, even though they were identified as a target as well as the pressure sensors. I raised this finding in RQ1581 (Ref. 90) to obtain clarity on the assessment of these sensors. The RPs response to the RQ (Ref. 90) provided additional functional analysis to demonstrate that the loss of all four of the level instrument systems was acceptable and would not impact nuclear safety. Based on the RP's response (Ref. 90) I was satisfied that this was acceptable.

238. For the pressure measurement sensors, the RPs functional analysis (Ref. 54) stated that the loss of all four was not acceptable. The RP’s fire analysis determined a radiative heat flux to assess impact to the sensors. The calculation showed that two of the four pressure measurement sensors would fail based on a generic damage criterion of 3kW/m^2 used for ‘sensitive electronics’ in NUREG/CR-6850 (Ref. 91). The other two sensors were found to be located far enough away from the heat source that the 3 kW/m^2 criteria were not met and therefore adequate number of sensors remained.

239. I reviewed the quoted guidance and noted that NUREG/CR-6850 highlights an additional 65ºC damage criterion in addition to the 3kW/m^2. The guidance issues a caution in using these criteria and says that they should not be taken as an absolute, only as a guide. The guidance also states that it is unlikely no damage would occur to sensitive electronic equipment when exposed to such elevated temperatures.

240. Through my review of the layout, I identified that the room BRA2633ZRM was located next to BRA2631ZRM which was the bounding case IH-IF-BRX-02. Through my assessment I found that the calculated hot gas layer in this area was estimated to be 83ºC. I also note that in the analysis for IH-IF-BRX-02 the same hot gas layer temperature as in BRA2631ZRM is assumed in room BRA2633ZRM (where the 4 PZR level measurement sensors of IH-IF-BRX-08 are to be installed).

241. I have considered the guidance quoted by the RP and the detailed analysis undertaken for IH-IF-BRX-02, and I am satisfied that it is likely that the 65ºC damage criterion would be exceeded if a fire was to occur in room BRA2631ZRM, and therefore is likely to lead to failure of the PZR measurement sensors. Therefore, the impact of this room to this area cannot be discounted.

242. I raised this observation in RQ-UKHPR1000-1581 (Ref. 90). In response the RP increased the damage criteria of the pressure sensors from ‘sensitive electronics’ to ‘thermoset cables’, for which the failure criteria of 330ºC (temperature) and 11 kW/m^2 (heat flux) are used in NUREG/CR-6850. Using these increased failure criteria, the RP concludes that a failure of the sensors will not occur.

243. It is ONRs expectation that the safety case should demonstrate that SSCs important to safety are adequately substantiated for its functionality under hazard conditions. Based on the evidence provided, I have not been satisfied that the RP has sufficiently demonstrated that the pressuriser measurement sensors would be functional under the postulated fire loads. Noting the shortfalls identified in IH-IF-BRX-02, the RP should review the current layout of the sensors to ensure functionality is not lost and provide robust justification to substantiate this. I have therefore raised the following Assessment Finding against SAP ELO.4 and EKP.3:

> AF-UKHPR1000-0059: The licensee shall, as part of detailed design, demonstrate that risks from internal fire hazards to the pressuriser sensors have been reduced to as low as reasonably practicable.

Bounding Case IH-IF-BRX-13

244. This bounding case scenario is based on the potential of a fire in BRA2631ZRM spreading hot gas to the two adjacent rooms BRA2632ZRM and BRA2633ZRM. The RP stated (Ref. 54) that in this scenario there is a potential common mode initiator where the fire from BRA2631ZRM (IH-IF-BRX-02) may impact SSCs such as sensors and cables within BRA2632ZRM and BRA2633ZRM.

245. In this instance the RP-calculated hot gas layer of 83ºC was acknowledged. Based on this temperature the RP accepted that there was a common mode failure of sensors

(Ref. 54), and stated it had undertaken optioneering to address this risk. The RP had captured this gap within its safety case, and it is detailed within its ALARP report (Ref. 33).

246. The hazard schedule (Ref. 92) highlighted that the safety measures implemented by the RP to protect the sensors are a combination of fire board and cable wrapping. However, it is unclear how these measures are to be applied to avoid common mode failure. From my assessment I noted that both the fire assessment report (Ref. 54) and the ALARP report (Ref. 33) imply that these modifications have been completed, however no details are provided by the RP to substantiate this.

247. It is my view that this lack of clarity regarding the safety measures and safety case consistency presents shortfalls against SAPs EHA.5, EHA.6, EHA.7 and SC.4. The shortfalls here have also been captured as part of Assessment Finding AF-UKHPR1000-0057. Therefore, at detailed design I expect the licensee to consider the layout and implementation of appropriate safety measures to demonstrate that the risks from fire in this area, and the adjoining areas are ALARP.

248. Overall, from my assessment of exception to segregation areas (criterion B), I have not been satisfied that the RP has provided a fully substantiated case for the two sample areas. This therefore places a risk of common cause failure to several important sensors, as described within its case. I acknowledge that the RP has implied that a combination of fire safety measures can be implemented, which I consider reasonable, and these need to be implemented at the detailed design stage. To ensure these improvements are tracked I have raised Assessment Findings AF-UKHPR1000-0057 and AF-UKHPR1000-0059.

4.3.4.5 HIC (Criterion C)

249. BRX fire assessment report (Ref. 54) highlighted only two fire cases that could impact HIC. However, following my detailed sampling as part of RO-UKHPR1000-053 I had identified three further examples that could impact HIC. I have discussed these in detail within the previous sections.

250. The two scenarios that the RP identified in the BRX fire report were:

- IH-IF-BRX-14 – This scenario relates to a cable fire located at the bottom of the pressuriser (PZR).
- IH-IF-BRX-15 - This scenario relates to a cable fire located at the top of the RPV.

251. I have sampled both cases as part of my assessment. I assessed the approach taken to determine the hazard loads to the components. For both scenarios, the RP's analysis consisted of radiation transfer calculations from the cable fires to the targets. Unlike IH-IF-BRX-15, where the cables are above the target, the case of IH-IF-BRX-14 in my view presents the most challenging case as the HIC is above the cable and potentially within the fire plume. I note that the RP calculated a HRR for the cable fire of 75kW which was then used as the basis for assessment. The RP interpreted the results as posing no risk for the PZR or RPV based on the calculated low heat fluxes.

252. I judge these initial conclusions to be plausible based on the low heat fluxes. I also consider the fact that the components are insulated, and that water/steam inside the components would provide some heat absorption, as additional factors that provide further confidence in the conclusion that the integrity of the PZR would be maintained. However, substantiation of the component is not provided by the RP. I am also unclear if the total fire load inventory has been used in the analysis. I judge that 75kW is a small HRR, which would indicate that protection measures, such as cable wrapping may have been credited to reduce the load, as per other scenarios assessed.

253. I have captured these shortfalls in Assessment Finding AF-UKHPR1000-0057. It is my expectation that at detailed design the licensee should provide clarity on the derivation of the HRR-curves, application of sensitivity analysis, and demonstration of safety margins for the pressuriser component as part of the work to satisfy the Assessment Finding.

254. In summary I have found that the RP has provided limited information on the analysis of fire against the HIC within the BRX. It is my expectation that the RP should ensure that all fire hazards are identified in the rooms where HIC are located. For the scenarios sampled, I have judged that based on the RP’s safety case there are no significant risks from fire. However, to ensure that this is justified I have included it in an Assessment Finding to ensure appropriate attention is provided at detailed design.

4.3.5 Assessment of the Fuel Building Fire Safety Case

255. The fuel building (BFX) fire safety case (Ref. 93) details how the BFX is divided into three independent divisions, corresponding to trains A, B and C to ensure the physical segregation of the safety systems arranged within this building. This is achieved through various internal walls throughout the building that form the claimed barriers. The fuel building is split into five fire safety compartments. These compartments are illustrated in the BFX fire zone drawings (Ref. 94) and can be summarised as:

- Fire compartment BFX10A1SFS covers levels -9.60m to +26.00m (the BFX roof), which mainly contains safety systems related to safety train A. This compartment contains heat exchangers of the fuel pool cooling and treatment system PTR[FPCTS], spent fuel pool (SFP) area, fuel loading and lifting area.
- Fire compartment BFX10B1SFS covers train B systems, including the train B PTR [FPCTS] heat exchanger, train B purification pump, skimming pump and train B HVAC shaft B from level -9.60m to level +18.30m. It also contains the containment filtration and exhaust system EUF [CFES] and Plant Radiation Monitoring System (KRT [PRMS]) equipment room from level +22.50m to level +26.00m.
- Fire compartment BFX10C1SFS contains a pipe room at level -9.60m, train C PTR [FPCTS] cooling pump, train C PTR [FPCTS] heat exchanger, steam generator blowdown system APG[SGBS] heat exchanger room and reserved room at level +4.50m.
- Fire compartment BFX24A1SFS contains the equipment room of Fuel Building Controlled Area Ventilation System (DWL [SBCAVS]), Annulus Ventilation System (EDE [AVS]) and Containment Sweeping and Blowdown Ventilation System (EBA [CSBVS]) from level +4.50m to level +13.70m.
- Fire compartment BFX29C1SFS contains the pipe rooms from level +9.10m to level +13.70m.

4.3.5.1 Bounding Cases for Barrier Assessment (Criterion A)

256. The fire report (Ref. 93) outlines the approach adopted by the RP to identify the bounding cases for criterion A. The fire safety case details the identification and selection of bounding fire scenarios based on both fire load density and ventilation conditions. With regards to ventilation, the RP has applied two ventilation scenarios (with and without ventilation).

257. The two bounding cases identified by the RP for criterion A were:

- IH-IF-BFX-01 in room BFX1550ZRM has the largest fire load density impacting the narrowest divisional barrier of 0.4 m being analysed under the ventilation condition ‘without ventilation’ and a ‘single failure’ scenario with ‘open door’.

- IH-IF-BFX-02 in room BFX2406ZRM has the largest fire load density with the narrowest divisional barrier of 0.4m being analysed under the condition ‘with ventilation’ considering mechanical ventilation.

258. Scenario IH-IF-BFX-01 relates to a cable shaft (BFX1550ZRM) located at level -4.90m of the BFX within the fire zone BFX10B1SFS. The cable shaft has an access door which is claimed as a fire-resistant door and therefore assumed to be closed during the fire. The RP stated that there are no other openings to the room and therefore the room is considered as being ‘without ventilation’.

259. The fire report states that the room consists of six vertical cable trays. The RP presented two assessments for this scenario, the first assuming no ventilation (door closed) and the second for sensitivity purposes with ventilation (in the case that the fire door to the compartment is assumed open). In both instances the RP assessed the impact to the barrier (the shaft walls), which are claimed class 1 barriers with a claimed 2-hour fire rating as defined within the hazard schedule within the BFX fire report (Ref. 93).

260. I have assessed the IH-IF-BFX-01 scenario and identified the following shortfalls, which are representative of shortfalls detailed in the previous BRX section. These shortfalls were:

- For ‘no ventilation’ scenarios, leakages through openings, such as through the door, have not been discussed. Airflow through such routes would provide a supply of oxygen and therefore the assumed heat release rate (HRR) may not be fully representative.
- If the room is deemed fully sealed, pressurisation of the compartment should be assessed, as this could damage SSCs such as the fire door seals. However, I judge this to be a minor issue given the actual height of the cable shaft.
- The HRRs to underpin the fire modelling were not provided in the BFX fire report.
- There is no specific claim on the fire door within the safety case or summarised in the hazard schedule.

261. I raised RQ-UKHPR1000-1336 (Ref. 95) to obtain clarity on the RP’s HRR curves used to underpin the modelling, particularly for the open-door scenario as I judge this scenario to be the bounding case. This is because an increased oxygen supply will be provided enabling a steady state phase to be sustained.

262. In response to RQ-UKHPR1000-1336 (Ref. 95), the RP provided its HRR curve for both ventilated and non-ventilated conditions. My assessment of the HRR-curve profiles against the reported time-temperature curves identified that the curves did not clearly align with one another, as the steady state phases and decay points did not coincide with the provided HRR curve.

263. Furthermore, I found that the area under the HRR curve shows that the fire had been based on a total fire load inventory of approximately 16920 MJ. The response to RQ-UKHPR1000-1336 stated that the RP’s analysis had considered all combustible materials in the location. I therefore checked the BFX fire assessment report (Ref. 93), which confirmed that the total fire load in the room is 32194.8 MJ. Therefore, it appears that only half the fire load had been considered in this assessment. I had not identified any claims on cable wrapping within the fire report, therefore it is unclear why only a fraction of the fire load was assumed. This does not satisfy my expectations (Ref. 7), as previously raised in sub-section 4.3.4.2 of this assessment report.

264. The details of the cable shaft (BFX1550ZRM) presented in the fire report stated that the room area is approximately 4.8m^2, containing cable tray lengths of 4.10m. In the RQ-UKHPR1000-1336 response, the RP clarified that the cable shaft is considered at

its full height, 32.1m, for the analysis modelling. It is my opinion that caution needs to be taken in using these modelling results. This is because zone models are sensitive to ‘extreme’ aspect ratios, such as those in long thin compartments. Based on the information provided, the aspect ratio of the given shaft is unlikely to be within the valid range for the RPs Zone model (Ref. 96) or aligned with guidance in PD ISO/TS 13447:2013 (Ref. 76).

265. Scenario IH-IF-BFX-02, relates to a cable room (BFX2406ZRM) located next to the thinnest divisional barrier. The RPs safety case (Ref. 55), highlighted that the room is comprised of multiple horizontal and vertical cable trays.

266. My assessment of IH-IF-BFX-02 found similar observations as for scenario IH-IF-BFX-01 as detailed above, and I captured these areas for clarification in RQ-UKHPR1000-1336 (Ref. 95). The RP in response to RQ-UKHPR1000-1336 (Ref. 95) provided the HRR curve. Again, I found that the HRR curve and the calculated time temperature curve did not adequately match. In this instance I found that the time-temperature curve peak temperature was reached at approximately 1500s, whereas the peak HRR was reached at 5000s; the justification or reasoning behind this inconsistent behaviour was not clear. Furthermore, the ventilation rates quoted in RQ-UKHPR1000-1336 did not seem to match the air ventilation requirements for the defined HRR.

267. In summary, I am not satisfied that the modelling claims for fire loads on the barriers for bounding cases IH-IF-BFX-01 and IH-IF-BFX-02 are adequately substantiated and in my view reassessment of these scenarios should be undertaken. However, the shafts are claimed as a class 1 barrier and I am satisfied that the shaft walls are adequate to provide the 2-hour safety claim. This is because the RP had substantiated the walls to meet the 2-hour requirement within the BFX barrier substantiation report (Ref. 97). This in my view provides a reasonable basis to judge that the risk from fire is low. As there is further work required to clarify the analysis undertaken to underpin this judgement and to meet SAPs AV.2, AV.3, AV.4 and AV.6, I have included these matters in Assessment Finding AF-UKHPR1000-0057.

268. In addition to divisional barriers, I decided to sample the RP’s safety case further to determine if sufficient analysis had been undertaken on non-barrier structural elements other than those that provide divisional segregation functions, and which are load bearing structural elements within the building. I found that the RP’s analysis report (Ref. 93)did not provide sufficient evidence to demonstrate that adequate analysis of such non-barrier elements had been undertaken.

269. I consequently raised RO-UKHPR1000-054 (Ref. 98) to gain confidence that the hazard loads on the non-barrier structural elements were appropriately bounded by the loads identified for the civil barriers. The sample areas chosen for RO-UKHPR1000-054 were the three floors below the spent fuel pool in the BFX. I selected to sample compartments and required further evidence (Ref. 58) to underpin the identification and data collection for each internal hazard within the sample area.

270. To ensure a conservative approach was adopted, I agreed in conjunction with the ONR civil engineering team that a series of de-coupled loads for each internal hazard would be selected and the RP should demonstrate the withstand of the non-barrier walls to them. The de-coupled loads are the loads to be used for civil engineering analysis that are sufficiently conservative to bound all other relevant internal hazard loads. The de-coupled load approach is described further in the ONR Civil Engineering report (Ref. 49).

271. For fire, the conservative de-coupled load was based on the ISO 834 time-temperature curve for two hours, with the objective of having a compartment temperature of less than 200ºC after the two-hour period. I judge this to be an adequate basis against

which to assess the structural elements, and this is in line with the requirements set for the divisional barriers.

272. The RP applied a screening approach based on fire load density to determine the compartments below the SFP that had the most significant fire load density. I judge this to be a reasonable screening approach as it factors in the quantity of combustibles and the size of compartment. The RP considered the type of combustibles to ensure rapid fire growth materials are accounted for that may not be bounded by the standard ISO 834 curve. Based on these screening criteria the RP identified the following compartments as the bounding cases:

- BFX1004ZRM and BFX1024ZRM is an L-shaped corridor located at level -9.60m in the BFX. The corridor sits within fire compartment BFX1002SFI and contains a large quantity of horizontal cable trays. This room has the largest fire load density.
- BFX1555ZRM is an RCV pump room at level -4.90m in the BFX. It is noted that this room is designated as an individual fire compartment BFX1502SFI. This room contains both cables and lubricating oil.

273. For the sampled areas BFX1004ZRM and BFX1024ZRM, the RP undertook a global fire assessment to determine the compartment temperatures following a cable fire. The RO-UKHPR1000-054 report (Ref. 58), contained the HRR curves and the time-temperature curves. Review of these curves indicates alignment and are shown to be bounded by the ISO 834 curve.

274. The RP provided two HRR curves, one for each of the two main cable trays, which provide a total fire power of 1300kW for the steady state period for eight hours. My assessment of the combustible loads in the BFX fire report (Ref. 93) for these rooms, found that the total fire load in these rooms sum up to 66423MJ. Taking the average total fire power of 1.3MJ, it is my estimation that the fire duration would be approximately 14 hours instead of the eight hours presented. Therefore, it seems that the RP did not apply the full combustible inventory in the case. Furthermore, I judge that clarification is required to justify the ventilation conditions, as the claimed sustainable HRR does not fully align with the HRR defined in the analysis.

275. I have also assessed the RP's analysis for BFX1555ZRM. The RP's case stated that the fire load in this room consists of a stack of three cable trays and 19 litres of lubricating oil which is contained within the pump.

276. The compartment temperatures calculated by the RP showed a sharp peak above the ISO 834 curve. This peak in my view represents the contribution and burning from the oil inventory. This is to be expected as the standard ISO 834 curve applied for the substantiation is not bounding of oil fires. However, it is my view that due to the small quantities of oil this fire hazard is not dominant. As in all the cases detailed above, I have found inconsistences with the claimed fire loads and heat release rates and the fire time temperature curves. My assessment of the fire in BFX1555ZRM is no exception, as it appears that not all the stated combustible inventory has been consumed.

277. In summary, I am content that applying the de-coupled fire loads are in line with ISO 834 and are an adequate basis to assess the non-barrier structural elements. However, for the sample areas I judge that the shortfalls identified need to be addressed as part of the detailed design to ensure adequate safety measures are identified to reduce fire effects, limit fire spread and ensure the fire is bounded by the ISO curve against which the compartment is substantiated. This does not satisfy SAPs EHA.6, FA.7 and ECS.3. These shortfalls are already captured as part of Assessment Finding AF-UKHPR1000-0057.

4.3.5.2 Exception to Segregation (Criterion B)

278. For exception to segregation areas within the BFX, the RP identified two scenarios. These scenarios are:

- IH-IF-BFX-03 – Fire in room BFX2096ZRM. This room contains pipes that connect to Train A and Train C PTR heat exchangers.
- IH-IF-BFX-04 – Fire in room BFX2419ZRM. This room contains multiple sensors for the level measurement (16.2m) for the Spent fuel pond (SFP).

279. For scenario IH-IF-BFX-03, the RP safety case presented a functional analysis assessment to determine the significance of the loss of both heat exchangers in delivering the required nuclear safety functions. The conclusions of the RP's analysis found that the loss of both trains of the heat exchangers would not be acceptable. This is because in shutdown the SFP requires two heat exchangers and, in normal operation, although only one train is required, no redundant trains would remain when the single failure criterion is considered. Therefore, the RP undertook analysis to determine the impact of fires to the heat exchangers.

280. The RP's safety case highlighted that the principal fire loads within room BFX2096ZRM are because of cable trays. As in the previous section, I noted through my sampling that the HRR curves used for the modelling analysis had not been provided to underpin conclusions within the fire analysis report (Ref. 55). I also found that the narrative justifying assumptions used in the analysis lacked overall clarity. I therefore raised RQ-UKHPR1000-1582 (Ref. 99) and RQ-UKHPR1000-1336 (Ref. 95) to obtain additional evidence to address the gaps I identified.

281. The RP response to the RQs provided additional narrative on its analysis including provision of the HRR curves (Ref. 95) and (Ref. 99). However, my assessment of the HRR curves found they did not adequately align with the time-temperature profiles provided in the fire report (Ref. 93). I also observed that the time/temperature peaks and general fire behaviour had inconsistencies.

282. It is my view that the evidence provided by the RP does not fully satisfy ONR expectations defined in SAPs AV.2, AV.3, AV.4 and AV.6 relating to the use of data, modelling, and documentation. Although the RP claimed that the fire would not impact the heat exchanger, the conclusions from the RP's analysis should be readdressed to ensure adequate safety measures are implemented to protect the two safety trains against a conservative fire loading. I have raised similar findings from my other sample areas in Assessment Finding AF-UKHPR1000-0057. It is my view that at detailed design the licensee through layout and design choices can reduce the fire risks, however this needs to be informed by improved analysis as per Assessment Finding AF-UKHPR1000-0057.

283. The second scenario (IH-IF-BFX-04) related to a fire in room BFX2419ZRM where the SFP level measuring sensors are arranged.

284. The RP's safety case (Ref. 55) presented a functional analysis assuming the loss of these systems and how this impacted the delivery of the required safety functional requirements. The RP's analysis identified that the failure of the L3 sensors was acceptable but failure of the L4 sensors was not. The RP undertook fire risk analysis of the L3 sensors. The RPs analysis focused on the sensor arrangement and determined how fires within the room would impact them. From review of the layout the RP stated that two sensors of each group are located underwater in a corner of the SFP. Because the sensors are protected by a substantial body of water, the RP concluded that a fire in BFX2419ZRM could not impact the sensors located in the SFP, and therefore sufficient sensors remained to deliver the required safety functions.

285. I have assessed the arguments and evidence provided by the RP in the fire report (Ref. 93) for this scenario, and I am satisfied that the arguments are adequate for the purposes of GDA. The report provides clarity on the location of the sensors and I agree with the view that the significant body of water is sufficient to protect the immersed sensors from fire effects.

286. In summary, I have reviewed the fire scenarios that could impact exception to segregation areas in the BFX. Whilst I was satisfied with the RP's consideration of the above scenario, I have not been satisfied with the evidence provided for the other scenario (IH-IF-BFX-03). This should be addressed at detailed design through the relevant Assessment Finding (AF-UKHPR1000-0057).

4.3.5.3 HIC (Criterion C)

287. There are no HIC located in the fuel building.

4.3.6 Assessment of the Safeguards Building Fire Safety Case

288. The Safeguards Building (BSX) is used to house the principal safety systems that provide various functions during accident scenarios, the MCR, and other supporting systems. Each building is completely independent (through divisions), Safeguards Building A (BSA), Safeguards Building B (BSB), and Safeguards Building C (BSC), which correspond to the three trains of safety systems respectively. BSA and BSB are located on opposite sides of the Reactor Building, spatially separated by BSC between them.

289. BSC contains the MCR and the RSS, each on a different floor and not situated one below the other.

290. All 3 divisions are separated from each other by substantial walls (divisional barriers), to ensure that no more than one safety train of the safety systems can be lost or damaged by an internal fire. Physical internal segregation of redundant safety trains of Class 1 SSCs is achieved by provision of Class 1 divisional barriers, which include walls, floors, ceilings, and all penetrations. The BSX is further vertically divided into mechanical areas (basement to Lv.+4.90m) and Electrical areas, Instrumentation and Control (I&C) areas, and heating, ventilation, and air conditioning area (Lv.+8.70m to roof).

291. The Safeguards Building is sub-divided internally by Safety Fire Compartments (SFS), or smaller Safety Fire Cells (ZFS) (Ref. 53). SFS are designed for the majority of areas within BSA/BSB/BSC, and also for the MCR, the RSS, and the Main Control Room Air Conditioning System (DCL) machine room, in order to limit the fire spread to these areas and to protect different safety trains from fire common mode failures. Defence in depth is claimed by the provision of fixed fire-fighting systems and smoke control systems in high-risk locations to further limit the potential fire size and control fire and smoke spread. The expectation of limited fire-fighting intervention by operators is also indicated but not explained.

292. ZFS are designed for the Main Steam System (VVP), the Main Feed-water Flow Control System (ARE) pipes and valve rooms, and the Safety Chilled Water System (DEL[SCWS]) machine room, which are areas where complete physical segregation of systems is not possible.

4.3.6.1 Bounding Cases for Barrier Assessment (Criterion A)

293. The RP's selection of bounding cases is based on the application of its fire analysis methodology. The BSX fire analysis report (Ref. 56) states that all potential fire sources and combustible materials within all areas and rooms of BSX have been identified. For each room the maximum fire loadings were calculated as well as a fire

load density (FLD). The rooms with the highest FLD's impacting divisional barriers were identified and analysed. The RP safety case (Ref. 56) identified 2 bounding cases for barrier assessment:

- Non-ventilated rooms or compartments. (IH-IF-BSX-01).
- Ventilated rooms or compartments. (IH-IF-BSX-02).

294. For the assessment of the withstand of the divisional barriers the RP's safety case states that all barriers have a safety functional requirement of a 2-hour fire resistance. These safety functional claims are also captured in the basis of safety case for safeguards buildings (Ref. 46), highlighting the claim that all concrete barriers shall remain functional, and collapse is not permitted. The walls are designed and assessed in accordance with BS EN1992-1-2:2004 (Ref. 41). I judge this to be an appropriate standard to be applied.

295. The most onerous bounding case identified within the RP's safety case in terms of temperature and duration is the scenario defined for the ventilated compartments designated IH-IF-BSX-02.

296. The RP's description of this scenario in the safety case states that a fire occurs within three interconnected rooms. The RP's analysis stated that the fire duration from the combustible material within all three rooms would exceed the 2-hour barrier substantiation claim. This is because there are no internal fire doors or partitions effectively separating the fire compartment to two adjacent rooms. I noted that although IH-IF-BSX-02 is identified as the bounding case, the characteristics of this scenario are applicable in several locations across the safeguard buildings, where multiple rooms are located within one fire compartment.

297. To address this the RP undertook optioneering including modification of the classification of the fixed fire-fighting system; modification of the layout design, and; provision of the cable wrapping. An ALARP assessment was undertaken by the RP to determine the most appropriate solution which is detailed in the fire safety case (Ref. 56). The conclusions of the RP's review included that fire-resistant cable wrappings could be implemented to reduce the fire loads such that the 2-hour claim can be achieved.

298. I acknowledge that cable wrapping is a recognised mitigation measure that could aid in the mitigation of fire spread to other cables, which in principle could reduce the overall fire load which would be driving the fire within these rooms. However, given the importance of this measure to demonstrate that the barrier safety functional requirements can be delivered, the claimed cable wrapping needs to be adequately justified and substantiated.

299. In my view cable wrapping is at the lower end of the hierarchy of safety measures (ONR SAPs EKP.5). Its effectiveness is very dependent on installation and the measure is susceptible to damage. Even if correctly fitted, common commercial wrapping systems are substantiated for, on average, 1-hour fire rating. However, in this instance the RP is placing a primary requirement of 2-hours claim. This extended withstand may be a challenge to achieve, but the claim is required to ensure the class 1 barrier withstand requirements can be met. Either additional substantiation of the barrier design or additional protective measures may be required. Assessment Finding AF-UKHPR1000-0057 detailed previously also applies here.

300. In my opinion, the reduction of fire load and implementing robust compartmentation is a fundamental safety characteristic of a modern nuclear power plant. I raised RQ-UKHPR1000-0924 (Ref. 100) to understand why the rooms in this scenario could not be compartmented through the addition of fire doors. The RP's response (Ref. 100) explained that the provision of fire doors was not possible due to the building

ventilation design and requirements in that area to enable the safety systems to remain within operable temperature limits.

301. Following my assessment of this scenario I am clear that the design is reliant on a combination of spatial segregation of safety systems and implementation of cable wrapping to mitigate the consequences from a significant fire as defined in this scenario. The fire drawings (Ref. 53) show that the connecting rooms are not specifically designated as individual fire safety zones (FSZs). Noting the importance of minimising fire spread between these compartments (and reducing the overall fire load), it is my opinion that the RP has not adequately justified why the connecting rooms within the larger compartment have not been designated FSZ in their own right. Minimising fire spread should be a design principle in line with relevant good practice such as IAEA SSR-2.2 (Ref. 11), and IAEA SSG-64 (Ref. 15). It is my opinion that the RP should demonstrate that the fire zoning applied reduces risk to ALARP in line with SAPs ELO.4 and EHA.14. I judge this as a gap in its safety case and should be addressed as part of Assessment Finding AF-UKHPR1000-0057.

302. The RP's determination of the barrier withstand is presented in the safeguard's barrier withstand report (Ref. 101). The report highlights that the minimum thickness of the claimed divisional barriers is 800mm thick concrete with the centre of the steel reinforcements to the outer surface of concrete being larger than 35mm, which satisfies the 2-hour requirement.

303. I have assessed the barrier report and I am satisfied that the RP has provided sufficient evidence that the divisional barriers meet the design requirement for a 2-hour fire withstand. This is because the relevant standard (Ref. 41) sets the minimum compliance requirement for a fire withstand of 2-hours for a concrete wall as a 200mm thick with the outer surface of the steel to the surface of the wall being 35mm. Based on the thicknesses of the barriers stated by the RP, I am satisfied that the barriers have adequate withstand and significant margin.

304. As part of my assessment of the BSX, I sampled the design layout to judge the adequacy of the boundaries to prevent fire spread. Of particular interest was how fire effects were mitigated through the various air shafts that provide air to the HVAC systems.

305. The RP safety case identified nine specific boundary locations (shaft walls) on levels +4.9m and +13.5m, which did not have sufficient thickness to satisfy the requirement for 2-hour fire resistance integrity. I noted that these air shafts provide a direct connection between two different floor levels and can be seen within the fire zoning diagrams (Ref. 53). I decided to sample these shafts to determine if fire within these areas could present a risk of rapid heat and smoke spread between levels and therefore had the potential to not satisfy SAPs EHA.6 and EKP.1. To progress this, I raised RQ-UKHPR1000-1039 (Ref. 102).

306. The RP's response to RQ-UKHPR1000-1039 (Ref. 102) clarified that in most instances the shaft walls are not designated as divisional boundary walls and are located within fire compartments. Therefore the 2-hour requirement was not applicable. The RP further clarified in the response that the fire loads were minimal, and failure of the walls would not impact other divisions.

307. I assessed the RP's response to RQ-UKHPR1000-1039 and I have some confidence that the divisional claims would not be impacted. However, I am not satisfied that the RP has adequately addressed the issue of transfer of heat and smoke to other areas within a division, as this should be minimised to prevent unpredictable fire spread.

308. It is my opinion that the design should be demonstrated to be robust such that the impact of fire within the various air shafts are adequately assessed, and the

consequences of potential spread of heat and smoke is minimised, but I judge this to be as a minor shortfall.

309. The RP's analysis of the bounding case IH-IF-BSX-01, presents a cable shaft (BSX1510ZRX) located on the boundary between two divisions. The RP's safety case stated that the room is an individual fire compartment whose fire door is fire resistant and is considered closed during the fire all penetrations are fire sealed. No mechanical ventilation is provided to this room and therefore it is classed as unventilated.

310. I have sampled the analysis undertaken by the RP for this bounding case. My review found a lack of sensitivity assessment on the effects of open fire doors. It is my expectation that appropriate sensitivity analysis is undertaken to ensure that there are no potential cliff-edge effects, and a conservative assessment is demonstrated. It is noted that in other areas of the assessment, non-fire doors have been assumed to be open in a possible fire, thereby increasing the availability of oxygen and resultant fire growth. Although the analysis indicates that the fire (non-ventilated) is adequately contained, any increase in fire effects could undermine this and therefore ONR SAPs EHA.6, EHA.7 and EHA.18 would not be met. I judge this as a gap within the RP's analysis which should be addressed at detailed design and I therefore captured it as part of Assessment Finding AF-UKHPR1000-0057.

311. In summary, the RP has presented the assessment of fire effects on the barriers claimed for segregation of the safeguards building. I have been satisfied that fire hazards have been screened on an adequate basis and the bounding cases are justified based on the evidence provided. The RP has provided sufficient evidence that the barriers have appropriate withstand for the 2-hour safety functional claims. I have confidence that across the three safeguards buildings adequate segregation is provided to deliver the required safety functions.

312. However, there are several shortfalls regarding sensitivity analysis, fire zoning, and additional safety measures that require further substantiation at detailed design to demonstrate they can provide the required functions and, also, that those measures are appropriately classified. These shortfalls are captured across the various minor shortfalls and Assessment Findings detailed above.

4.3.6.2 Exception to Segregation (Criterion B)

313. Within the safeguards building there are two principal exception to segregation areas as defined in the list of segregation and exception to segregation areas (Ref. 29). These areas are also presented within the fire safety case (Ref. 56).

- The VVP[MSS] / ARE[MFFCS] pipes and valves of trains B and C are in a non-segregated area of BSB.
- The Main Control Room located in safeguard building C.

314. For my assessment I specifically sampled the RP's fire safety analysis related to the Main Control Room (MCR) and the Remote Shutdown Station (RSS). The MCR is where in the generic UK HPR1000 design the operators monitor and control the plant and is located within BSC on level +13.20m. The RSS provides an alternative means for operators to maintain the safe state of the plant should the MCR become unavailable, which is also located within BSC on level +8.70m.

315. I note that the safety case sets out specific requirements for the habitability of these rooms. These are presented in the 'General requirements of protection design of internal hazards and external hazards report' (Ref. 27) that stated the habitability of the MCR should be maintained, and the availability and the accessibility of the RSS should be ensured in the case that the MCR is unavailable. This requirement is also in line with the principles set out in RCC-F 2017 B1000 (Ref. 63). Noting that both these

rooms are in the same building, I sought further clarification on the justification for the design layout of the RSS and MCR and therefore raised RQ-UKHPR1000-911 (Ref. 103).

316. The RPs response to RQ-UKHPR1000-911 (Ref. 103) provided additional clarification on the design features incorporated in the generic UK HPR1000 design to demonstrate how a design basis fire would not impact both the RSS and MCR and they both remain viable; this includes the following:

- The RSS and MCR are spatially separated. The MCR is located on floor 13.2m and the RSS is located on floor 8.70m.
- The MCR and RSS have separate air conditioning systems. The MCR has a bespoke air conditioning system while the RSS is supported by the general HVAC system for the electrical division areas.
- The RSS and MCR are designed as independent 2-hour fire compartments
- The escape route to the RSS from MCR is designed as a SFA with a 1-hour fire rating.
- The RSS has complete electrical separation from the MCR.

317. The RP's safety case and response to RQ-UKHPR1000-911 highlighted that the purpose of the RSS is to provide a robust alternative means to maintain the safe state of plant in case of the MCR is unavailable. The RSS is served by the electrical division of safeguard building ventilation system (DVL [EDVS]).

318. The design layout and segregation between the MCR and the RSS is presented in the safeguard fire zoning drawing (Ref. 53). I consider that the fire zoning drawings provide adequate evidence to substantiate the claims that the MCR and RSS are segregated and are designated as individual 2-hour fire safety compartments.

319. I have assessed the adequacy of the 2-hour claim for the RSS fire compartment as I noted from my review of the design that there are several cable rooms directly below the RSS that contain significant fire loadings. I also identified a ventilation airshaft connecting the RSS to the cable rooms below as both floors are served by the same ventilation system (DVL [EDVS]). To understand how the functionality of the RSS was assured in a fire within these cable rooms I raised RQ-UKHPR1000-1236 (Ref. 104).

320. The RP's response to RQ-UKHPR1000-1236 (Ref. 104) conceded that the fire loading would exceed the 2-hour claim. As a solution, the RP proposed to implement cable wrapping as a protection measure to reduce the fire loading such that the fire load will not exceed the 2-hour rating. The RP also highlighted that a fire suppression system is installed as a defence-in-depth measure. Although these are adequate safety measures that aid in preventing fire spread, it is my opinion that the generic UK HPR1000 design should ensure that the fire loads and associated effects are adequately controlled such that the potential for a fire to exceed the compartmentation withstand claims is removed were reasonably practicable. At present the current FSZs defined are large and in this instance does not indicate the importance of ensuring fire does not spread between compartments and is a shortfall against SAP EHA.14, EHA.17 and EHA.16.

321. It is my expectation that at detailed design the licensee should ensure that, where claims are made on spatial separations appropriate FSZ are designated to minimise the risk of fire spread. This shortfall is captured in Assessment Finding AF-UKHPR1000-0057.

322. Through my assessment of the cable rooms below the RSS, I identified several locations where penetrations from the adjoining safeguards building entered the BSC within this location. The purpose of these cables was not clear, therefore, to ensure that a fire within this area would not lead to multiple divisional failures of SSCs, I raised

RQ-UKHPR1000-1234 (Ref. 105) to determine if there was a potential for common cause failures.

323. The RP's response to the RQ clarified that the generic UK HPR1000 design adopts a series of principles that define the placement of cables for different divisions which are defined in the NI Cable Routing Guidelines (Ref. 106). Such principles include:

- The cabling should be physically segregated by distance and barriers, for example the cable trays could be separated by effective distance and fire protection barriers.
- Once the common cause failure is identified by hazard analysis, protection measures like the cable wrappings can be adopted to separate the cable trays from different divisions.

324. The RP also clarified in the response to RQ-UKHPR1000-1234 (Ref. 105) that the cable routing schematic that was presented in the fire safety assessment report (Ref. 56) was taken directly from the reference plant FCG3. The RP stated that the generic UK HPR1000 design cable layout will be different to that presented because of the implementation of the cable routing principles, thus the RP stated that the number of penetrations from adjacent buildings will be reduced. I note that the cable routings are to be finalised as part of the detailed design stage. Therefore, the final routing and segregation of cables have not been finalised and presented as part of the GDA. However, I judge that the principles defined are adequate and provide confidence in the future design in line with SAPs EKP.3 and ELO.4.

325. However, it is important that at detailed design phase the design should ensure that the potential fire hazards are used to inform the final cable routing layouts. It should also ensure that fire loads are minimised and adequate segregation from an Internal Hazards perspective is implemented. This can be followed up as part of normal regulatory business through review of the cable layouts and the expected hazard analysis at detailed design.

326. The RSS and MCR are served by separate heating, ventilation, and air conditioning (HVAC) systems. The MCR is vented by the Main Control Room Air Conditioning System (DCL [MCRACS]); while the RSS is vented by the Electrical Division of Safeguard Building Ventilation System (DVL [EDVS]). These two ventilation systems are co-located on the same floor of the BSC on floor 26.3m.

327. I have assessed the layout on floor 26.3m and the detailed response to RQ-UKHPR1000-1598 (Ref. 107) that focused on explaining the segregation of these systems. From this I have sufficient confidence that the RP has demonstrated that adequate layout is provided, through the provision of fire compartments and spatial segregation, to protect the various trains of the HVAC systems from fire. The principal arrangements can be summarised as:

- There is spatial segregation between the DVL air chambers and the DCL trains.
- The DVL system is located within a 2-hour fire compartment and each DCL train is also located within an individual fire compartment.

328. It is my judgement that, for the purposes of GDA, sufficient segregation has been demonstrated. In the event of a fire in this location resulting in the loss of HVAC, the RSS would remain viable. This is because the Train A of the DVL [EDVS] located in safeguard building A can be used to provide the required HVAC functions to the RSS thus allowing the required activities to maintain nuclear safety. This provides a diverse and segregated safety measure.

329. The RP's internal hazards fire analysis has been predicated on the basis that a fire would be limited to one initiating event, and the likelihood that two independent fires

occurring at the same time would be beyond the design basis criteria. This approach is in line with SAP EHA.19 and FA.6. However, consequential fire can occur from common initiators. Such an initiator is a seismic event.

330. ONR's safety assessment principles (SAPs') (Ref. 2) and Internal Hazards TAG NS-TAST-GD-014 (Ref. 7) set out expectations for identification, characterisation, and screening of hazards (including combinations), and analysis of the design against these hazards. ONR expects that consequential internal hazards should be analysed against relevant good practice, including those internal hazards initiated by external hazards such as seismic events.

331. My assessment of the Earthquake Safety Evaluation Report for the BSX (Ref. 108), and the RP's response to RQ-UKHPR1000-832 (Ref. 109) requiring further evidence to underpin the assumption made in the evaluation reports, identified that seismic fire hazards had been screened out from assessment. It was my judgement that the screening out of fire hazards was not in line with relevant good practice and I deemed this a significant enough gap to raise regulatory observation RO-UKHPR1000-055 (Ref. 110).

332. As part of RO-UKHPR1000-055 I elected to sample safeguard building C because both the generic UK HPR1000 design Main Control Room (MCR), and the Remote Shutdown Station (RSS) are located within this building. Following the RPs review of potential seismic induced fire sources (Ref. 59), the RP identified that there were several credible ignition sources identified around both the MCR and RSS that could impact functionality in the following ways:

- A fire in the computer room adjacent to the MCR (BSC3323ZRE) could result in smoke transfer through various connections that would result in evacuation of the MCR.
- A fire in the electrical switchgear room adjacent to the RSS (BSC2825ZRE) would result in the RSS fire dampers being closed, preventing adequate flow of air within the compartment.
- Fires in room BSC2825ZRM could also impact the functionality of required electrical switchboards designated as SSE1 (Seismic classification 1 – safety function required following seismic event) in an adjacent compartment (BSC2862ZRE) by elevating the compartment temperature above the maximum operating qualified temperatures (50ºC). The switchboards in BSC2826ZRE provide emergency electrical power to all of Division C, including supplies for both the DCL and Division C DVL HVAC systems, thus would have a significant impact both the MCR and RSS.

333. Through my assessment of the described scenarios it became clear that the totality of these shortfalls meant that both the MCR and RSS could be rendered unavailable following seismic event. As this challenged some of the key safety claims regarding the control of plant following a seismic event, I raised RQ-UKHPR1000-1684 (Ref. 111) to ensure that adequate measures would be put in place to address the identified gaps.

334. The RP's response to RQ-UKHPR1000-1684 (Ref. 111) acknowledged these shortfalls, and the RP committed to:

- Address the fire in the computer room adjacent to the MCR through the provision of seismically qualified equipment to eliminate the ignition source.
- Address the impact of non-seismically qualified equipment in room BSC2825ZRM impacting the HVAC emergency power switchboards in room BSC2825ZRM, by qualifying the non-qualified cabinets as SSE2.

335. I have assessed the proposed changes to the safety functional requirements of the systems that present a challenge to the MCR and RSS. I am satisfied that the RP has

adequately addressed this by ensuring the equipment meets SSE2 requirements, and therefore its potential as a fire initiator can be eliminated. Equipment needs to be substantiated to demonstrate that they can meet the SSE2 classification, but I am satisfied that this can be done as normal business at detailed design.

336. The RP has captured these new requirements in an updated report (Ref. 112) and transferred them to the external hazards schedule (Ref. 113). I am therefore satisfied that the requirements are adequately captured in the safety case and their classification are appropriate providing additional assurance that the MCR and RSS would remain habitable following multiple seismically induced fires.

337. Although I am satisfied that the RP has addressed the issues with the MCR and RSS, my sampling has identified a shortfall in the potential classification (or lack of) of equipment that can impact SSE1 classified equipment following a seismic event. I recognise that the generic UK HPR1000 design has demonstrated that it provides a diverse means to manage the loss of various systems, for example; the loss of Train C of the DCL system can be addressed through utilisation of train A DCL system from safeguard building A. However, it is important to recognise that similar vulnerabilities could potentially exist in the other buildings that could impact the claims on associated HVAC trains or other key systems. This assessment can only feasibly be completed at the detail design stages as more detailed information is available on the cable routing and system layouts. I consider that the analysis should be undertaken and therefore I raise the following Assessment Finding to ensure that appropriate review and regulatory oversight is provided at detail design.

AF-UKHPR1000-0060: The licensee shall, as part of site-specific design, demonstrate that seismic category 1 structures, systems, and components are substantiated against the direct and indirect consequences of seismically induced fires.

338. In summary, I have sampled the fire safety case claims for the MCR as an example of an exception to segregation area in the generic UK HPR1000 design. I am satisfied that within the scope of the GDA assessment the RP has provided adequate evidence to demonstrate that the risks to the MCR from fire is generally low. However, I have identified several minor shortfalls, but these do not undermine my overall view that the MCR has an adequate safety case and the RSS as a diverse option is adequately segregated.

4.3.6.3 HIC (Criterion C)

339. The RP's safety case (Ref. 56) identified scenario IH-IF-BSX-03 as an area where a cable fire within the main steam line (VVP [MSS]) and feedwater line (ARE [MFFCS]) pipe and valve rooms within safeguard building B, could impact the main steam line.

340. The RP's analysis of this scenario concluded that the maximum fire temperatures are insufficient to impact and result in the loss of integrity of the MSL HIC components. The RP explained that because the temperatures within the compartment would be below the designed operational temperature of the component, it would not impact the pipes operability or integrity.

341. I have assessed the evidence presented, including the responses as part of RO-UKHPR1000-046 (Ref. 89), and I am satisfied that it is unlikely that the global temperatures within the room would be of sufficient magnitude to lead to loss of integrity of the main steam line. However, a clear justification and substantiation in line with the standards (RCC-M) to which the component has been designed has not been presented by the RP. This omission presents a gap in the evidence within the safety case. I also note from my review of the plant layout that the cable trays pass directly

over the HIC components and, therefore, there is a potential for localised heat effects that may impact the pipe these have not been assessed. However, I am satisfied that based on my review of the layout this is a lesser issue, as the fire effects would not directly impinge the pipes. The Fire assessment report (Ref. 56) also identifies defence-in-depth measures to segregate the cables passing through the fire safety cell, however, the final layout has yet to be finalised at detailed design.

342. Therefore, although I judge, based on the evidence assessed that the risk from fire to the main steam line are likely to be low, further work is required by the licensee to justify that the main steam line is adequately protected from fire hazards. I consider that this a gap in the safety case that the licensee should address at detailed design and is captured within Assessment Finding AF-UKHPR1000-0057.

4.3.7 Summary of Assessment and Affirmation of PCSR Claims

343. For fire hazards the principal safety measures claimed by the generic UK HPR1000 design safety case are the class 1 civil structures that provide the required segregation of safety trains. I have been satisfied from my assessment that the RP has provided adequate evidence to substantiate the claimed civil barriers against the 2 -hour fire resistance safety functional requirement. In many instances I have found that the barriers are significantly thicker than required, which are likely to provide additional margin and give additional confidence in the GDA conclusions. I have identified shortfalls within the RP’s methodologies and its analysis, and I have raised a number of minor shortfalls and Assessment Findings. However, these shortfalls do not undermine my view that, in line with SAPs EHA.15, ESS.1, sufficient segregation between SSCs important to nuclear safety has been demonstrated with respect to fire hazards.

344. Additional measures such as fire detection, fire suppression and cable wrapping have been identified as providing defence-in-depth. In some instances, these measures require further assessment and substantiation. However the RP’s hazard identification provides confidence within the scope of GDA that adequate systems exist to control the risks providing defence in depth-in-line with SAP EKP.5.

345. Overall, I judge that the RP has demonstrated that, for fire, the current generic UK HPR1000 design layout as assessed for GDA provides adequate measures and segregation to demonstrate that a design basis fire would not significantly impact nuclear safety. This satisfies SAP ELO.4.

4.3.7.1 Affirmation of PCSR Claims for the Fire Safety Case

346. This section provides a summary of my assessment of the principal claims associated with the internal fire hazard safety case.

- Sub-claim 3.2.2.SC19.2.1: The internal fire sources are sufficiently identified.

347. Based on the evidence provided and assessed, I conclude that the RP has demonstrated that the principal fire sources have been identified. Evidence provided through RO-UKHPR1000-053, has highlighted that further assessment work is required to ensure all bounding cases are bounding. However, following my assessment, I have sufficient confidence based on the RPs source data that the most significant fire hazards have been addressed within the scope of the GDA assessment. I have assessed these fire hazards and where gaps have been identified, I have raised Assessment Findings which I expect the licensee to address at detailed design.

- Sub-claim 3.2.2.SC19.2.2: The safety measures to mitigate the consequences of internal fire are identified and properly classified.

348. The analyses carried out by the RP based on the identified fire sources have adequately justified that the identified barriers will provide the required fire withstand to ensure that the effects from fire are retained within one train this is based on the evidence provided in its fire assessment reports and RO-UKHPR1000-53 evidence. I have identified some areas where additional analysis is required to underpin the safety case claims and these have been captured in Assessment Finding AF-UKHPR1000-0057.

349. The RP has clearly identified areas of exception to segregation and assessed the potential impacts of fire spreading between redundant safety trains. It has identified SSCs to minimise the impacts of fire. However minor shortfalls have been observed as well as an Assessment Finding (AF-UKHPR1000-0059). The outputs of RO-UKHPR1000-055 have also provided confidence in the withstand of the MCR during multiple seismic induced fires following the modifications to the seismic classification of various plant. I note that further analysis work is required for the wider plant at detailed design in seismic fire and this has been captured in AF-HPR1000-0060.

350. The RP has also provided adequate evidence to provide confidence that the impacts to HIC from fire effects are negligible and their integrity would be maintained in the event of fire. However, the basis of the analysis has been based on generic criteria rather that the specific standard; this was a gap identified that is addressed by AF-UKHPR1000-0057 and AF-UKHPR1000-0058.

- Sub-claim 3.2.2.SC19.2.3: The safety measures for internal fire are sufficiently substantiated.

351. The principal safety measures for fire largely related to the various class 1 barriers and the inclusion of cable wrapping. I have been satisfied that the RP has provided sufficient evidence that barriers are adequate to justify the safety functional requirements. However, further work is required to substantiate the reliance on cable wrapping which has been captured as part of Assessment Finding AF-UKHPR1000-0057.

4.3.8 Fire Safety Case Strengths

352. Through my assessment recorded above, I have noted the following strengths in the RPs internal fire safety case:

- The RP has adequately addressed the queries raised during this assessment.
- The RP has applied relevant good practice where appropriate.
- The RP has demonstrated that its principal safety measures (barriers) have appropriate withstand to maintain divisional segregation.

4.3.9 Outcomes

353. Through my assessment of the RP’s internal fire safety case I have been satisfied that the RP has provided adequate evidence to underpin the fire assessment for the purposes of GDA, based on the adequacy of its class 1 barriers.

354. Following my sampling, several additional cases that had not been adequately analysed by the RP were identified. I have assessed these cases and I have found for the purposes of GDA no fundamental shortfalls that significantly challenge the safety claims of the generic UK HPR1000 design, but I have identified several areas of improvement.

355. The RP has demonstrated that adequate hazard identification and screening has been undertaken in line with its assessment criteria (A, B and C). However, following my

assessment, I judge that further work is required to ensure full coverage of all the buildings are analysed by the licensee at detailed design.

356. I acknowledge that the RP has implemented modifications to the reactor coolant pump to mitigate fire risks and changed classification of seismic equipment to address fire shortfalls, however further work is required to fully substantiate the modifications.

357. To address the gaps, I have identified and raised Assessment Findings associated with the fire hazards analysis methodology, risks from oil fires; substantiation of SSCs in fire conditions, and; risks associated with seismically induced fires.

4.3.10 Conclusions

358. I have assessed the merits of the generic UK HPR1000 fire safety case. My assessment has been informed by several references, RQs and regulatory observations. The breadth and depth of this assessment has been focused on key risk areas and the quality of evidence provided by the RP.

359. Although several minor shortfalls and Assessment Findings have been identified, I am satisfied that the principal risks from fire have been identified by the RP and understood. Principal safety functions for SSCs have been captured and where appropriate adequate safety measures have been identified by the RP within the scope of GDA, but I judge that further substantiation is required, which should be done at detailed design stage.

360. However, the evidence provided by the RP is sufficient for me to have confidence that the design and layout of the generic UK HPR1000 design is such that any potential changes relating to fire can be incorporated at detailed design by the licensee. Therefore, based on the outcomes of my assessment of the RP’s internal fire hazards safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and have raised Assessment Findings accordingly. I do not judge that these gaps are significant enough to prevent the issue of a DAC, as I am content that they can be addressed by the licensee at detailed design.

4.4 Hazard Assessment – Explosion

4.4.1 Principal Claims from the Generic UK HPR1000 Explosion Safety Case

361. The generic UK HPR1000 explosion safety case for the sample buildings (BRX, BFX and BSA/BSB/BSC) is comprised of the following documents:

- Internal explosion safety evaluation methodology report (Ref. 114).
- Internal explosion safety assessment report for reactor building (Ref. 115).
- Internal explosion safety assessment report for fuel building (Ref. 116).
- Internal explosion safety assessment report for safeguards building (Ref. 117).
- RO-UKHPR1000-054 Report (Ref. 58).

362. The principal claims for the internal explosions safety case for the generic UK HPR1000 design are defined within the pre-construction safety report (PCSR) Chapter 19 Internal hazards (Ref. 3). The principal claims are stated as:

- Sub-claim 3.2.2.SC19.2.4 (Explosion): The internal explosion sources are sufficiently identified.
    - Argument 3.2.2.SC19.2.4-A1 (Explosion): The systems and components which have potential chemical and physical explosion risk are sufficiently identified.

- Sub-claim 3.2.2.SC19.2.5 (Explosion): After the safety assessment, the safety measures to mitigate the consequences of internal explosion are sufficiently identified and properly classified.

    - Argument 3.2.2.SC19.2.5-A1 (Explosion): In segregation areas, safety measures are identified to ensure that the consequences of any internal explosion are limited to one train of the systems delivering safety functions through use of barriers.
    - Argument 3.2.2.SC19.2.5-A2 (Explosion): Where there are exceptions to segregation, safety measures are identified to ensure that sufficient Structures, Systems and Components (SSCs) are available, during and after an internal explosion, to deliver the safety functions.
    - Argument 3.2.2.SC19.2.5-A3 (Explosion): Internal explosion does not cause unacceptable damage to High Integrity Components (HIC).
    - Argument_3.2.2.SC19.2.5-A4 (Explosion): The safety measures to mitigate the consequences of internal explosion are classified in accordance with the methodology of safety categorisation and classification.

- Sub-claim 3.2.2.SC19.2.6 (Explosion): The safety measures to mitigate the consequences of internal explosion are sufficiently substantiated.

    - Argument 3.2.2.SC19.2.6-A1 (Explosion): Barriers can effectively withstand the overpressure from the explosion.

4.4.2 Explosion Methodology Assessment

363. This section details the findings from my assessment of the RP’s explosion hazard methodology (Ref. 114) used for the generic UK HPR1000 safety case. The RP’s explosion methodology stated that the most significant explosion sources within the generic UK HPR1000 design are:

- Explosive gas (explosive atmospheres).
- Oil mist.
- High energy arcing fault (HEAF).
- Blast wave from high pressure vessels and in Boiling Liquid Expanding Vapour Explosions (BLEVE).
- Other scenarios (dust, explosive materials).

364. In line with the source listed above, I have assessed the methods presented by the RP to quantify the relevant explosion loadings; my findings are as follows:

365. For the analysis of deflagrations (such as from gas atmospheres), the RP has applied the ideal gas law. I judge this to be an adequate method when a detonation is not credible. The RP’s approach is generally based on applying stoichiometric mixtures, which in my view may not always result in the most onerous conditions. This is because in-air environments (which are applicable in this design) can lead to lean mixtures which are likely to form larger gas clouds.

366. It is my expectation that the most conservative conditions are considered to minimise the potential for cliff-edge effects. I judge this to be a shortfall in the methodology against SAPs EHA.2, EHA.6, EHA.7 and AV.2, which is captured as part of Assessment Finding AF-UKHPR1000-0061. I have also sampled this gap within the RP’s case to judge the impact of this shortfall and my findings are detailed in the relevant sections below.

367. For oil mists the RP had predominantly screened out oil mist hazards on the basis that the oil sources in the generic UK HPR1000 design within the GDA sample areas are not pressurised. I judge this to be appropriate and in line with appropriate hazard screening expectations (Ref. 7). The most significant oil source is located within the BRX (reactor coolant pump). The RP confirmed that this oil source is not pressurised (Ref. 118). I assessed the RCP with respect to fire hazards and I am content that this source can be screened out regarding oil mist hazards.

368. For HEAF hazards the RP has applied screening criteria based on the voltage of the electrical supply equipment. The RP stated that voltages ≥ 10kV are credible HEAF sources. The explosion loads from the HEAF had been calculated based on equating the electrical energy released to an equivalent mass of an explosive, in this case TNT. I judge this to be a reasonable method and in line with good practice (Ref. 15).

369. For the analysis of blast waves from failure of high-pressure gas vessels, the RP applied a two-step process:

- Calculating the energy released from the gas cloud.
- Calculating the blast load on the target.

370. The methodology applied by the RP to determine the energy release from the gas cloud volume is based on the Brode energy equation. The method, based on the ideal gas laws, determines the difference in the internal energies of the gas at the initial and final pressures: this difference is defined as the explosion energy (Ref. 119). In my view this is an adequate approach which I consider relevant for the analysis of vessel failure and satisfies SAP AV.2.

371. A similar approach is also used by the RP for pressurised pipes. Noting that a pipe may run for significant lengths, the RP adopted a method to characterise a representative section of pipe that contributes to the explosion. The RP adopted the R3 impact procedure (Ref. 44), to characterise the explosion size and breach opening time. This is used to then generate an explosion source term, which is then used to calculate the energy of explosion using the Brode energy equation. I am satisfied that this is a reasonable approach, if the breach opening time is adequately substantiated.

372. The associated distances to a given target had been calculated by applying scaled standoff distances using Sachs' scaling. This type of approach in my experience is common practice (Ref. 120) and is an effective way to determine the effects of explosions through scaling laws, such as Sachs'. Based on the scaled distances, the RP then calculated the scaled positive overpressure and the scaled positive impulse from Baker-Tang curves, allowing the side-on peak overpressure to the target and the side-on impulse to the target to be calculated.

373. The RP's methodology report also highlighted the requirements for adjustments to be made for the vessel temperature and vessel geometries. The RP stated that "Elevated temperature increases the positive overpressure near the vessel compared to the same vessel at ambient temperature, but the effect diminishes with distance away from the vessel." Adjustment factors for non-spherical geometries like the cylindrical geometries were also quoted by the RP. These considerations are aligned to those presented in literature (Ref. 120) and therefore I am content that the RP captured such requirements within its methodology.

374. Notwithstanding the above I noted that the methodology did not provide any guidance on blast target interaction. It is my view that blast wave target interactions are complex and need to be assessed particularly for confined explosions. Depending on the strength of the blast and the distance to the target, account needs to be taken for blast wave reflections. For significant blast pressures the reflected pressure can be more than 8 times the initial incident pressure (Ref. 121), (Ref. 122) therefore it is my view

that reflection factors need to be considered for determining design loads. This is an omission within the RP's methodology and a shortfall against expectations defined in SAPs FA.4, FA.7, EHA.6 and EHA.7. I have captured this gap as part of Assessment FindingAF-UKHPR1000-0061 for the licensee to address during the detailed design. In addition, I have also sampled this gap within the RP's safety case to judge the impact of this shortfall and my findings are detailed in the relevant sections below.

375. For the BLEVE analysis, rather than adopting the Brode energy approach, the RP calculated the energy of explosion by calculating the difference between internal energies of the liquid state and the final two-phase state to define the explosion energy. Once the explosion energy was derived the RP then applied the blast scaling approached to derive the blast loads.

376. In contrast to the methodology for compressed gases where the Brode energy is used, the explosion energy calculated by the RP had not been multiplied by 2 to consider ground effects. This multiplication factor is to account for enhanced pressure from reflection if the explosion source is close to the ground surface, resulting in a hemispherical source.

377. This is also relevant to application of the Baker-Tang curves, as these curves are valid for spherical explosions. If the bast is more representative of a hemispherical blast, then appropriate factors must be applied. I consider this a shortfall within the RP's methodology that should be addressed at detailed design as part of AF-UKHPR1000-0061 as the location and positioning of pipes need to be finalised. Therefore, it is important that the licensee considers these factors in line with SAPs AV.2, AV.1 and EHA.2.

378. A further finding from my assessment of the RP's methodology relates to the screening criteria applied for BLEVE conditions. The RP's methodology assumed the conditions for a BLEVE are only reached when the temperature of the fluid inside the vessel exceeds 89 % of its critical temperature. The resulting temperature is also referred to as 'superheat limit temperature' (SLT). When the method is applied for water, which has a critical temperature of 374.14°C, the SLT is calculated to be 302.9°C. This approach applied by the RP meant that the water or steam temperature inside a pipe or vessel must exceed 300 °C for it to be considered as a source of a BLEVE.

379. I questioned this approach in RQ-UKHPR1000-1030 (Ref. 123) and requested further evidence to demonstrate the conservativeness of this assumption. The RP's response to RQ-UKHPR1000-1030, highlighted that it had used what it deemed as relevant good practice including excerpts from the 'yellow book' (Ref. 124). The RP believed the criteria was conservative.

380. I assessed the response presented by the RP and noted that none of the sources/ methods referenced excluded the potential of BLEVE occurring at temperatures below the SLT.

381. The principal factors that determine the severity of the BLEVE are the temperature and diameter of the pipe, and it is my opinion that the references support this view. Based on the methods presented, reductions in pipe diameter and temperature will reduce the overall energy release, rather than the SLT being a specific threshold value, below which there is no credible BLEVE event. I therefore raise the following Assessment Finding in line with SAPs EHA.19, EHA.14 and AV.2, to ensure that appropriate screening methods are applied by the licensee in the detailed design. I have also sampled this gap within the RP's case to judge the impact of this shortfall and my findings are detailed in the relevant sections below.

AF-UKHPR1000-0061**:** The licensee shall, as part of detailed design, demonstrate that the risks from internal explosion hazard are reduced to as low as reasonably practicable. This should include but not be limited to:

- The application of relevant blast reflection and correction factors
- The justification of the screening criteria used for boiling liquid expanding vapour explosions.

382. In conclusion I am satisfied that the RP has presented a methodology that is consistent with relevant good practice. However, there are some aspects of the methodology that have resulted in shortfalls that can result in non-conservative findings (as detailed in the sections below). These specific areas have been highlighted to be updated within its methodologies for detailed design assessment purposes. For the gaps identified I am content that detailed design considerations and licensee choices are available to reduce the risks.

4.4.3 BRX: Assessment of Reactor Building Explosion Safety Case

383. The BRX explosion analysis report (Ref. 115) stated that the layout of the generic UK HPR1000 design had been optimised to eliminate flammable gas hazards and there are no tanks or pipes containing explosive (flammable) gases.

384. The report highlighted one instance of a high voltage system located within the Reactor Coolant Pumps (RCP). The RP stated that this hazard had been screened out on the basis that the RCP systems are designated as HIC and are not considered as an explosion source within the design basis.

385. From my sampling of the RP’s methodology (Ref. 114) and screening process applied (Ref. 115), I am satisfied that the areas screened out are adequately justified and satisfy SAP EHA.19. For the remaining explosion hazards I have assessed them in the sections below.

4.4.3.1 BRX: Bounding Cases for Barrier Assessment (Criterion A)

386. The RP’s bounding cases had been based on the scaled distance approach as described in its methodology, identifying the most significant explosion loadings to the thinnest barriers.

387. Through this approach, the RP highlighted (Ref. 125) that the BRX contains three trains of the reactor injection system (RIS [SIS]) with one accumulator per train. The RP’s safety case (Ref. 125) stated that accumulators are a principal FC1 safety system designed to inject borated water into the cold leg of the primary loop in response to a RPV pressure drop. To deliver this function the liquid in the accumulator is pressurised with compressed nitrogen.

388. The RP’s internal explosion report (Ref. 115) identified these accumulators as a credible explosion source and analysed the failure of them in two bounding cases IH-IE-BRX-01 and IH-IE-BRX-02. I considered these scenarios and decided to sample IH-IE-BRX-02 based on the location and potential consequences.

389. The RP’s scenario IH-IE-BRX-02 analysed the failure of accumulator RIS1320BA and impact to barrier BRE2113VB, which segregated that accumulator from another train of accumulator. The divisional barrier wall is stated by the RP to be 400mm thick (Ref. 115). The RP’s explosion report presented analysis that should the accumulator fail, a peak overpressure of 300kPa is predicted at the wall. I assessed the barrier substantiation report (Ref. 83) where the wall was substantiated against the 300kPa. I noted that the blast was represented as a triangular pulse as I would expect for such a loading. However, it appeared that no dynamic loading factors had been applied. It is my view that reflection factors should have been accounted for, given the proximity of

the concrete wall to the explosion source. I therefore raised RQ-UKHPR1000-1766 (Ref. 126).

390. The RP's response to RQ-UKHPR1000-1766 (Ref. 126) provided a detailed re-analysis of the scenario, the key points from the response were:

- A re-evaluation of the blast loads on the barrier BRE2113VB was provided. The analysis confirmed the peak side-on overpressure at the wall, with additional reflection factors applied. The RP's analysis confirmed that the overpressure at the wall should have been 1200kPa. I assessed the updated analysis, and I am content that the RP undertook an adequate analysis, including reflection factors, and thus satisfying SAP EHA.2.
- Based on the updated loads, the claimed barrier BRE2113VB design cannot be substantiated against the failure of the accumulator.
- The RP provided clarification of the positioning of the isolation and check valves to prevent loss of system integrity. These valves are located within the annular space behind the secondary shielding wall.
- The RP also re-evaluated all the key barriers surrounding the two accumulators following a domino failure. The RP provided a summary of the loadings expected and applied them to static equivalent loads in line with ACI349M and assessed the barrier withstand. In all instances the RP applied a dynamic loading factor of 0.3. In all instances, except for the barrier BRE2113VB, the RP claimed they would withstand. The affected barriers are illustrated in figure 3 below:

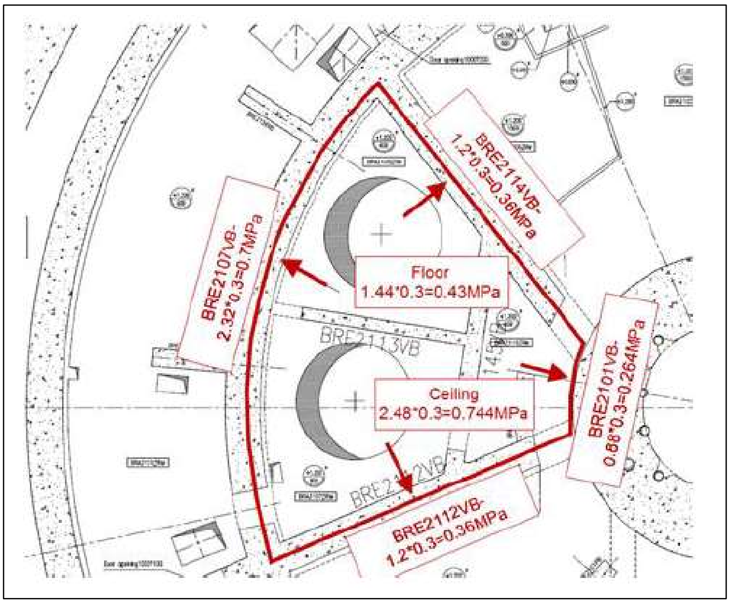

Figure 3: Illustration of the blast loads on the barriers surrounding the accumulators.

391. In response to the analysis undertaken to address the concerns raised in RQ-UKHPR1000-1766 (Ref. 126), the RP updated the explosion assessment report to include further functional analysis (Ref. 127) for this scenario. The updated functional analysis provided the following additional details:

- The isolation valves and check valves are located behind the secondary shielding wall. The shielding wall has been substantiated to withstand the blast loads. Therefore, the RP stated that the isolation valves and the check valves can perform their function to isolate the breach to avoid a loss of coolant accident (LOCA). Therefore, the RP stated there is no direct impact on RCP coolant circulation and the safety function of accumulators are not needed.
- A third accumulator located in BRA2132ZRM remains available.

- The loss of two accumulators is acceptable.

392. I have assessed the evidence provided by the RP and I am satisfied that my initial query has been addressed, thereby satisfying SAP's EHA.1, EHA.3 and EHA.6. I am content that the design for each train is of sufficient capacity to deliver the required safety function. I am also content that the RP has applied adequate methods in the substantiation of the barriers surrounding the two accumulators, and the relevant barrier withstands have been demonstrated (Ref. 83). I am also satisfied that the accumulator located in room BRA2132ZRM is appropriately segregated from the other two accumulators and therefore the claim of one train being available is justified.

393. However, I have not been satisfied that the current design meets the expectations in SAPs EKP.3 and EDR.4. I base this judgement on the fact that failure of one accumulator could result in loss of two of the three trains available. If the remaining train experienced a fault (for example a single random failure (EDR.4)), the safety function would be lost. The generic UK HPR1000 design intent was to segregate these systems through claimed barriers, and this has not been achieved in this instance. As detailed design progresses, I expect the licensee to address this shortfall, and to enable appropriate regulatory scrutiny I raise the following Assessment Finding.

AF-UKHPR1000-0062: The licensee shall, as part of detailed design, demonstrate that all reasonably practicable measures are adopted to prevent and mitigate the risks from blasts following an accumulator failure.

4.4.3.2 BRX: Exception to Segregation (Criterion B)

394. For Criterion B, the RP screened in sources that could affect more than one train of SSCs within the specific areas of the BRX listed in the exception to segregation area report (Ref. 29). For each exception to segregation area, the internal explosion cases that may impact redundant safety trains were listed by the RP as cases IH-IE-BRX-03 to IH-IE-BRX-06. These are described below:

- IH-IE-BRX-03 – This scenario relates to failure of the accumulator RIS1320BA- in room BRA2107ZRM and the high-pressure pipe RIS1510TY in room BRA2101ZRM and BRA2121ZRM, impacting all three trains of the APG [SGBS] in room BRA2131ZRM.
- IH-IE-BRX-04 – This scenario relates to the failure of the accumulators RIS1320BA-, RIS3320BA- and the high- pressure pipes RIS1510TY-, RIS2510TY-, RIS3510TY- and RCP6140TY, impacting multiple sensors for the reactor coolant pump.
- IH-IE-BRX-05 – This scenario relates to the failure of the surge-line, impacting several pressure sensors for the pressuriser.
- IH-IE-BRX-06 – This scenario relates to the failure of accumulator located in BRA2107ZRM and high-pressure pipes BRX2101ZRM, impacting the narrow range pressure sensors for the steam generators.

395. In all the scenarios listed above the principal safety measures claimed by the RP for protection of the sensors and pipes is the secondary shielding wall. The RP had derived the blast loads from its analysis and used them for barrier substantiation (Ref. 83). The barriers claimed for these scenarios are illustrated in figure 4 below:

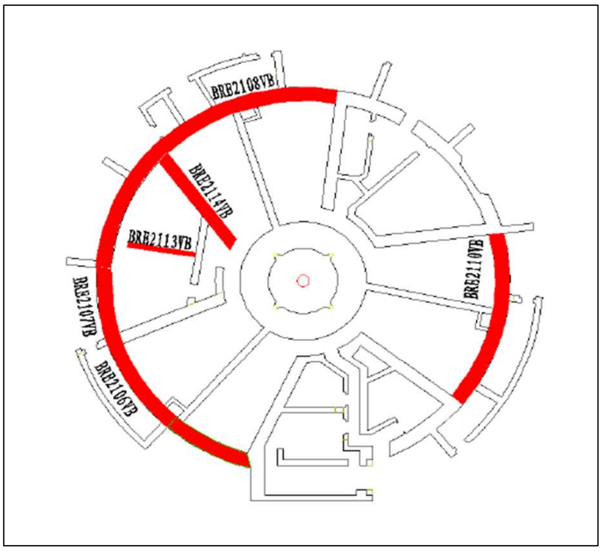

Figure 4: Illustration of barriers claimed for the exception to segregation areas.

396. In all instances of the barrier substantiation the RP had applied the equivalent static method (ACI349-M) (Ref. 40) to determine the global resistance of the identified barriers. The RP claimed that all the required barriers meet their safety functional requirements for strength, and therefore all scenarios have adequate protection in place and in my view satisfies SAPs EHA.3 and EHA.6. However, as highlighted in the previous section, the RP had not adequately considered reflective overpressures in the derivation of the blast loadings for barrier substantiation assessment. This is a shortfall against SAP EHA.2 and I raised it through RQ-UKHPR1000-1766 (Ref. 126)

397. My assessment of the blast loadings for cases IH-IE-BRX-03 to IH-IE-BRX-06 found that they are bounded by the accumulator failures. This provides me with confidence that, for the cases highlighted above, even considering reflection factors, the withstand of the barrier walls is likely to be substantiated. This analysis should be readdressed at detailed design to ensure that the claims are fully substantiated. I have already highlighted these shortfalls in the methodology section and in the relevant Assessment Finding AF-UKHPR1000-0061, and I expect that this to be applied for these cases also.

4.4.3.3 BRX: HIC (Criterion C)

398. For Criterion C, according to the RP’s latest equipment structural integrity classification list (Ref. 128), there are six HIC types arranged in BRX. These are the RPV, the SGs, PZR, MCL, MSL, and the RCP casing and flywheel.

399. Based on the RP’s explosion screening methodology, the RP identified the following bounding cases for explosion hazards:

- IH-IE-BRX-07 which deals with an explosion load on the MCL of loop 1.
- IH-IE-BRX-08 and IH-IE-BRX-09 which both deal with impacts on the pressuriser.

400. These scenarios had also been analysed by the RP as part of RO-UKHPR1000-046 (Ref. 88) to demonstrate that the risks to HIC from hazards are ALARP. In the response to RO-UKHPR1000-046, the RP analysed the explosion loads according to relevant codes and standards such as R3 (Ref. 44) and RCC-M (Ref. 80). The RP concluded that the explosion loads would not challenge the HIC integrity. It was also noted by the RP that all cases have a safety margin.

401. From my assessment of these cases, it is my view that further substantiation of the blast loads is required at detailed design to ensure HIC integrity can be fully substantiated. The licensee should identify and apply all relevant blast correction factors to determine their impact to the HIC, to demonstrate that the risks to HIC are ALARP. From my assessment of these cases I have confidence that the shortfalls relating to the lack of blast correction factors and accounting for blast damage can be addressed through the available margins, but this needs to be considered and demonstrated at detailed design. This is captured in Assessment Findings AF-UKHPR1000-0061 and AF-UKHPR1000-0076. If issues are highlighted, I am content that there are options available to the licensee (such as thickening sections of equipment) to reduce risks further.

402. In addition to the cases described above, an additional case was identified by the RP responding to my queries on the BLEVE criteria. In response to RQ-UKHPR1000-1030 (Ref. 123) the RP acknowledged that the main feedwater (ARE) pipes yielded the highest explosion energy even though it was below the 300ºC screening criteria.

403. The ARE pipes are attached to the SG as they provide water as part of the secondary system for the generation of steam. The RP’s analysis of the blast loading to the SG applied a geometrical adjustment factor to account for the radial direction of the pressure from source to target by multiplying the maximum overpressure by 2. According to the substantiation report of the Steam Generator (Ref. 129) (provided within the RP’s RO-UKHPR1000-046 response), the margin of the upper shell of the SG against the blast load was approximately 99 %. There were also unquantified margins reported by the RP for the nozzles and support structures of the SG. I sampled the geometries involved and I concluded that the applied factor of 2 was conservative based on pipe location relative to the SG. This is sufficient to substantiate the safety margin (99%) thereby providing confidence in the SGs withstand and integrity.

404. Based on the evidence provided by the RP and the analysis undertaken, I am satisfied that explosion hazards to HIC have been minimised and adequate safety margins have also been demonstrated to ensure their integrity. However, there are several shortfalls in the application of its methodology that may lead to non-conservatisms. These need to be addressed by the licensee at detailed design.

4.4.4 BFX: Assessment of Fuel Building Explosion Safety Case

405. The BFX explosion report (Ref. 116) described the application of the RP’s explosion methodology (Ref. 114) and screening. The outputs from the RP’s screening were:

- The RP identified a risk of explosive atmospheres from the hydrogen system.
- The RP stated that oil sources are limited to dampers and pumps, but none are pressurised or contain volatile oil. Due to the systems and materials used, the RP concluded that these items can be excluded from further assessment.
- The RP confirmed there are no high voltage systems therefore HEAF sources had been screened out.
- The RP’s review of the pipe systems with a potential BLEVE risk had been based on the 300°C criteria. The RP concluded that all the pipes were of insufficient size to warrant a bounding case. However, the RP stated that it assessed the APG pipes with a working temperature of 295 °C and diameters up to 150 mm for cliff edge assessment.

406. From my sampling of the RP’s screening approach above and the systems listed in the BFX (Ref. 125), I am content that it is adequate for GDA and meets SAP EHA.19. I also noted the RP had expanded its BLEVE criteria to include pipes outside of its initial screening criteria in response to ONR challenges. For the remaining explosion hazards, I have assessed them in the sections below.

4.4.4.1 BFX: Bounding Cases for Barrier Assessment (Criterion A)

407. As identified by the RP (Ref. 115) there are several rooms within the BFX that contain pipes filled with hydrogen. These pipes transit through the BFX and enter several rooms located directly below the spent fuel pool. The use of hydrogen to control reactor coolant chemistry in the generic UK HPR1000 design is described in (Ref. 130). The hydrogen required for the BFX hydrogenation system is delivered by the nuclear island (NI) hydrogen distribution system [HDS (HI)]. Although the system is identified as [HDS (HI)], the associated pipework is designated as SGH (Ref. 131).

408. The BFX explosion report (Ref. 116) identified that the bounding explosion scenario within the BRX was a hydrogen explosion in room BFX2020ZRM that can impact divisional barrier BFX2058VB (designated in the report as scenario IH-IE-BFX-01).

409. Further assessment of rooms containing hydrogen was also undertaken in response to RO-UKHPR1000-054 (Ref. 58) which specifically sampled the substantiation of walls other than divisional barriers. The RO-UKHPR1000-054 report (Ref. 58) added further confidence that the bounding hydrogen hazard case (Ref. 116) was in room BFX2020ZRM. This is because the RP highlighted that this room had the smallest volume and contained joints and valves which presented credible leak paths. I sampled the evidence provided from both RO-UKHPR1000-054 (Ref. 58) and the explosion report (Ref. 116) and I am satisfied that it provides adequate justification for the bounding case, meeting expectations in ONR SAPs EHA.1 and EHA.19.

410. Based on the hydrogen source, the RP calculated the size of the explosive cloud. A key RP assumption was the hydrogen pipe isolation valve actively closed 10s after the start of hydrogen release. As the RP’s case indicated a reliance on the detection and isolation of the hydrogen, I queried the classification of the valves in RQ-UKHPR1000-1027 (Ref. 132). In response, the RP stated (Ref. 132) that the isolation valve classification was a class 1 system, which was also confirmed in the hazards schedule within the RP’s explosion report (Ref. 116).

411. On the basis that the isolation valve was class 1, I was satisfied that the required reliability was adequate for the potential unmitigated consequences and thus satisfied SAPs ECS.1, ECS.2, FA.3 and FA.4. This was in addition to the RP confirming that the hydrogen pipes are coaxial. The RP stated that the shroud is nitrogen-filled and connected to a class 1 leak detection system. The combination of these measures provided me with confidence on the RP’s claim that the system could achieve the 10s actuation time. On this basis I was satisfied that the RP’s calculated average hydrogen concentration of 7.59 % within the volume, which I noted is above the LEL for hydrogen (4%), was justified. However, in the most recent ALARP review (Ref. 33) and updated consolidated hazards schedule (Ref. 92), I noted that the RP had revised its classifications on both the isolation valve and detection to a class 2. This was a change to the evidence provided and the discussions held with the RP during the step 4 assessment period.

412. As stated earlier, it is my view that reliance on the valve operation is essential to ensuring the volume of hydrogen released stays within acceptable levels for the safety case. Inability to isolate the system within the required time would challenge the barrier claims and potentially lead to a significant blast impact to the fuel pond. This does not satisfy SAPs ESS.1, EHA.1, EHA.3, EHA.18, EHA.7 and EHA.14. I have therefore raised the Assessment Finding AF-UKHPR1000-0063 for the licensee to demonstrate that the safety measures claimed can deliver the required safety functions to reduce the risks to ALARP.

413. Once the hydrogen concentration had been determined, the resulting overpressure needed to be calculated. The RP adopted the ideal gas law approach, based on the assumption that the overpressure was a result of a deflagration rather than a

detonation. I am satisfied that this approach to calculate the explosion is appropriate as the hydrogen concentration is less than 10%, thus the potential of detonation is unlikely. This is predicated on the fact that adequate safety measures are in place to detect and isolate a hydrogen leak before a higher concentration can develop. I judge this an acceptable approach satisfying SAP EHA.6.

414. I sampled the approach applied by the RP to calculate overpressures resulting from the hydrogen explosion. I found that the initial calculations had been based on hydrogen in oxygen mixtures rather than hydrogen in air. This indicated an underestimate of overpressure as calculated by the RP. I considered that may lead to the application of non-conservative dynamic load factors in the barrier substantiation. I discussed my findings at length with the RP and raised RQ-UKHPR1000-1027 (Ref. 132), RQ-UKHPR1000-1337 (Ref. 133) and RQ-UKHPR1000-1654 (Ref. 134). The key outputs from the RP's responses to these RQ's were:

- The RP indicated that there are two SGH [HDS] hydrogen pipes present in the room, the hydrogen concentrations from failure of both could present a detonation hazard which is a more severe challenge to the building.
- The RP stated that its review of the design of the SGH [HDS] system was not within GDA scope. However, the RP stated that according to the system design manual of the SGH [HDS] system for reference plant (FCG3), the two hydrogen pipes of the SGH [HDS] system in the BFX are backup for each other.
- During normal operation, the RP stated that only one SGH [HDS] hydrogen pipe would be filled with hydrogen and the other SGH [HDS] pipe will be empty.
- Both hydrogen pipes are connected to the same upstream pipe.
- The maximum flow rate in the upstream main pipe is limited to 50m^3/h by a restriction orifice.
- The RP presented further analysis assuming both pipes are damaged by fire when changing from one pipe to another. The RP stated that the release would include the residual hydrogen from the off pipe in addition to the 10s release of the operational pipe. The RP also highlighted that due to the restriction orifice on the upstream main pipe, the maximum leaking flow rate is always limited to 50m^3/h.
- Based on these assumptions the additional analysis concluded that the hydrogen concentration in room BFX2020ZRM would increase to 8.74%. The RP stated that this value is slightly larger than the hydrogen concentration of one pipe leakage but still below the threshold of detonation.
- The RP's analysis was re-done based on the updated hydrogen volume and corrected factors for hydrogen in air.
- The RP's results provided an updated estimation of overpressure. The RP's analysis resulted in an internal compartment pressure of 0.3MPa, which was 50% larger than the original analysis predicted.
- The RP stated that the withstand of the thinnest walls, with a thickness of 0.6m, under the spent fuel pond can be substantiated against the compartment pressures.

415. Based on the analysis presented by the RP and responses to my queries as described above, I am satisfied that the RP's initial argument to exclude the consideration of detonation from hydrogen within the fuel building is acceptable. I base this on the RP's calculated hydrogen concentration on my current understanding of the design and operating intent of the system. The RP has addressed my concerns within the analysis and recalculated loadings in line with appropriate methodologies. The RP has also demonstrated barrier withstand (Ref. 97). Notwithstanding my findings on the classification of the valves and detection, I am satisfied that the RP has implemented appropriate defence-in-depth methods with regards the management of hydrogen satisfying SAP. EKP.3. This includes:

- Co-axial piping; the inner pipe containing hydrogen and the outer pipe containing a nitrogen gas.
- Automatic isolation valves.
- Connection to the NI hydrogen detection system; the alarms are set to actuate the isolation valves at hydrogen concentration levels higher than 0.4%. This is in line with relevant good practice (Ref. 135).

416. Although I have been satisfied that the RP addressed my concerns with the analysis of the hydrogen hazard in the BFX, I raised a further challenge in RQ-UKHPR1000-1654 (Ref. 134) regarding the layout and the RP's decision to locate the hydrogen pipes under the spent fuel pool within the generic UK HPR1000 design. In response (Ref. 134) the RP argued that the current design is fixed with respect to the routing of pipes and, given the assessment, the RP concluded that the risks are low.

417. ONR SAP.ELO.4, states that a design should look to optimise its layout to eliminate hazards so far as is reasonably practicable. Despite the conclusions of the analysis, the hydrogen hazard still exists, and noting my findings on the reliability claims for the isolation valve and detection systems addressing this is key for the safety case to justify the exclusion of a detonation hazard. It is therefore important that not only does the licensee substantiate the isolation claims but also reviews the pipe work layout optimisation (such as rerouting the SGH [HDS] pipes). I consider this a matter for detailed design which the licensee should address. I therefore raise Assessment Finding AF-UKHPR1000-0063 for the licensee to identify and implement pipework optimisation to reduce the risks to ALARP.

AF-UKHPR1000-0063: The licensee shall, as part of detailed design, demonstrate that the risks from blast following failures in the hydrogen pipe network within the fuel building are reduced to as low as reasonably practicable. This should include but not be limited to:

- Demonstration that the layout of the hydrogen pipe network in the fuel building is optimised for hazard elimination.
- Demonstration that the reliability of safety systems for the detection and isolation of hydrogen gas, can deliver the safety case requirements arising from the consequences of an unmitigated hydrogen release.

418. In the BFX, a second explosion source was identified by the RP. This source related to two APG [SGBS] pipes in room BFX1596ZRM that could impact the divisional walls BFX1565VB and BFX15G1VB. Based on the distance to the relevant walls, the RP calculated the explosion loadings from failure of the pipes. The RP's analysis identified that barrier BFX15G1VB was the thinnest part of the divisional barrier (500mm) between division A and C, and presented the bounding case.

419. I sampled the Reinforced Concrete Barrier Substantiation Report for BFX (Ref. 97) to assess the RP analysis. From my sampling I noted that barrier BFX15G1VB had not been analysed in the barrier substantiation report. However, the other barrier BFX1565VB had been analysed. Recognising that the APG system was a high energy pipe, I also sampled the 'High Energy Pipe Failures Safety Assessment Report for Fuel building' report (Ref. 136) to determine if the barrier was identified in that report. I noted the following:

- The HEPF report did highlight barrier BFX15G1VB as a sample area.
- The blast values and narrative in the HEPF report were aligned with the explosion report. This provided me with confidence that there was a level of consistency across the reports.

- The HEPF report stated that the loads on barrier BFX15G1VB are bounded by another equivalent 500mm barrier with a higher blast loading and combined steam release. This bounding barrier (BFX1517VB) was identified by the RP as bounding case IH-HEPF-BFX-09.
- The barrier BFX1517VB was analysed in the barrier substantiation report (Ref. 97). The RP's analysis was undertaken in line with ACI349M (Ref. 40) and demonstrated withstand from the loading. I am satisfied this is an adequate approach.

420. From my assessment of the RP's evidence across the safety case, I am satisfied that barrier BFX15G1VB will have an adequate withstand based on the bounding case analysis applied by the RP, and I have confidence that the safety functions are assured and satisfy SAPs ECS.2 and ECS.3.

421. In summary, for the bounding case analysis within the BFX, I have been satisfied the RP provided an adequate case to demonstrate that the risks from the explosion hazards in the plant are acceptable, for the purposes of GDA. I am content that the barriers have been adequately substantiated; however, this is predicated on having adequate hydrogen detection and isolation systems. It is also my view that consideration should be made by the licensee to remove the hydrogen hazard from below the spent fuel pool through pipe layout optimisation.

4.4.4.2 BFX: Exception to Segregation (Criterion B)

422. The RP's assessment has identified that there are no explosion sources located in any of the exception to segregation areas within the BFX. The RP has shown that all the explosion sources will be segregated from the redundant equipment with divisional barriers. The impact on the divisional barriers is assessed in the assessment against criterion A as discussed above.

423. Based on my assessment of the RP's evidence, (Ref. 116), (Ref. 58), I am content that the RP has demonstrated that adequate screening of the explosion sources has been undertaken. The RP has provided me with confidence that there are no explosion sources that can impact exception to segregation areas.

4.4.4.3 BFX: HIC (Criterion C)

424. There are no HIC identified within the BFX.

4.4.5 BSX: Assessment of Safeguard Building Explosion Safety Case

425. The BSX explosion report (Ref. 117) presented the RP's hazard identification and screening of the systems and components that could present a risk of an explosive hazard. The RP's report highlighted the following:

- There are no flammable gas pipes within the BSX buildings, however there are six back-up battery rooms with the potential of hydrogen gas build up.
- For oil mist hazards there was no equipment identified with pressurised oil, and therefore oil mist was ruled out.
- The safeguards building contains a number of electrical systems and several sources of equipment operating above 10kV had been identified.
- Several sources of BLEVE exist in the BSX that could impact barriers, exception to segregation areas and HIC.
- To eliminate explosion hazards high pressure vessels are arranged away from the MCR and electrical instrument and control equipment.

426. I have sampled the RP's screening as described above and I am satisfied that the RP has identified the key systems in the BSX (Ref. 125), and applied appropriate hazard screening for the purposes of GDA, thereby satisfying SAP EHA.19.

4.4.5.1 BSX: Bounding Cases for Barrier Assessment (Criterion A)

427. Following the RP's hazard identification and screening as detailed in the explosion analysis report (Ref. 117), the RP identified the following bounding cases:

- IH-EX-BSX-01 – This scenario relates to a build-up of hydrogen within one of the battery rooms in the BSC.
- IH-EX-BSX-02 – The Scenario relates to a HEAF within the BSC.
- IH-EX-BSX-03 – This Scenario relates to a BLEVE within BSB.

428. I elected to sample each of these cases as part of my assessment as each scenario related to a separate explosion source.

429. Scenario IH-EX-BSX-01 described the failure of the battery room's ventilation system resulting in a build-up of hydrogen. The RP's screening identified that battery room BSC2429ZRE had the smallest volume and is adjacent to a divisional barrier. My sampling of this scenario identified that the explosion assessment had not included design modifications which had enlarged the capacity of the battery rooms to deliver the required 24-hour battery capability. To obtain clarity on how this modification had been analysed by the RP I raised RQ-UKHPR1000-1340 (Ref. 137).

430. The RP's response (Ref. 137) clarified that only two battery rooms had a significant increase in the number of batteries, however, the RP also clarified that the volume of these rooms had also been increased. The RP stated that the increase in room volumes had resulted in a reduction of the average hydrogen concentration when compared to the original assessment. Based on the evidence provided I was satisfied that the RP had adequately addressed my query.

431. For the analysis of the hydrogen hazard, the RP applied the same methodology as I described in the previous section. The RP applied the same non-conservative approach assessing the scenario with values that did not represent the hydrogen in air scenario, which was addressed through RQ-UKHPR1000-1654 (Ref. 134). The RP's response to RQ-UKHPR1000-1654 (Ref. 134) provided improved calculations demonstrating an appropriate analysis methodology for a hydrogen deflagration.

432. However, the RP's response to RQ-UKHPR1000-1654 was specific to the BFX rather than BSX, and it is my view that the RP's updated approach is also directly relevant to this hydrogen hazard in the BSX. I judge that the current analysis does not appropriately apply these methods and therefore does not satisfy SAP AV.2. Based on my findings I consider this a shortfall which should be addressed as part of AF-UKHPR1000-0061 where, at detailed design the licensee should apply the updated approach to reassess the hydrogen explosion loads in the BSX buildings, to demonstrate that the risks are ALARP.

433. Although this shortfall remains, I have assessed the scenario to judge if the overall risk from this hazard is acceptable. From my sampling I highlight the following:

- The explosion load used in the RP's analysis had been based upon a postulated worst-case hydrogen concentration of 10% within the given volumes.
- There are multiple safety measures identified in the safety case (Ref. 117) and clarified in the RP's responses RQ-UKHPR1000-1340 (Ref. 137) and RQ-UKHPR1000-1435 (Ref. 138) that are in place to reduce the likelihood of the hydrogen concentration in the room reaching 10%. These measures include:

- The HVAC system DVL[EDSBVS] is designed to provide the required air change rates in the battery rooms ensuring hydrogen levels remain below the prescribed alarm limits. The system has a primary fan and a secondary back-up system.
- If both ventilation systems fail, a first stage hydrogen alarm is set to be triggered at 0.4% and a 2nd stage hydrogen alarm is to trigger at 1% - I am satisfied that these values are consistent with DSEAR requirements (Ref. 135).
- The battery room is classified as a DSEAR zone 2. Therefore, lights and fans should be appropriately EX-rated to minimise the ignition source risk. As a further mitigation the room light switches are located outside the room.
- In the event of a hydrogen alarm, the plant requires manual isolation of the charging current to the batteries. The RP has stated that, at the point of the alarm, it would take 4 hours 50 minutes to reach 25% of the lower explosive limit (1%) (Ref. 139).

434. Based on my sampling and the above measures to prevent and mitigate hydrogen hazards, I am satisfied that although a shortfall exists in the analysis, adequate measures are in place to detect and to respond to the build-up of hydrogen - this satisfies SAP ESS.1. However, to ensure that the classification of these systems is correct and adequate substantiation of the barriers is provided, the analysis needs to be updated to reflect the improved methods.

435. For IH-EX-BSX-02, the RP identified a 12kV system, stated to be the highest voltage of equipment, located in room BSA2822ZRE. As per the RP’s explosion methodology it applied the TNT-equivalent approach (Ref. 114). From the RP’s analysis based on the electrical energy released from the 12kV system equating to 547g of TNT equivalent mass, this was then used by the RP to convert to a blast load on the target barrier BSC2801VB which is stated by the RP to be 50kPa. I am satisfied from my sampling of IH-EX-BSX-02, that the RP applied an appropriate methodology which I consider conservative. I have assessed the BSX barrier substantiation report (Ref. 101) and I am satisfied that the barrier withstand was adequately substantiated with significant margin.

436. The final bounding case identified by the RP related to a BLEVE. The IH-EX-BSX-03 scenario describes the failure of the atmospheric steam dump system VDA [ASDS] VDA3210TY within BSB3702ZRM, impacting barrier BSC3718VB. The VDA [ASDS] system performs the function of removing residual heat by discharging steam from the steam generators directly into the atmosphere, this is a claimed heat removal system under DBC 2/3/4 and DEC-A. This system consists of three trains. Train A is located in the BSA and trains B & C are located within the BSB.

437. From my sampling I am satisfied that the RP’s analysis had applied the appropriate methodology as described for BLEVE (see sub-section 4.4.2). The RP calculated the characteristic explosion size and derived the energy of the explosion release. The total energy released was calculated by the RP to be 2.97MJ. The RP stated that the pipes are approximately 9.8m away from the barrier, adopting the Baker-Tang curves the RP derived overpressure was 9kPa.

438. I assessed the BRX Barrier substantiation report (Ref. 101). I noted that the barrier had been assessed as part of the BSX HEPF assessment (Ref. 140) as the failure of the pipe VDA3210TY included additional combined loadings (2m flooding and 38.84kPa internal pressure) which had been included in the substantiation analysis in line with ACI349M (Ref. 40). I am satisfied that the RP’s analyses demonstrate withstand of the barrier with significant margin, satisfying SAPs EHA.3 and EHA.6.

439. In summary, based on my sampling I am satisfied that sufficient evidence has been provided by the RP to demonstrate that the divisional barriers have adequate withstand against explosion loads.

4.4.5.2 BSX: Exception to Segregation (Criterion B)

440. The BSX explosion report (Ref. 117), stated that screening of explosion hazards for exception to segregation areas has been done in accordance with the generic UK HPR1000 exception to segregation list (Ref. 29). This highlighted the following relevant areas within the BSX:

- The locations where the two trains of main feedwater (ARE [MFFCS]) and main steam lines (VVP [MSS]) are located. For these areas the RP screened out BLEVE. The explosion report stated that the operating temperature of the ARE [MFFCS] system is 228^{0}C and concluded that the ARE [MFFCS] system would not result in an explosion load. The failure of the VPP [MSS] was discounted by the RP as it is HIC.
- The main control room (MCR). The generic UK HPR1000 design sets out requirements that hazards to the MCR should eliminated as far as is reasonably practicable. The RP's survey of the plant and building layout identified there are no explosion sources within the BSC capable of impacting the MCR. However, the RP identified that there are pipe systems routed around the external perimeter of the BSX buildings. This includes the main steam lines and drainage systems which all co-locate outside the MCR external wall. As a result, the wall of the MCR is claimed as barrier BSC3337VB in bounding case IH-EX-BSX-04. The scenario is illustrated in figure 5 below.

441. I am satisfied that the RP's exclusion of VPP [MSS] as an explosion source is acceptable based on the HIC classification of the system. This should ensure that it is sufficiently reliable that its failure can be discounted from the design basis satisfying SAP. EMC.1. However, for the ARE [MFFCS] system it is my view that the impact of its failure with respect to BLEVE should be assessed, and I have captured this in Assessment Finding AF-UKHPR1000-0061. Notwithstanding this, I judge that the pipe temperature quoted by the RP is sufficiently low not to present a significant hazard and therefore, I am of the opinion that there is not a significant risk gap. However, at detailed design, the licensee should consider this scenario in response to the recommendations already raised for BLEVE analysis.

442. I also sampled the RP's analysis of scenario IH-EX-BSX-04. My sampling identified several inconsistencies across the various RP's safety case documents relating to the RP's calculated overpressures from failure of the steam lines, and the MCR external wall structure. I raised RQ-UKHPR1000-0925 (Ref. 141) and RQ-UKHPR1000-1340 (Ref. 137) to clarify the RP's safety case regarding the overpressure analysis and the barrier withstand.

443. The RP's responses to RQ-UKHPR1000-0925 (Ref. 141) and RQ-UKHPR1000-1340 (Ref. 137) highlighted the following:

- The failure of the main steam line pipe VPU3101TY would result in an overpressure of 82kPa.
- The failure of all three high pressure pipes would result in overpressure of 310kPa.
- The dynamic loading factor of 0.2 has been derived in accordance with ACI349M-13 (Ref. 40).
- The MCR external wall is designed to withstand aircraft impact and the external wall of the MCR has been increased to 1.6m.
- There are multiple pipe restraints on the external wall to limit the pipe whip and avoid loads on the wall.

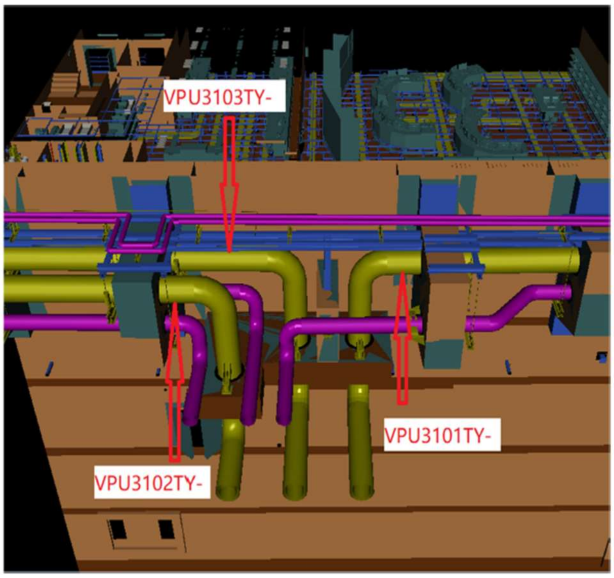

Figure 5: Illustration of Steam line configuration

444. I have assessed the responses from the RP as described above in addition to the explosion report (Ref. 117) and I note the following:

- The explosion analysis undertaken by the RP related only to the failure of the VPU pipes. This is because the RP had screened out BLEVE of the ARE pipe due to its operating temperature the comments I made above in this regard are also relevant here. However, given that the main steam line operates at temperatures meeting the RP’s BLEVE criteria and is larger in diameter, I am satisfied that the blast loads in this scenario will be dominated by the main steam line failure considered to be the bounding scenario, satisfying SAP EHA.3.
- I sampled the RP’s analysis in the BSX barrier substantiation report (Ref. 101). I noted that the RP had included the combined loads from jet loads and blast as the VPU is a high energy pipeline. Pipe whip was screened out by the RP due to the pipe restraints located on the side of the building. Flooding and overpressure were also screened out as the pipes are in open air. I am satisfied that the RP’s assumptions and screening of the loads are appropriate, thereby satisfying SAP EHA.19.

445. Based on the findings above I further sampled the barrier substantiation report (Ref. 101) to get confidence that the hazard loads have been appropriately applied. My sampling identified a lack of clarity in the justification of the pipe break locations and the hazard loads applied, such as the claimed restraints. To get further clarification, I raised RQ-UKHPR1000-1564 (Ref. 142) to understand how each hazard load was applied, including pipe whip (on the restraints), jet load, and blast.

446. In its response (Ref. 142), the RP clarified that the loads had been based on a single pipe break. However, the RP extended its analysis to consider the failure of all three pipes. The RP derived the overpressure on the MCR wall of 310kPa for the combined failure of the pipes and applied the appropriate jet forces. Based on the combined loadings, the RP concluded that the MCR external wall would have withstand. I am satisfied that the additional analysis presented by the RP addressed my queries. I also note that the analysis had been based on a wall thickness of 1.2m. The RP confirmed that the thickness of this wall has now been increased to 1.6m (Ref. 142); this provides me with further confidence that the MCR would remain available in the event of this hazard.

447. The RP's response to RQ-UKHPR1000-1564 (Ref. 142) also provided me with confidence that the RP had applied appropriate loadings to the various restraints following pipe failures demonstrating that they would prevent pipe whip. I note that blast reflections had not been considered on these structures. I am of the opinion that these are unlikely to change the conclusions of the RP's assessment, but the additional loads should be considered by the licensee as part of the design loads. This is captured in Assessment Finding AF-UKHPR1000-0061.

4.4.5.3 BSX: HIC (Criterion C)

448. The RP's screening identified that the pipework associated with the Atmospheric Steam Dump System (VDA [ASDS]), could also impact the main steam line within the BSX. The VDA system is a high energy system and has been discussed above as this system can also impact the divisional barrier BSB3702ZRM.

449. The impact of this system to the main steam line has also been analysed by the RP in its response to RO-UKHPR1000-046 (Ref. 89). The RP's analysis concluded that a blast loading of 90kPa overpressure would impact the MSL (VVP2120TY) and a 30kPa overpressure would impact the main steam isolation valve MSIV (VVP2220VV). The RO-UKHPR1000-046 analysis (Ref. 89) presented the substantiation of the explosion loadings on the MSL and the MSIV.

450. I noted that in this instance the RP stated that the blast loads included reflected pressures and drag pressures, however the overpressures derived in the explosion report did not provide the evidence to support this claim (Ref. 117). The shortfall related to the application of relevant explosion factors has been raised several times within this report and the associated shortfalls apply here, although in this case relates to the justification of them. The RP applied the RCC-M (Ref. 80) codes in line with the HIC analysis methodology (Ref. 143) to demonstrate the components' integrity.

451. From my sampling, I am satisfied that the RP has applied the appropriate RCC-M damage criteria and the withstand of the MSL had been demonstrated with a safety margin of 77.38%. For the MSIV, the RP stated that because the MSIV (VVP2220VV) is thicker than the MSL, it could also withstand the blast loading. However, I could not find any substantial evidence to underpin this claim. In principle this seems a reasonable assumption and the conclusions by the RP are plausible, however, it should be acknowledged that a valve has multiple components, and therefore appropriate analysis should be undertaken by the licensee to adequately substantiate this claim at detailed design. As the MSIV is a HIC, I have raised this as an Assessment Finding against SAPs EKP.2, EKP.3, EKP.4, EHA.6 and FA.4.

AF-UKHPR1000-0064**:** The licensee shall, as part of detailed design, substantiate the main steam isolation valves against blast loads.

452. Overall, notwithstanding the Assessment Finding, I am satisfied that for the purposes of GDA the RP has provided sufficient evidence to demonstrate that the blast loads to HIC would not lead to loss of integrity. The RP's analysis to determine the loadings has been in accordance with appropriate and relevant standards (RCC-M). This provides me with confidence that the withstand claimed is within the acceptable code limits. The margins demonstrated provides further assurance that any additional analysis is unlikely to undermine these claims.

4.4.6 Summary of Assessment and Affirmation of PCSR Claims

453. For explosion hazards, the principal safety measures identified by the RP are primarily the class 1 divisional barriers. I am satisfied the RP provided sufficient evidence to substantiate the barriers, noting that various shortfalls exist within its methodologies,

and I have seen sufficient margins to judge that these shortfalls are unlikely to challenge the withstand claims.

454. There is one specific location within the BRX where segregation between two trains of accumulators had not been demonstrated by the RP and therefore does not satisfy SAPs EDR.2, EHA.15 and ESS.1. I have captured this shortfall as an Assessment Finding (AF-UKHPR1000-0062) to be considered by the licensee at the detailed design stage. I have sampled the consequences in relation to plant safety, and I judge that the RP has provided an acceptable case, for the purposes of GDA.

455. I identified further shortfalls regarding the layout and routing of the hydrogen pipes in the BFX. I was satisfied that the RP had in place sufficient safety measures to manage the hydrogen hazard, for the purposes of GDA, but demonstration that the reliability of the safety systems for the detection and isolation of hydrogen gas had not been adequately justified and therefore does not satisfy SAPs ESS.1, ESS.2, ELO.4 and EHA.6. I have captured this shortfall as part of AF-UKHPR1000-0063.

456. Overall, taking all my findings into account, it is my view that the generic UK HPR1000 layout has not been demonstrated to be optimal from an explosion hazards perspective. However, based on the claimed safety measures identified by the RP for the prevention and mitigation of explosion hazards, I am satisfied that the RP has provided an adequate assurance, for the purpose of GDA. The analysis undertaken by the RP has provided me with confidence that explosion hazards do not challenge the fundamental safety of the plant within the scope of my GDA assessment. At detailed design I expect the shortfalls I have highlighted to be addressed by the licensee, through a combination of analysis and design choices.

4.4.6.1 Affirmation of PCSR Claims for the Explosion Safety Case

457. This section provides a summary of my assessment of the principal claims associated with the internal hazards explosion safety case.

- Sub-claim 3.2.2.SC19.2.4 (Explosion): The internal explosion sources are sufficiently identified.

458. Based on the evidence provided and assessed, I am satisfied that the RP has demonstrated that the principal explosion sources have been identified. I am satisfied that the methodologies applied are in line with relevant good practice. Although several shortfalls exist, the RP’s responses and updated analysis has given me confidence that they do not result in significant risks to the plant.

- Sub-claim 3.2.2.SC19.2.5 (Explosion): After the safety assessment, the safety measures to mitigate the consequences of internal explosion are sufficiently identified and properly classified.

459. The analyses carried out by the RP adequately demonstrated withstand of the barriers. However, one barrier was identified through my sampling that did not meet its safety functional claim and an Assessment Finding raised to ensure appropriate focus on the shortfall. The RP clearly identified areas of exception to segregation and analysed the impacts of explosion load to redundant safety trains as well as for HIC.

- Sub-claim 3.2.2.SC19.2.6 (Explosion): The safety measures to mitigate the consequences of internal explosion are sufficiently substantiated.

460. The principal safety measures for explosion loads are largely related to the various class 1 barriers. The RP has provided sufficient evidence through the demonstration of explosion loads and barrier substantiation to justify the safety functional requirements on the identified barriers.

4.4.7 Explosion Safety Case Strengths

461. Through my assessment recorded above, I have noted the following strengths in the RP's internal explosion safety case:

- The RP has provided adequate responses to the queries raised and applied appropriate good practice.
- Explosion sources to HIC have been minimised by the RP and withstand has been substantiated where required.

4.4.8 Outcomes

462. Through my assessment of the RP's internal explosion safety case, I am satisfied that the RP has provided adequate evidence to underpin its explosion assessment for the purposes of GDA. The RP has demonstrated adequate hazard identification and that screening has been applied in line with its assessment criteria (A, B and C). Further work is required to ensure full coverage of the buildings at detailed design

463. My assessment has identified several areas of improvement through a mix of Assessment Findings and minor shortfalls. My Assessment Findings relate to the explosion hazards analysis methodology, the shortfalls identified with the claimed divisional barrier segregating two trains of accumulators, and hydrogen hazards under the spent fuel pool.

4.4.9 Conclusions

464. My assessment of the generic UK HPR1000 internal explosions safety case has been informed by several submissions, RQs and ROs. The breadth and depth of the assessment was focused on the key risk areas and the quality of evidence provided.

465. Although I have identified several Assessment Findings, I am content that the principal risks from explosions have been identified and understood for the purposes of GDA.

466. Therefore, based on the outcomes of my assessment of the RP's internal explosion hazards safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and have raised Assessment Findings. I do not judge that these gaps are significant enough to prevent the issue of a DAC, as I am content that they can be addressed by the licensee at detailed design.

4.5 Hazard Assessment – Flooding

4.5.1 Principal Claims from the Generic UK HPR1000 Flooding Safety Case

467. The generic UK HPR1000 flooding safety case for the sample buildings (BRX, BFX and BSA/BSB/BSC) is comprised of the following documents:

- Internal flooding methodology report (Ref. 144).
- Reactor Building Flooding Zoning Drawing (Ref. 145).
- Fuel Building Flooding Zoning Drawing (Ref. 146).
- Safeguard Building Flooding Zoning Drawing (Ref. 147).
- Reactor building flooding safety assessment report (Ref. 148).
- Fuel building flooding safety assessment report (Ref. 149).
- Safeguard building flooding safety assessment report (Ref. 150).

468. The principal claims for the flooding safety case for the generic UK HPR1000 design are defined within the pre-construction safety case report (PCSR) Chapter 19 Internal hazards (Ref. 3). These principal claims are stated as:

- Sub-claim 3.2.2.SC19.2.7 (Flooding): The internal flooding sources are sufficiently identified.

    - Argument 3.2.2.SC19.2.7-A1 (Flooding): The systems and components (i.e. pipes, tanks/ vessels) containing liquid are sufficiently identified.

- Sub-claim 3.2.2.SC19.2.8 (Flooding): After the safety assessment, the safety measures to mitigate the consequences of internal flooding are identified and properly classified.

    - Argument 3.2.2.SC19.2.8-A2 (Flooding): Where there are exceptions to segregation, safety measures are identified to ensure sufficient SSCs are available, during and after an internal flooding, to deliver the safety functions.
    - Argument 3.2.2.SC19.2.8-A3 (Flooding): An internal flooding does not cause unacceptable damage to HIC.
    - Argument 3.2.2.SC19.2.8-A4 (Flooding): The safety measures to mitigate the consequences of internal flooding are classified in accordance with the methodology of safety categorization and classification.

- Sub-claim 3.2.2.SC19.2.9 (Flooding): The safety measures for internal flooding are sufficiently substantiated.

    - Argument 3.2.2.SC19.2.9-A1 (Flooding): Barriers between different internal flooding zones can withstand the loads imposed by flooding associated with the maximum flooding level.

4.5.2 Flooding Methodology Assessment

469. This section presents the findings of my assessment of the RP’s flooding methodology (Ref. 144). The methodology included identification, screening and assessment of flooding hazards and their consequences within the generic UK HPR1000 design.

470. My assessment has been undertaken in line with ONR expectations for a flooding safety case, as described in ONR SAPs (Ref. 2), and against relevant international standards for safety in the design of nuclear power plant including from IAEA SSR 2/1 (Ref. 14), SSG-64 (Ref. 15) and WENRA SRLs (Ref. 60). These standards highlight the key elements that should be demonstrated by a flooding safety case and include:

- All internal flooding sources should be identified and analysed taking account of fluid type, pipework layout, source inventories and isolation arrangements credited.
- All effects from floods should be considered including flow rates, deluge, submergence and spray, and water spread paths.
- Relevant safety measures should be identified, appropriately classified and substantiated, such as flood doors, drainage, bunding and flood detection and isolation to minimise the risks from flood effects.

471. The RP’s flooding methodology and philosophy sought to demonstrate that floods occurring within the generic UK HPR1000 design do not undermine the main design principles (Ref. 61), namely:

- A design basis flood should not result in loss of any fundamental safety function.
- A design basis flood should not result in design extension conditions (see sub-section 3.2.2.4).

472. To achieve these high-level principles, the RP’s methodology presented guidance to inform the layout of flood sources and subsequent identification, analysis, and management of any potential flood hazards within the design. The principles established include avoidance of pipework in areas with components sensitive to water, minimising the amount of flood sources, segregating redundant safety trains, and either to locate vulnerable components above the maximum flood levels or to protect them by other means. For analysis, the methodology details the main assumptions used to determine the severity of the flood. These included the following:

- Assuming that any source containing a liquid (e.g. pipes, tanks, and vessels) has the potential to present a flood hazard.
- The failure is based on a double ended guillotine break.
- Release of the full inventory is assumed as a basis of initial assessment for all piping components.

473. I am satisfied that the above methodology is aligned with relevant good practice such as IAEA SSG-64 (Ref. 15). The methodology sets out clear requirements to reduce the risks of flood to SSCs, through focusing on design optimisation (via design principles) and required engineered measures. The RP’s methodology also sets out requirements for the identification and analysis of flood effects including of submergence, spray, condensed steam, and waves, and conservatively assumes double ended guillotine break.

474. The RP’s flooding methodology also outlined the generic UK HPR1000 primary safety measures for protecting SSCs from flood waters through the provision of defined flooding zones. The methodology outlines the flooding zones’ requirements applied within the design that provides the required protection for the relevant safety functions. The RP’s different types of internal flooding zones are defined as:

- Common Mode Prevention Internal Flooding Zones: the boundaries of separate safety divisions i.e. divisional barriers. These boundaries are predominantly reinforced concrete structures (barriers), including active elements (e.g. doors) which can be open, or penetrations designed as watertight.
- Forbidden Internal Flooding Zones: areas where the RP cannot tolerate flooding by an internal source because they constitute exceptions to segregations (ETS). By identifying these zones, the RP intended to ensure that redundant safety trains are located within different common mode prevention internal flooding zones to the extent practical.
- Non-Safety Internal Flooding Zones: these are areas from which releases and flooding to one of the other types of internal flooding zones must be prevented.

475. The RP’s methodology presented a stepwise approach for the identification of flooding zones. The approach is based on designating zones in each building based on required nuclear safety functions and segregation of trains, and then requires the identification of flood sources in each zone. Subsequent steps included the determination of potential flood levels, flood duration and the identification of protection measures to reduce the likelihood and severity of the consequences to nuclear safety systems within each zone. The RP’s safety case also has two specific safety functional requirements defined for flood zone boundaries in addition to the requirement for flood zone designation, these are:

- Boundaries of floors below the ground floor (i.e. level ±0.00 m), to withstand, as a minimum, the flood height between the floor level and the ground floor.
- Boundaries of floors at level ±0.00 m and above, to withstand at least 2 m hydraulic pressure.

476. It is my opinion that the implementation of flood zones, to segregate different safety divisions from flood effects and the additional design principles is in line with

international guidance, in IAEA SSG-64 (Ref. 15). For each internal flooding zone, the RP required a flooding liquid storage area (i.e. basement) to have a capacity sufficient to hold the credible worst-case flooding volume in the design. The RP's methodology provides a strategy to enable flood waters to flow into these liquid storage areas that are designed to keep the waters within them. I judge that these design principles are adequate and in line good practice such as IAEA SSG-64.

477. For the analysis of the flood effects and consequences the RP's methodology presented its approach for determining the:

- The flow rate of the flood.
- Flood duration.
- Flood spread paths.

478. I have assessed the analysis methods presented by the RP and note the following findings:

- The flood flow rate from a pipe is calculated based upon a full guillotine break and this is in line with ONR expectations (Ref. 7). The flow rate is calculated using the Torricelli formula. The formula uses the cross-sectional area of the pipe (in this case the full bore) and pressure at which the pipe is operating and therefore, in my opinion, provides a conservative value as the most onerous values are used. For vessel failure and closed loop systems, the RP assumed the total release of liquid for the entire system. With these assumptions I am satisfied that the assessment of full volume release for vessels and closed systems is conservative, as all the volume is considered, and for pipe rupture this is based on a full guillotine break at maximum operating pressures.
- Flood duration is a key parameter in the determination of a flood hazard. This parameter, given the RP's approach, mainly applies to the systems that do not have a finite volume, such as pipes with a water feed from an external source. In this instance the flood duration is a function of the time it takes to detect the flood and isolate the flood source.
- The RP's methodology presented a series of assumptions underpinning the various methods incorporated in the design to detect and isolate flood waters. These measures include automatic detection and isolation, alarm and manual isolation and manual detection and action. These measures are in my opinion all representative of good practice; assuming the detection and isolation systems are adequately classified. However, for the purposes of the methodology assessment, I am satisfied that the crediting of these measures is adequate as part of the determination of the flood duration.
- For areas that have no detection measures the methodology presents an assumption on operator intervention. The methodology assumes that they would be able to detect and isolate a flood within a maximum of 8 hours. This 8-hour value presented by the RP has been based upon the assumption that visual inspections undertaken by operator personnel during normal plant walk-downs (3 shifts per day) would detect and lead to isolation (Ref. 144).
- I have considered the assumptions proposed and, in my opinion this assumption may not provide a conservative estimation of the potential flood duration. This is because it is possible that operators of two shifts may not necessarily take the same route for the walk-downs or may schedule plant areas for different periods in their shift. It is therefore my view that the 8-hour claim should be viewed as a medium/mean value, but not necessarily a wholly conservative assumption (16h would be the worst case). The methodology also includes a minimum delay (non-intervention) time of 30 min between the detection of the flood and operator action; this is a widely used standard value which I judge to be adequate and in line with SAP ESS.9. Overall, I am satisfied that the RP's approach for determining flood durations is adequate. However, a non-conservative assumption had been adopted to determine flood

durations in areas or systems that do not have automatic leak detection. It is possible that a single shift may not detect the flood due to not inspecting a specific location. This is a minor point at this stage as the licensee choices can address it, for example, increasing walk down frequencies, I therefore consider this a minor shortfall.

- The RP adopts the methods for the assessment of spread paths defined in the standard ‘Design Criteria for Protection against the Effects of Compartment Flooding in Light Water Reactor Plants’ (Ref. 151). For flood spread paths, the methodology stated that the analysis takes account of the maximum release volume and assumes that the flood water will propagate through the buildings, accounting for the various engineered design elements such as drainage gaps and door gaps, stairwells, and unsealed penetrations. I judge that the standard and its application by the RP is aligned with ONR expectations (Ref. 7).

479. My assessment of the overall completeness of the RP’s methodology, with respect to identification of sources, identified that the methodology predominantly focuses on the fixed water systems within the design, such as the reactor cooling systems and the installed fire suppression systems. It is my view that the methodology does not clearly set out the expectation that all potential sources of floods are captured; this includes those which are introduced from external sources, e.g. those that could be caused by firefighting activities, from deployed hoses in the event of fire. The effects of such sources should be considered as part of a flooding hazard analysis and is highlighted in both ONR guidance (Ref. 7) and IAEA guidance (Ref. 15) as the effects from these sources may have an impact on SSCs. I consider this a minor shortfall as the overall inventory and its control is a matter for detail design and licensee choices.

480. My expectations (Ref. 7), in determining the overall consequences of a flood requires the RP to identify safety significant SSCs (targets) that could be subject to flood effects, and, where appropriate, identify suitable safety measures to protect them.

481. The RP’s methodology stated that the identification of potential targets is a key element of the internal flooding zone designation process. The RP methodology stated that all equipment within a flooding zone is defined as a potential target and is assumed to fail, except where equipment is required to be qualified against flooding to assure its survival and function. This approach is also applied as the basis for the functional analysis assessments where multiple trains can be affected by the same flood source, noting that the main claim is that multiple divisions are adequately segregated.

482. In my opinion the above approach sets appropriate expectations in line with international guidance, such as IAEA SSG-64 (Ref. 15), which highlights that a variety of protection measures is possible for SSCs and depends on the type of equipment to be protected and the effects of flooding (e.g. spray, submergence, etc.). I acknowledge that the detailed selection of suitable and reliable measures, including the qualification of equipment, will be part of the detailed design (and confirmation of detailed plant layout). I am therefore content that the methodology provides an adequate process to identify targets and identify the flood effects that they will need to be qualified against, in line with SAPs EHA.1 and EHA.15.

483. In addition to the identification of plant layout and determination of SSCs, the methodology should also outline the importance of the selection of materials and fixtures for flood events. It is important that the methodology should recognise the potential of failure of drainage and the impact of debris moving in flood waters impacting SSCs. It is my view that during the detailed site-specific design, a detailed appraisal of the materials which could lead to blockage of flood relief openings should be carried out to ensure that the assumptions in the flow rates and drainage systems are conservative. As this requires detailed design information, I am content that this is a matter that can be followed up as part of further detailed design assessment, and I

acknowledge that this is beyond the scope of GDA. However, this point should be followed up as part of normal regulatory business.

484. The RP's methodology (Ref. 144) described the approach adopted for barrier substantiation against the internal flooding loads. The RP's approach sub-divides the barriers into (i) civil structures (e.g. concrete walls and ceilings) and (ii) penetrations. For civil structures, a certain strength and watertightness according to typical nuclear requirements are applied, such as the ACI 349-13 (Ref. 40), and British standard BS ENI1992 (Ref. 42). The methodology includes combining different loads in accordance with the above-mentioned standards.

485. The methodology also outlines two key requirements for penetrations within claimed barriers such as, doors or hatches in walls and ceilings, dampers for ventilations ducts, or penetrations seals for cables and pipework. These requirements are stated as watertightness and minimisation of penetrations.

486. I have assessed the approach and I am satisfied that it follows international guidance provided in IAEA SSG-64 (Ref. 15). The RP is applying relevant standards (Ref. 40) for the assessment of flooding loads on the barriers and includes requirements that all penetrations need to be assessed as well as setting out the design target of minimising the number of penetrations. I acknowledge that the substantiation of penetrations is out of scope for GDA as the detailed designs and options have not been decided. For GDA I am satisfied that the RP's approach should establish the performance requirements that will inform the future penetration designs.

487. The analysis approach for the assessment of cliff-edge effects is described in the RP's methodology and is largely based on applying various assumptions to determine the maximum flood source and associated flood depths. The main assumptions defined in the methodology by the RP are:

- All SSCs containing liquid within the buildings, except for HIC, are considered in internal flooding analysis.
- The maximum flooding level is calculated according to the worst-case scenario of internal flooding.
- Gross failure is postulated for both high energy piping systems and moderate energy piping systems.
- Margins are considered between the protection measures and calculation results. For example, the watertight doors for the lowest level of the building are designed to withstand 10m hydraulic pressure (this decoupling value is larger than the largest basement height).
- A sensitivity analysis of the flooding level parameter is performed in the internal flooding analysis report. It is to determine that, as for rooms in which the flood is released, the flooding level is not sensitive in the case of high break flow rate and will not challenge the boundaries of internal flooding zones.

488. I have assessed the RP's approach to cliff-edge effects, and I have not been fully satisfied that the methodology adequately outlines all key parameters expected for a flooding cliff-edge analysis. Cliff edge analysis is aimed at identifying sensitivities that may result in a disproportionate increase in radiological consequences and informing the selection of additional protection measures. Such measures provide additional hazard resilience if the consequences are shown to be sensitive to the various underpinning assumptions, such as detection and isolation times and blockages to water flow. The latter assumptions have not been considered by the RP and I therefore judge the current approach does not fully satisfy SAP EHA.7. I raise this as an Assessment Finding as the licensee will need to consider them to make appropriate design and safety case choices.

AF-UKHPR1000-0065: The licensee shall, as part of detailed design, undertake sensitivity analysis of internal flooding hazards to demonstrate that cliff edge effects are understood and prevented so far as is reasonably practicable.

489. In summary, it is my opinion that the RP's flooding methodology provides an adequate basis for its flooding analysis. I have identified several minor shortfalls and one Assessment Finding; however, I judge these not to be significant enough to undermine the overall case if the methodology is adequately applied. The methods identified are consistent with relevant good practice and I judge them to be adequate for identification and analysis of key flooding risks for the purposes of GDA.

4.5.3 BRX: Assessment of Reactor Building Flooding Safety Case

490. The flooding hazards for the BRX are presented in the RP's BRX flooding report (Ref. 148) and flood zoning diagrams (Ref. 145). The combination of these illustrates how the BRX building is split into two defined independent flooding zones and describes how flood hazards are managed within them. The two zones are principally characterised as the BRA (internal to the inner containment boundary) and the BRB (annulus between the internal and external containment boundaries).

491. Through my assessment of the BRX flooding report (Ref. 148), and the RP's responses to RQ-UKHPR1000-1035 (Ref. 152) and RQ-UKHPR1000-1339 (Ref. 153), I identified that the underpinning information and evidence was not complete. This meant, for example, that aspects of the identification and screening of potential flood sources, and assessment of the flood consequences, had not been covered. I therefore included flooding as a sample area within the scope of RO-UKHPR1000-053 to obtain additional evidence to demonstrate that the RP could sufficiently underpin its safety case claims. RO-UKHPR1000-053 was specifically targeted at the BRX as this building contains the reactor and therefore significant radiological inventories.

492. The RP's submission in response to RO-UKHPR1000-053 included the main hazard assessment report (Ref. 57), room data sheets (Ref. 77), and room drawings (Ref. 78). I used this additional evidence in addition to the flooding report to satisfy myself that the flooding risks to nuclear safety had been adequately identified and analysed.

493. Through the response to RO-UKHPR1000-053, the RP demonstrated that the basic building design of the BRX had integrated flood paths which are designed to divert floodwater from higher elevations (levels) of the building to the floor levels below + 1.20m. Below the +1.20m level the flood water is captured within a large storage area/pool, the In-containment Refueling Water Storage Tank (IRWST). The IRWST is located at the bottom floor of the BRX and has a total volume of 1976m^3 (which is less than the bounding case flooding volume). However, the RP stated that additional flooding capacity is provided by available free volumes above this tank. The available volume from building level - 5.00m up to, but not including, level +1.20m is 3653m^3, which is significantly larger than the calculated maximum released volume of 2850m^3.

494. Based on the evidence provided by the RP for the available flooding capacity within the BRX compared to the largest potential flood source, I am satisfied that the building design has incorporated sufficient capacity with a demonstrated margin to minimise the impact of submergence of the key safety significant SSCs located above the +1.20m level. I judge this approach to be in line with ONR guidance (Ref. 7). I have sampled the area under the +1.20m level to determine if any safety significant SSCs could be impacted by flood effects below +1.20m; my findings are detailed below.

495. To address the flow of water within the BRX, the RP's submissions explain that flood paths are delivered by:

- Engineered gaps between floors and the inner containment wall.

- Drain holes in the floor in the annular space and inside of the shielding wall.
- Gratings or by horizontal flow paths (through engineered holes in the walls) allowing water flow towards the annular space.

496. The principal focus of the RP's flooding analysis was to demonstrate that all potential flood waters can flow downwards to the collection pool areas below the +1.20m level.

497. However, through my assessment of the various flow paths presented by the RP in the flooding reports, I identified that horizontal spread paths of some compartments within BRX had only been qualitatively analysed. I raised this finding through RQ-UKHPR1000-1725 (Ref. 154) to get clarity in the RP's assumptions for horizontal flow paths. My RQ sampled two areas on floor level +1.20m that had a potential to impact multiple redundant trains of equipment and impact other divisions through horizontal flow. The RP's response to the RQ stated that:

- The safety case does not make any specific claims on non-grated doors as either being watertight or opening to form a flood path.
- The calculated flood depth with all doors open is insufficient to impact SCCs or HIC.
- For a flood within the inner rooms with the doors closed, the flood height is higher than with doors open, but the bounding flood height has been conservatively determined based on the flood being restricted by the doors. The resulting flood depths are not high enough to impact SSCs or HIC.

498. I have taken account of the evidence provided and the RP's response to RQ-UKHPR1000-1725 (Ref. 83). I am satisfied that the RP's response provided suitable arguments on the management of flood waters, including the provision of grated floors and further clarity on the assumptions applied to the failure of doors in the modelling of floods. I note that, irrespective of whether the doors on level +1.20m are open or closed, the flood heights calculated by the RP are not able to impact the SSCs or HIC in the sample areas; this provides confidence that the hazard of submergence can be largely discounted. However, the principal argument made by the RP is based on the fact that flood water heights are sufficiently low that they would not lead to submergence of equipment. However, it is my view that other localised water effects, such as spray, humidity, and splash on equipment, cannot be disregarded. I acknowledge that the RP refers to these effects and they are also highlighted within its methodology, however a complete analysis is not provided based on the specific water flow paths. I therefore judge that there is a minor shortfall within its analysis with respect to ensuring the directed flow minimises local effects to safety systems.

499. Overall, I judge that the RP has provided sufficient evidence of the application of relevant good practice regarding the measures that have been implemented to manage flood waters within the BRX. This includes the application of flood zoning and engineered drainage routes. However, I have identified a minor shortfall with respect to assessment of local flood effects. I judge this a minor shortfall as the locations of SSCs (including pipework) will need to be finalised as part of detailed design based on licensee choices, and therefore will influence the local conditions.

4.5.3.1 BRX: Bounding Cases for Barrier Assessment (Criterion A)

500. There are two distinct flood barriers within the BRX, namely BRA15O1FPZ and BRB15O1FPZ. BRA15O1FPZ is designed to enclose the flooding volume due to any system failure in the internal containment (BRA), and BRB1501FPZ designed for enclosing the flooding volume within the reactor annulus (BRB).

501. The bounding case approach taken by the RP in both instances was to identify the largest flood volume (2850 m^2 from the PTR) and the largest flow rate (3050 m^3/h from

the RRI). The selection of these sources has been underpinned through the supporting datasheets presented in response to RO-UKHPR1000-053, which I have assessed and judged to be adequate in the context of the systems inventories and the generic design/maximum leak rates to underpin the claimed bounding cases.

502. The RP used the bounding case values to calculate the maximum flood levels. I have sampled the analysis undertaken by the RP and I judge that the approach is in line with its flooding methodology; I am content that the assumptions applied are conservative. I am satisfied that the RP's analysis conclusions adequately demonstrate that flood depths on all floor levels above level +1.20m would not exceed the 2m height with a significant margin.

503. Below the +1.20m level, the RP's flood safety case does not make any claims on flood barriers to segregate divisional systems. This is because the flood management strategy allocates all the floors below level +1.20m as liquid/flood water storage. The RP has identified the largest flood inventory and calculated the total flood water depth below the +1.20m level that would flood with the worst-case flood source. This analysis is presented in the BRX flooding report (Ref. 148) and confirmed in the RO-UKHPR1000-053 report (Ref. 57) that the calculated flood depth would be approximately 5.6m.

504. The RP undertook barrier substantiation for this case and reported it in the BRX barrier substantiation report (Ref. 83). The analysis was based on static dynamic pressure for the full design flood height for the barriers concerned in retaining the water (10.00m below building level +1.20m, and 3.80m above the + 1.20m level). The assessment applies a 3D structural analysis model and considers local loads on barriers as well as global structural loads.

505. I have assessed the barrier substantiation and I am satisfied that the RP has demonstrated that the barriers have appropriate withstand and have margin with respect to the flood heights presented. This is because the barriers have been substantiated at the full design height rather than the calculated flood heights which are significantly less. I note that dynamic wave loads have not been considered within the barrier substantiation report. In my view, the potential of wave loads should be determined to ensure that there will be no cliff-edge effects. However, given the margins available, I have reasonable confidence that this shortfall does not present a significant risk to the design. Noting that further detailed work is required, I judge that this can be followed up as part of normal regulatory business at the detailed design stage.

506. However, through my assessment of the design layout and flood management strategy, I noted that the flood management approach will lead to multiple areas below level +1.20m that contain other equipment and systems which will be affected by flood water. This is discussed by the RP in the BRX flooding report where it is highlighted that:

- The containment isolation valves which deliver the containment isolation function may be immersed by internal flooding. The containment isolation valves underneath +1.20m are located in the annular space within rooms BRA1731ZRM/ BRA1732ZRM/ BRA1733ZRM/ BRA1734ZRM/ BRA1735ZRM).
- RIS [SIS] isolation valves which deliver the safety injection function may be immersed by internal flooding. The RIS [SIS] isolation valves underneath +1.20m are located in the annular space (BRA1731ZRM/ BRA1732ZRM/ BRA1733ZRM). Redundant trains of RIS [SIS] are located respectively in BRA1731ZRM/ BRA1732ZRM/ BRA1733ZRM.

507. For both scenarios the RP makes the argument that, if the valves are required to operate, they could be actuated before the flood levels reach the location of these

valves. While the physical location may be specified to be at sufficient height to provide the time to actuate before flood levels impact these systems, this makes no allowance for the potential impact of water flowing through these rooms as it transits.

508. It is my opinion that further evidence is required to demonstrate that either the flood waters do not flow in the valve locations, or the valves' safety functions would not be impacted by flowing water. Furthermore, clarity is required to demonstrate that all required safety functions for SSCs under the +1.20m level can be delivered under flood conditions to demonstrate that there is no impact as claimed. I judge that this is a gap in the RP's current safety case and does not satisfy SAPs EKP.4 and EKP.5, relating to clarity in safety function and identification of appropriate safety measures. I therefore included this issue in Assessment Finding AF-UKHPR1000-0066 raised at the end of this section (assessment of flooding in BRX) below. Given the number and significance of safety systems that could be affected by the dynamic flood effects. It is for the licensee to consider the impact of dynamic water effects and to make appropriate detailed design and safety case choices.

509. Notwithstanding the shortfalls I have identified, and in summary for the BRX bounding cases for barrier assessment, I am satisfied that the RP has provided sufficient evidence to demonstrate the sampled barrier designs provide the appropriate withstand against flooding. The flood management strategy by the RP may result in multiple SSCs being impacted. This impact needs to be assessed in further detail to ensure all required SSCs can fulfil their safety functional requirements if required.

4.5.3.2 BRX: Exception to Segregation (Criterion B)

510. In line with the criterion B requirements, the BRX flooding report (Ref. 148) identified a total of 6 cases where non-segregated redundant SSCs important to safety could be potentially damaged by a single flooding event. These cases principally relate to electrical and mechanical systems, such as valves identified by the RP to perform nuclear safety functions. The identified scenarios are listed below:

- IH-FL-BRX-03 - Fuel Pool Cooling and Treatment System, PTR [FPCTS] pipe break in room BRA2113ZRM.
- IH-FL-BRX-04 - Internal flooding in BRA4110ZRM where the pressuriser (PZR) safety valves are located.
- IH-FL-BRX-05 - internal flooding in BRA2131ZRM, BRA2132ZRM and BRA2133ZRM where the reactor coolant pumps differential measurement sensors are arranged.
- IH-FL-BRX-06 - internal flooding in BRA2633ZRM where the PZR pressure measurement and PZR level measurement sensors are arranged.
- IH-FL-BRX-07 - internal flooding impacting steam generator (SG) level measurement sensors (narrow range) are arranged.
- IH-FL-BRX-08 - internal flooding impacting steam generator level measurement sensors (wide range) are arranged.

511. For scenarios IH-FL-BRX-05, 06, 07 and 08, the RP undertook functional analysis to determine the impact of the loss of the associated equipment. For all the scenarios listed, the RP concluded that either the flood only affected one loop, in which case two other loops remain available, or the flood results in an automatic reactor trip. This functional analysis is also supported by claims on the various barriers and flood management. I have assessed the analysis presented and I judge that the conclusions of this functional analysis are adequately substantiated for the purposes of GDA and are in line with SAPs EHA.14, FA.4 and FA.7.

512. For scenarios IH-FL-BRX-03 and 04, I did not consider the functional analysis presented by the RP to be as clear. In scenario IH-FL-BRX-03, multiple valves required to control the isolation of the reactor pool would be lost through immersion. Functional

assessment of this scenario highlights that this could also impact the accident condition 'Non isolable small break or Isolable RIS [SIS] break affecting fuel pool cooling (DBC-4)'; when the reactor pool level decreases, the affected valves are required to close. The RP stated internal flooding is postulated to occur during design basis and therefore a flood is not postulated to occur as an independent fault in combination with the DBC-4 accident where the valves would be required. Therefore, the RP deemed that this was acceptable on a combined event frequency basis.

513. For scenario IH-FL-BRX-04, a similar position was presented by the RP, where it claimed that, during normal operation, the PZR valves would be in a closed state. The RP claimed that the flood event would not impact the valve state and therefore there is no impact to safety.

514. As I highlighted in section 3 of this report, the RP's fundamental principle of the internal hazard analysis was to demonstrate that the safety functions needed to bring and maintain the plant to a safe state are adequately protected from hazards. In both scenarios, IH-FL-BRX-03 and 4, the valve function would be lost. Whilst I recognise the RP's argument on hazard frequency and sequencing, the RP has not undertaken a review of options that may be practicable to either move, protect, or qualify these valves against flood effects. This in my view does not meet the expectations set out in EHA.14 and EHA.15. I judge that this is a shortfall as the licensee should identify and implement reasonably practicable measures to reduce the risk in line with the hierarchy of measures in SAP EKP.3 (Para 155) as part of the detailed design of the plant and this is captured as part of Assessment Finding AF-UKHPR1000-0066.

515. In summary, for the BRX exception to segregation (criterion B), the BRXs exception to segregation areas have been assessed. I have identified two specific areas that require further evidence to demonstrate that the risks from flooding are reduced to ALARP and I have captured this shortfall within Assessment Finding AF-UKHPR1000-0066. However, in the majority of cases I judge that the RP has provided adequate evidence that through a combination of flood management and segregation of the trains of equipment in my view provides suitable confidence that the design is adequate and there are no fundamental risks from flooding for criterion B.

4.5.3.3 BRX: HIC (Criterion C)

516. The flooding analysis report for BRX identified one case relating to criterion C.

517. Scenario IH-FL-BRX-09 relates to the potential of flood waters impacting reactor pit area BRA1501ZRM and ultimately the reactor pressure vessel (RPV). The RP identified that there is a maintenance access door (BRA1708VVD) from room BRA1706ZRM to room BRA1704ZRM which provides access to the reactor pit (room BRA1501ZRM).

518. The RP stated in its flooding report (Ref. 148) that during normal operation, room BRA1706ZRM could be immersed by internal flooding due to pipe break of any system containing liquid inside the internal containment, and therefore there is a risk that water can enter the reactor pit if the door (BRA1708VVD) failed or was left open. The water could result in rapid cooling of the RPV and potentially impact nuclear safety.

519. This issue had also been identified by the RP through the analysis work undertaken as part of RO-UKHPR1000-046 (Ref. 155) which specifically focuses on hazards to HIC. The RO-UKHPR1000-046 report highlighted that the door is integrated as part of the barrier arrangement for the reactor pool. The door is designated as barrier BRA1708VVD in the BRX flooding report (Ref. 148). The RP has allocated a safety functional requirement on the door to have the same 10m watertightness requirement as the barrier and is designated as a class 1 system.

520. I judge the safety functional requirements on the door to be appropriate and in line with claims made on the barrier, and therefore satisfy SAPs EHA.5, EHA.6, FA.9 and EKP.5. However, in this instance SAP EKP.3 (defence in depth) and consideration of single failure criterion EDR.4 are also relevant, as the failure of the door could result in significant consequences. In my view the RP has not been able to demonstrate that it would not be reasonably practicable to provide a lobby configuration that avoids reliance on a single door, and therefore I have raised Assessment Finding AF-UKHPR1000-0066.

AF-UKHPR1000-0066: The licensee shall, as part of detailed design, demonstrate that all safety functions required to bring and maintain the plant in a safe state within the reactor building can be delivered in the event of internal flooding hazards. This should include but not be limited to those structures, systems and components located below the +1.20m level and the barrier door BRA1708VVD.

521. Additionally, as part of the RO-UKHPR1000-053 response (Ref. 57), the RP undertook further assessment of flood effects to HIC. I am confident from the evidence provided that the water depths from the worst-case flooding are not significant and that the submergence of Steam Generators (SGs), Reactor Coolant Pumps (RCPs), the Main Coolant Lines (MCLs), Main Steam Lines (MSLs) and Pressuriser (PRZ) can be excluded. This is based on the demonstration that floodwater is directed to lower levels of the BRX while all HIC except the RPV are at higher levels (above +1.20m). I have assessed this evidence and I am content that the RP has provided adequate evidence to demonstrate that these components would not be submerged.

522. In summary, for BRX: high integrity components (criterion C), I have sampled the RP’s analysis on the potential for flooding to affect HIC. I am satisfied that the RP has demonstrated that the impact of flood to HIC is limited and has been largely mitigated by design features to enable the flow of water to the lower levels. The evidence provided by the RP in my opinion has been adequate and in line with relevant good practice, thereby satisfying SAP EHA.14, and provides confidence that the risks to HIC in the BRX from internal flooding can be reduced to ALARP as design progresses.

4.5.4 BFX: Assessment of Fuel Building Flooding Safety Case

523. The flooding hazards for the BFX are presented in the RP’s BFX flooding report (Ref. 149) and flood zoning diagrams (Ref. 146). The combination of these reports illustrates how the BFX building can be sub-divided into two parts with respect to flooding, one including and below level +4.50m and the other above that level. The lower area (covering building levels from –9.60m up to +4.50m) is clearly segregated by claimed barriers into three independent flooding zones. There are some ‘exception to segregation’ areas housing multiple trains of systems important to safety. Above +4.50m (covering building levels +4.50m to +26.0m) only specific areas are segregated relating to specific systems. The BFX has several flooding zones to segregate various trains, and these are defined following the RP’s methodology (Ref. 144).

524. There are three ‘common mode prevention flooding zones’ BFX10A1FPZ, BFX10B1FPZ and BFX10C1FPZ directly related to the three safety trains A, B, and C, in the Fuel Building, with the trains A and B fully segregated with boundaries from the bottom building level up to the top level, and BFX10C1FPZ segregated from the bottom level (- 9.60m) up to level + 4.50m, these zonings are confirmed in the Fuel Building Flooding Zoning Drawings (Ref. 146).

525. Additional ‘common mode prevention internal flooding zones’ are:

- BFX24C1FPZ, where train C of the PTR pipes and valves (connecting to the Spent Fuel Pool (SFP)) are located. This flooding zone is physically segregated from BFX10A1FPZ.
- BFX24O1FPZ, covering the SFP itself, the fuel reception compartment, the new fuel assembly storage room, and the fuel handling hall.
- BFX24O2FPZ, an area that has an ‘exception to segregation’ area.

526. A catastrophic failure of the spent fuel pool (SFP) is excluded as a flood source, even if this is not explicitly stated in the BFX flooding report (Ref. 149). The SFP is a substantial reinforced concrete structure with no openings in the lower part of the pool. The structure has been designed for seismic resistance and has been subject to detailed ONR civil engineering assessment (Ref. 49) and ONR external hazards assessment (Ref. 156).

527. Both the ONR civil engineering report and the ONR external hazards report support the view that the SFP is of sufficient size and thickness that an independent failure of the structure is deemed unlikely due to the following reasons:

- The SFP is a seismically qualified Class 1 structure.
- The SFP has a single skin stainless steel liner to provide additional leak tightness.
- A leak detection system is located behind the lining to detect any leakage from the SFP.

528. From an internal hazard perspective, I have assessed the impact to the spent fuel pool from dropped loads and explosions and my findings are documented in the relevant sections of this report. In both instances I have been satisfied, for the purposes of GDA, that gross failure of the SFP has been adequately discounted and therefore not considered further as a flood source.

529. Because the BFX contains all three divisions of equipment, it is important that the claimed integrity of flood barriers is assured. However, to facilitate access through the building (both for systems and operators) I recognise that there is a need to have penetrations such as doors connecting rooms though each divisional barrier. To ensure that the RP had a robust set of measures on these barrier penetrations, I raised RQ-UKHPR1000-1233 (Ref. 157) to gain assurances on the classification of doors and other relevant safety measures, specifically to ensure that if the doors are opened, they would not undermine the safety case barrier claims. The RP responded to RQ-UKHPR1000-1233 (Ref. 157) and stated the following:

- The safety class of these doors located on the barriers is equivalent to that of the barriers.
- The doors located on the barriers are also fire-resistant doors, which have the function to be closed automatically.
- The doors in divisional barriers are maintained in closure states during normal operation. If operators need to walk through these doors to perform any activities, there are administrative measures to ensure the closure of these doors. The administrative measures on doors should be detailed in the site-specific stage.

530. I have been satisfied that the RP’s response (Ref. 157) to my query is in line with what I would expect for a door on a divisional barrier, in particular having the same integrity as the barrier in which it sits. However, except for the auto-close function for the doors, no other additional defence in depth measures are highlighted, such as audible or visual alarms, to indicate if active barrier elements (barrier penetrations) such as doors or dampers, have been be left open this could result in loss of the assumed barrier integrity. I note that the RP generally assumes that confirmation of door closure will rely on administrative measures and operator actions, which is towards the bottom of

the hierarchy of measures as stated in SAP EKP.3. I note that at GDA these measures have not been fully finalised, however adequate safety measures should be implemented to reduce risks ALARP. This is captured in Assessment Finding AF-UKHPR1000-0067.

531. For divisional barriers and claimed barriers, where one door performs a significant safety function and if these doors are opened in routine operations (e.g., for plant walkdowns), it is good practice to consider engineered measures to enhance safety (Ref. 7). Examples of such measures include arranging two doors in a lobby style configuration to provide defence in depth, or to have an alarm system warning if the door is left open or not closed properly. To address this shortfall I raise the following Assessment Finding in line with SAPs EHA.15, ECS.2 and EKP.5:

AF-UKHPR1000-0067: The licensee shall demonstrate that the detailed design of divisional barrier penetrations reduces risks to as low as reasonably practicable in the event of internal flooding hazards in the fuel building. This should include demonstration of the application of the hierarchy of safety measures.

4.5.4.1 BFX: Bounding Cases for Barrier Assessment (Criterion A)

532. The BFX flooding assessment report (Ref. 149) provides an overview of SSCs important to safety as well as a description of their basic distribution around the building. The design concept with respect to protection against the adverse effects of internal flooding is explained with the hierarchy of measures. Some examples of elimination of flood sources by design were given, followed by those with reliance on the protection provided by flooding zones and the associated claims on flood barriers and engineered flood routes via openings. Room drains and leakage detection were assumed by the RP to be defence-in-depth measures and therefore not claimed/credited within its analysis.

533. The RP identified the main liquid containing systems important to safety related to the PTR, RBS, and APG. Appendix B of the flooding report (Ref. 149) systematically identifies the pipes, vessels and tanks serving as flooding sources within the BFX. I sampled the flood sources listed in the flooding report and cross referenced them with the list of key systems in the PCSR plant overview (Ref. 125). From this review I identified that pipework related to the chemical and volume control system (RCV) had apparently been excluded from the analysis with no clear justification. I therefore raised RQ-UKHPR1000-1233 (Ref. 157) to clarify why the RCV system was excluded from the analysis as a flood source. The response to RQ-UKHPR1000-1233 (Ref. 157) provided clarification that the RCV system had been excluded from the analysis as it is bounded by other systems, and that the connection to the RCP (reactor coolant pressure) boundary would be automatically isolated in a break scenario. The response provided me with confidence that the bounding cases identified by the RP contained larger flood volumes and therefore conservatively bounded this case. The upstream flooding volume of the RCV is stated by the RP to be 596.25m^3 (Ref. 157).

534. Based on this I was satisfied that the principal systems that presented a flood source had been identified and I consequently judge that the identification of flood sources by the RP was adequate.

535. I noted that the RP had not included systems for design extension conditions (DEC systems) as the RP stated this was out of the IH analysis scope. I challenged this point and raised RQ-UKHPR1000-1029 as IAEA guidance (SSG-64) explicitly requires the consideration of DEC systems. The RP's response to RQ-UKHPR1000-1029 (Ref. 158) provided the additional information regarding a DEC system that could present a flooding source within the BFX. This DEC system was the Extra Cooling System (ECS). The RP stated that there are two fully segregated trains of this system within

the fuel building. The RP stated that the system is energised during normal plant operational states, and therefore is filled and pressurised, to perform the residual heat removal (RHR) safety function required under DEC-A conditions. The RP also stated that the analysis of the ECS had been undertaken in the HEPF assessment for the BFX.

536. I therefore assessed both the BFX HEPF report (Ref. 136) and BFX flooding report (Ref. 149). I am satisfied that adequate evidence had been provided by the RP to demonstrate that:

- Both ECS trains are adequately segregated from each other within different divisions in the BFX.
- The largest lines of the ECS system have been identified (being DN 250/300) which have a design pressure of 2.54 MPa which meets the definition of a High Energy Pipe (HEP).
- The total potential volume release of the system is 67m^3, I am satisfied that this flood volume is sufficiently bounded by the BFX bounding cases identified by the RP.
- Assessment of the ECS system had been undertaken by the RP as part of the HEPF analysis. For flooding aspects, in line with the RP's HEPF methodology, the RP applied a worst case 10m flooding height for the assessment of the barriers. Based on the defined volume and the fact that the relevant bounding case (IH-FL-BFX-02) does not exceed this value, I am content that a conservative value had been adopted by the RP.

537. As a result, I judge that adequate information has been provided by the RP to address my queries for DEC systems in the BFX.

538. Based on the identified flood sources the RP applied its flooding methodology to derive the bounding cases to fulfil the criterion A requirements. The RP identified two bounding cases based on maximum flooding volumes:

- IH-FL-BFX-01: Failure of the fire-fighting system JPI [FWSNI] with a total volume of 2270m^3.
- IH-FL-BFX-02: Failure of the nuclear island water distribution system SED [DWDS (NI)] with a total volume of 2000m^3.

539. The analysis identified that, for case IH-FL-BFX-01, the unmitigated flooding volume of 2270 m3 (from the JPI [FWSNI] system) exceeds the capacity of BFX10C1FPZ below the ground level. In this case, the barrier safety functional requirement is to withstand a 10m hydrostatic load. Following the failure of the JPI [FWSNI] system the flow rate and volume is sufficient to exceed the 10m hydrostatic head within 1 hour and 36 minutes. For case IH-FL-BFX-02 the unmitigated flooding volume would result in a flood level of 8.86m and therefore is within the barrier's performance requirements.

540. As case IH-FL-BFX-01 exceeds the safety functional requirement of the barriers, I focused my sampling on this case. As the barrier capacity is exceed, the RP identified additional measures to mitigate the flooding hazard. The RP claimed isolation measures for limiting the flood volumes. These include measures such as closing isolation valves or stopping pumps from pumping water to the connected pipes. These measures should in principle be adequate provisions. Further assessment of the case identified that the RP's principal claim remains on the class 1 barrier which is supported by a class 2 claim on an operator to intervene to stop the relevant pumps. As no claims are made by the RP for effective flood detection, it is assumed by the RP that the operators in the MCR are unable to fully distinguish between a fire and a flood.

541. As a result of this inability to distinguish between a fire and flood, the RP assumed a delay in the isolation to account for further investigation to determine if the initiating

event was a fire. The RP had applied the assumption that the pump is only shut down after a 1-hour period if there are no fire alarms triggered. This means that, for analysis purposes, the RP assumed that flood duration would be a minimum of 1 hour. The RP's analysis work based on this duration results in a flood depth of approximately 6m.

542. Further assessment of the potential consequences highlighted that the combination of the operator action and barriers would ensure that only train C would be impacted by this flood, and therefore two safety divisions should be unaffected by this event.

543. Given that the RP has provided evidence that the sources may be isolated and there is some margin to account for operator action, I judge that, for the purposes of GDA, sufficient evidence has been provided for the bounding case. However, further work should be undertaken to demonstrate that leaks and associated flooding events can be adequately identified as expected by ONR SAP EKP.3 (Para 151 (d) additional measures are provided to mitigate consequences of accidents, especially severe accidents) which I consider to be normal business during detailed design.

544. The RP performed barrier substantiation work (Ref. 97) based on its barrier analysis methodology. This involved calculating the static pressure for both bounding cases, thus demonstrating a full design flood height of 2m above the ±0.00m (ground) level and of 10m below the ground level. As the flood levels are below the values used for the barrier withstand analysis, I judge that, for the purposes of GDA, the RP has provided adequate substantiation for flood barriers in the BFX.

545. As stated above, the failure of the SFP has been discounted, however various connections to the pool have been analysed by the RP. One area of focus has been when the SFP is connected to the transfer pool and the reactor pool for fuel movements.

546. To allow drainage of the transfer pool (and similarly the spent fuel cask pool) these compartments have drainage connections at the bottom. These lines (which connect to the SFP purification system) have double isolation valves with automatic Class 1 valves, which are claimed to close in case of a low-level alarm to prevent complete drainage of the SFP via the transfer compartment.

547. I elected to sample these drainage connections due to the potential for failure and flooding. I queried if the RP had considered failure of these valves and the associated consequences in RQ-UKHPR1000-1233 (Ref. 157). The RP's response to RQ-UKHPR1000-1233 (Ref. 157) highlighted that this flooding scenario had been considered under the "postulated initiating event of non-isolable failure on a system connected to SFP" and had been ruled out as extremely unlikely and beyond design basis within the RP's analysis (Ref. 159).

548. Following my assessment of the drainage connections, including the RP's response to RQ-UKHPR1000-1233 (Ref. 157) and the water purification system schematic detailed in the flooding report (Ref. 149), I am satisfied that the implementation of double isolation valves as part of the water purification system under the transfer pool is adequate. It is my view that a sequence of failures would be required to result in a flooding event, and I also note there are additional valves in the system. This concurs with the evidence presented by the RP in response to RQ-UKHPR1000-1233 (Ref. 157).

549. Notwithstanding the above points, the RP's safety case has not presented a clear and complete analysis to underpin the current design of the system. The potential flooding scenario of a non-isolated release involving the SFP when connected to the transfer compartment, via the purification system drainage valve under the transfer compartment, has not been fully presented with appropriate cliff edge analysis.

Therefore, it is unclear within the safety case if additional safety measures could be implemented to reduce, mitigate, or eliminate flooding in this scenario.

550. I acknowledge that the RP has in place class 1 provisions, that provides me with confidence that this is not a significant shortfall. However, further requirements for additional defence in depth measures may arise from undertaking unmitigated detailed analysis to demonstrate that there are no cliff edge effects. I consider this is a shortfall in the safety case, where I expect the licensee to demonstrate that the risks of drainage of the SFP are ALARP. This is addressed by AF-UKHPR1000-0065.

551. In summary, I have assessed the RP's flooding safety case for the assessment of claimed flood barriers within the BFX. I am satisfied that the RP has provided adequate evidence for the purposes of GDA that the barrier claims are adequate; and there are appropriate measures in place to mitigate flood consequences. The RP has provided sufficient arguments and evidence to justify that flooding would be limited to one division. However, I have identified a shortfall that should be addressed as part of AF-UKHPR1000-0065 during detailed design. Notwithstanding this, based on the claimed bounding cases, I am satisfied that the barriers between the different internal flooding zones can withstand the hydrostatic loads, which have been conservatively calculated for the maximum flooding levels for both bounding cases.

4.5.4.2 BFX: Exception to Segregation (Criterion B)

552. The BFX flooding analysis report (Ref. 149) identified two exceptions to segregation areas labelled IH-FL-BFX-03 and IH-FL-BFX-04. From my review of the exception to segregation criteria for flooding, I noted that the RP had not considered areas where only pipework is present as an exception to segregation area even if multiple trains existed. The RP argued in its analysis report (Ref. 149) that in such cases flooding would only result in static hydraulic pressure loadings on pipework. It is my view that the argument made by the RP has some merit, but it does not consider any dynamic forces from flowing water that could cause any damage to SSCs (including pipework) important to safety, including from additional loadings debris (e.g. failed doors). In my judgement, all such potential flood effects should be considered. I judge this to be a minor shortfall, as the types of debris can only feasibly be identified at the detailed design phase.

553. For the two identified scenarios I chose to sample case IH-FL-BFX-03. This is because in this case it was shown that two trains of the Fuel Pool Cooling and Treatment System PTR [FPCTS] valves for trains A and C rely in a flooding event on floodwater flows between the two divisions as part of the flood management process, and therefore I wanted assurance that the RP had an adequate safety case for this specific scenario.

554. The RP's arrangement of the PTR system is described within its flooding report (Ref. 149). The report stated that the isolation valves and pipework are arranged over three floor levels (+ 4.50 m, + 9.10 m, + 13.70 m) with an isolation valve for Division C in each of the rooms BFX3311ZRM and BFX2911ZRM, and an isolation valve for Division A in each of the rooms BFX3312ZRM (adjacent to the Division C room 3311) and BFX2912ZRM (adjacent to Division C room 2911). The rooms below 2911 and 2912, BFX2411ZRM (Division C) and BFX2412ZRM (Division A) are pipework rooms.

555. The Division C and Division A rooms are arranged above each other in vertical 'slices' with pipework and isolation valves in the lower rooms at the levels +9.10m and +13.70m. The Division C rooms do not have any floor openings, in order to prevent floodwater flooding up from below. The flood relief path for a flooding in Division C room BFX2911ZRM is presented in the safety case and relies on floodwater flowing transversely to Division A (room 2912) then vertically through Division A (room 2412)

and then transversely spreading through Division C (room 2411) and Division A (room 2406). This arrangement is illustrated below in figure 6.

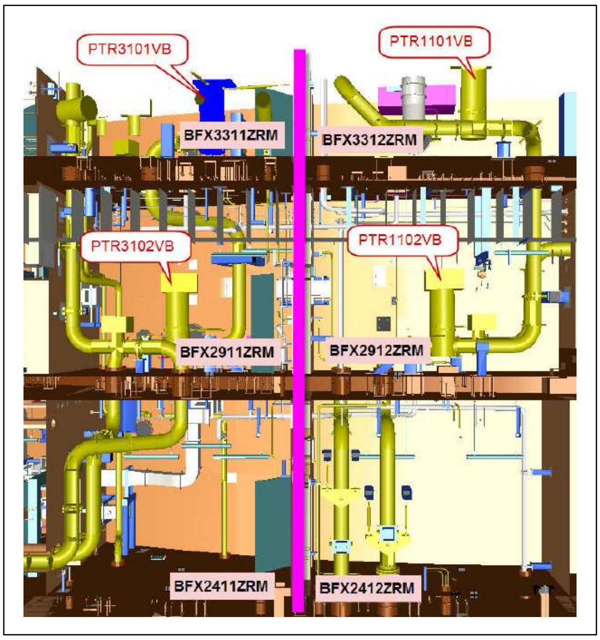

Figure 6: PTR [FPCTS] Trains C and A in the BFX

556. The equipment in Division A is claimed not to fail as flood heights in room BFX2912ZRM are not considered by the RP as reaching a level high enough to cause damage. The analysis by the RP (Ref. 149), shows that the flood height margin to the valves is negligible (0.07 m).

557. Following my assessment of the RP's approach and analysis, I acknowledge that the RP has applied some levels of conservatism in the analysis, such as assuming that drains are not available, not crediting isolation measures, and assuming double-ended guillotine break. I consider that the postulated flood levels are very close to the valve heights with little margin (0.07m). However, any changes of its assumptions, such as blockages of openings (which are not considered in the assessment), could eliminate this margin. I also noted that there is a possibility that assumptions on the degree to which doors are watertight could also impact this margin further as this affects the modelling of flows through as flood paths. I have been satisfied that other effects such as spray have been considered by the RP and that the RP has claimed that the valves are IP68 rated, which means that the valve should remain operable underwater for at least 30 minutes. However, I note that this is defence-in-depth and not a specific claim within the hazard schedule (Ref. 92). Based on the valves' rating, the loss of the claimed margin would not result in the immediate loss of the valves' safety function. However, adequate sensitivity analysis should be undertaken to determine if additional safety measures should be implemented to reduce the risks ALARP. I consider this shortfall in line with SAPs EHA.7 and EHA.6 which should be addressed by the licensee through the resolution of AF-UKHPR1000-0065.

558. I have also found the flooding report (Ref. 149) does not present analysis for the uppermost rooms (BFX3311ZRM and BFX3312ZRM) where floodwater originating in Division C has the potential to cascade down over multiple isolation valves, potentially affecting safety functions in two divisions. To address this shortfall, I raised RQ-UKHPR1000-1726 (Ref. 160) for clarification. The RP's response to RQ-UKHPR1000-1726 (Ref. 160) stated that there are no spread paths to the adjacent Division A room BFX3312ZRM because there are no openings between BFX3311ZRM and BFX3312ZRM, thus the rooms are fully segregated. I judge this as a plausible claim,

but no evidence had been presented to fully substantiate this. I consider this a minor shortfall in the documented evidence, as it does not wholly satisfy the intent of SAPs EHA.12 and EHA.15, which may be addressed at the detailed design stage.

559. In summary, following my assessment of the sample areas for the BFX exception to segregation (criterion B), I have reviewed the RP's flood analysis on the two trains of the PTR systems and their associated valves. Based on; the current analysis; the conservatisms applied in determining the flood paths, and; the safety case claim that the PTR class 1 valves are IP68 rated, I am satisfied that, for the purposes of GDA, there is not a fundamental shortfall in the design. I have raised a number of minor shortfalls and an Assessment Finding, but these do not undermine my overall view that, for the purposes of GDA, the BFX has an adequate safety case for the areas sampled.

4.5.4.3 BFX: HIC (Criterion C)

560. There are no HIC within the BFX.

4.5.5 BSX: Assessment of Safeguard Building Flooding Safety Case

561. The safeguard buildings flooding management strategy is described within the safeguard buildings flood analysis report (Ref. 150) and illustrated within the associated flood zone diagrams (Ref. 147). In total the safety case states that the three independent sub-buildings, BSA, BSB and BSC are fully segregated through the 'Common Mode Prevention Internal Flooding Zones': BSX10A1FPZ, BSX10B1FPZ and BSX10C1FPZ.

562. In addition to the common mode flooding zones, the flooding analysis report (Ref. 150) highlights that there are two 'Forbidden Internal Flooding Zones' these zones relate to specific areas in the BSB and BSC, a forbidden internal flooding zone is defined by the RP as "flooding cannot cause damage to the fundamental safety functions by affecting redundant equipment located inside the zone" (Ref. 144):

- BSB includes the flooding zone BSX33O2FPZ, where VVP[MSS] / ARE [MFFCS] pipes and valves of two redundant safety trains B and C are located, which must not be impaired by flooding.
- In BSC, the MCR and computer offices are arranged in the flooding zone BSX33O1FPZ, where an arrangement of systems containing fluids is not permitted.

563. In addition to the flood zoning, the flooding report (Ref. 150) also provides a summary of the internal protection design measures adopted in BSA/BSB/BSC to reduce the flood hazards, measures include:

- Minimisation of pipe routes and segregation from electrical and I&C areas including the main control room.
- Installation of protection measures such as divisional barriers, Isolation measures, sump detection, drainage systems and administrative measures.

564. As per the other buildings reviewed, the BSA/BSB/BSC have set flood paths to divert floodwater from higher building elevations through floor levels, down to the bottom level where it is captured. These flood paths are principally delivered through door gaps and stairwells allowing the vertical flow of water down to the lower levels. Horizontal spread paths of some compartments were qualitatively analysed by the RP within the analysis report (Ref. 150) but a clear narrative was not presented. I noted the walls, floors and doors in these compartments are not claimed barriers and therefore it is unclear if the water would transit in the way that it is assumed by the RP. It is my opinion the flood spread paths are not well defined, as there is also a lack of

clarity in the assessment of dynamic effects as water spreads through the building. In my view a clear narrative is required to demonstrate how flood waters are expected to behave, and I judge that the analysis is not fully aligned with ONR expectations in SAPs EHA.15 and EHA.7. However, I consider this a minor shortfall and expect that at the detailed design stage, when the location of the equipment is finalized, flood spread paths are clearly identified (including all components/features required to control/influence the path) and claimed within the safety case as appropriate.

4.5.5.1 BSX: Bounding Cases for Barrier Assessment (Criterion A)

565. The BSX flooding report (Ref. 150) details the key systems that the RP considers could provide a significant flooding source, and their locations. In summary, the safeguard buildings are split into nominally 3 areas (vertically), relating to mechanical, electrical, and environmental systems. The majority of the large flood sources are located at the lowest level of the safeguard buildings in the mechanical engineering sections (Ref. 147).

566. To check the validity of the systems listed in the report (Ref. 150), I sampled the list against the general plant descriptions provided in the PCSR chapter 2 (Ref. 125). Through this check, I satisfied myself that the key flood hazard initiators had been identified and that these were consistent with the general plant description. Although the sources were listed, I noted that the RP did not detail the specific locations of these systems. As a result, I was not satisfied that the worst break locations in terms of impact to SSCs important for nuclear safety had been identified. Furthermore, the RP makes no claims on withstand of SSCs, although I accept that this is in line with its methodology. To understand these gaps and to get confidence in the overall approach, I raised RQ-UKHPR1000-0872 (Ref. 161).

567. The RP's response to RQ-UKHPR1000-0872 (Ref. 161) provided clarity on the flooding assessment assumptions for the BSX buildings. The key points provided in the response are summarised below:

- The RP considered the unsealed openings between different rooms as spread paths which allow water to propagate to other rooms/ areas.
- The RP assumed that the flood waters will spread through the sub-building (BSA, BSB or BSC) to the lowest level of the building.
- The RP has not included the availability of drains to reduce the amount of flooding water.
- The RP stated that non-watertight doors within an internal flooding zone are claimed to fail before water within the compartment reaches 2m height.
- The RP stated that for segregated areas of BSA/BSB/BSC, flooding is limited within one sub-building (e.g., BSA) which contains only one safety train of SSCs. The RP states that the loss of one safety train due to internal flooding within a segregated area is acceptable.

568. I have been satisfied that the basis of the assumptions to underpin the RP's flooding analysis and the list of identified sources have been confirmed. Based on my sample check, I have confidence that the RP identified the largest water sources as the basis for the flooding assessment. I also judge that, for the purposes of the GDA flooding assessment, the layout of the safeguard buildings, in terms of their defined segregation between the 3 buildings through substantial barriers, can be deemed adequate to underpin the RP's assessment process. Consequently, in my view the RP's approach to their screening satisfies SAPs EAH.14 and EHA.15.

569. My assessment of the safeguard buildings identified that the ASP [SPHRS] tanks have a drainage pipeline that appeared to connect to the safeguards building at the roof. Because the ASP [SPHRS] is a significant flood source I decided to sample this area further. My assessment found that the RP's flooding analysis did not identify the ASP

[SPHRS] tanks directly as a potential flooding source for the bounding case assessment. To understand the RP's justification of this approach I raised RQ-UKHPR1000-0872 (Ref. 161) . The RP's response to RQ-UKHPR1000-0872 (Ref. 161) and the information presented in the flooding analysis report stated the following:

- The Main pipelines entering the BSB are directly connected to the condenser. The condenser is positioned within the ASP tank. Therefore, the pipes are not directly connected with the main body of water within the ASP [SPHRS] tank. The system is a backup for removing residual heat from the secondary side after an accident and is in standby mode during normal operation and therefore the pipelines are dry.
- In the Drainage pipeline, there is a valve that is closed during normal operation, therefore there is no more water that can flow from this tank into the safeguard building.

570. The RP stated that the flood source from the drainage system was discounted as the valve is closed during normal operations and therefore flooding could be discounted. The schematic of the system (Ref. 162) illustrates the drainage system connections to the BSB. The system has a single valve in place to prevent the pipework in the BSB to be charged and present a potential flood source. As per SAPs EHA.1 and EHA.19, my expectation was that all credible hazards should be identified and analysed. It is my judgement that due to the significance of the flood source the RP should have identified this as a flood hazard and undertaken analysis to determine unmitigated consequences. It is from these consequences that the classification requirements of the valves should be derived to prevent potential flooding in the safeguard building.

571. I have liaised with the ONR mechanical engineering team regarding the adequacy of valving for safe isolation, including drainage. The ONR mechanical engineering inspector concurred that adequacy of valve isolation from a maintenance aspect was an area where they identified a shortfall within their assessment, and they had raised Assessment Finding AF-UKHPR1000-0137 requiring the licensee to demonstrate safe isolation for all systems and components (Ref. 163).

572. From an internal hazard's perspective, I have decided to raise a separate Assessment Finding AF-UKHPR1000-0068 to ensure that the licensee analysis includes the potential unmitigated consequences to inform the performance requirements of the valves. The Assessment Finding is based on the following considerations:

- The drainage valve is closed during normal operation.
- The categorisation and classification of the current isolation method has not been adequately substantiated; however, I recognise that valve systems are in place.
- It is my view that failure of the first isolation valve is unlikely to lead to immediate significant flooding within the safeguard buildings. The valve (based on the latest system diagrams (Ref. 162)) is positioned outside of the BSB (favourably positioned), thus water would be collected on the roof if a catastrophic failure occurred. If the valve failed allowing water to enter the piping, a consequential full-bore failure of the pipe would have to occur.
- I have confidence that additional measures, such as additional valve arrangements, pipe qualification, and leak detection could be implemented at detailed design to address the risks from this flood source.
- The consequences of the potential flooding from the ASP are significant. However, the connections are relatively small (DN150) and thus these should, if appropriate measures are implemented, allow sufficient time to detect and respond to the flood, noting also that the three safeguard buildings are segregated.

AF-UKHPR1000-0068: The licensee shall, as part of detailed design, demonstrate that the internal flooding risks from failures within the secondary passive heat removal system have been reduced to as low as reasonably practicable. This should include but not be limited to valves, joints, and welds.

573. Commonly for all the buildings assessed on the nuclear island, firefighting system JPI [FWSNI] was deemed by the RP to present the largest flood challenges. The RP defined two bounding case scenarios relating to the full guillotine failure of the JPI system within the areas with the smallest volumes found in BSA/BSB/BSC at the relevant floor levels. These cases were; case 1 (IH-FL-BSX-01) for floods below the ±0.00m level, and; case 2 (IH-FL-BSX-02) for flooding on or above ±0.00m. I am satisfied that the basis for the bounding case selection is reasonable and demonstrates a bounding approach, as the cases are aligned to the two specific barrier requirements of a 2m water withstand above ±0.0m level and a 10m withstand below, as defined in the RP's flooding methodology (Ref. 144).

574. In both instances, as compared to the other sources located in the BSX, I am satisfied the JPI [FWSNI] system is the largest flooding volume and therefore I am satisfied that selection of these bounding cases is adequate for the purposes of the GDA flooding assessment.

575. For case 1, the RP analysis concluded that the maximum flooding level below level ±0.00m would be 2.4m and, for case 2, the maximum flooding level would be approximately 1m. I have assessed the barrier substantiation report and I am satisfied that the analysis approach is in line with ACI349M-13 (Ref. 46) which I judge to be an adequate approach. My review of the analysis presented in the barrier substantiation report provided me with confidence that the barriers identified had been appropriately substantiated (Ref. 164).

576. In summary, for the BSX bounding cases for barrier assessment, I am satisfied that the RP has provided sufficient evidence, for the purposes of GDA, that suitable margins exist from internal flooding hazards, to demonstrate that the BSA/BSB/BSC is adequately segregated. I have identified one Assessment Finding that I expect the licensee to address at detailed design, but this does not undermine my view that for GDA an adequate case has been provided for the BSX criterion A.

4.5.5.2 BSX: Exception to Segregation (Criterion B)

577. For flooding in the BSX exception to segregation areas the flooding report (Ref. 150), identified two specific cases:

- IH-FL-BSX-03 – Relates to a double guillotine break of the Main feedwater system ARE [MFFCS] where two trains of feedwater pipes are located.
- IH-FL-BSX-04 – Relates to a break in the nuclear island fixed firefighting system JPI [FWSNI] located in a room adjacent to the MCR.

578. For the purposes of my GDA assessment I sampled the adequacy of the RP's safety case for both scenarios, as they could result in the loss of either multiple trains or impact the main control room.

579. The RP's flooding analysis (Ref. 150) for scenario IH-FL-BSX-03 is based on a double ended guillotine break on the ARE [MFFCS] system. The RP stated that ARE [MFFCS] pipework is a high energy pipe with a high flow rate of 4000 kg/s. The RP's analysis highlighted that, because of high temperature and high-pressure liquid (water) inside the ARE [MFFCS] pipes, this scenario will result initially a steam release, followed by room overpressure and flooding as the steam condenses. The RP's assessment of the failure of the pipe work assumes that water can flow across the compartment.

580. I have also sampled the ARE main feedwater system as part of the HEPF assessment and my associated findings are detailed in sub-section 4.6 of this report. However, my assessment of the flooding aspects is detailed here.

581. The BSX flooding report (Ref. 150) outlines that there is a significant opening on level 13.2m within the compartment that is 2m wide and 3.5m high and the RP argued that this provides an adequate drainage opening to the outside of the safeguard building. Within its analysis, the RP credits the openings and the flow rates via these drainage paths. It estimates an internal compartment flood depth of approximately 1.6m, which is lower than the height of the redundant ARE [MFFCS] valves within the room.

582. To obtain better clarity in the analysis undertaken I requested further information on the assumptions made by the RP in deriving the calculated flood depths and I raised RQ-UKHPR1000-0872 (Ref. 161) to address this. The RP's response (Ref. 161) to my queries provided me with confidence that adequate assumptions were made and that a conservative analysis had been undertaken.

583. However, from my assessment I noted that an adjacent room BSB3329ZRM contained four pressure sensors that would be submerged because of the potential flood level. The sensors are used for monitoring the SG of one loop. I assessed the functional analysis undertaken by the RP within its flooding analysis (Ref. 150). This stated that the sensors are fail safe, and failure would lead to the reactor being shut down. Furthermore, the RP stated that there are two other safety trains available that would not be affected. From this analysis I am satisfied that the RP has provided an adequate argument for GDA.

584. Scenario IH-FL-BSX-04, in the RP's flooding report (Ref. 150) specifically relates to a flood source external to the MCR, but yet may still impact it. The MCR is located within the forbidden internal flooding zone BSX33O1FPZ. This means within the RP's flooding methodology requirements (Ref. 144) that no fluid systems can be located within this zone.

585. It was identified by the RP through analysis (Ref. 150) that failure of the firefighting main JPI [FWSNI] within room BSC333OZRX external to the MCR flooding zone could result in flood waters entering the MCR if any of the access doors in the MCR are opened. Because the doors form part of the flooding barrier it is relevant good practice (Ref. 7) to ensure that the doors are rated appropriately.

586. However, in this case the RP did not make claims on the doors being watertight, thereby protecting against this scenario. The RP recognised this vulnerability and undertook optioneering studies. The outputs of this process are reported in the RP's ALARP review report (Ref. 33). The output of the ALARP review resulted in a modification M45 (Ref. 165) to the JPI system that introduced a motor-driven butterfly valve on the wet riser at the +8.70m level of the safeguard building (located in BSC333OZRX). This changes the wet riser into a dry- riser system from this level and above, thereby removing the water hazard.

587. I have assessed the work undertaken by the RP to address the shortfall identified with the JPI [FWSNI] and I judge that the modification is adequate, as the design effectively eliminates the water hazard from the area. However, it is my view that the RP should consider defence in depth measures to ensure the survivability of the MCR, especially if the firefighting system had to be used. In this instance the RP should consider implementing further measures that may be reasonably practicable e.g. proving watertight doors, considering lobby arrangements or other passive measures already discussed in this report, to minimise water effects from this system. However for the purposes of GDA I consider this to be a minor shortfall and I am content that an adequate solution has been reached.

588. In summary, for the two identified exception to segregation areas in the BSX, I am satisfied that sufficient evidence has been presented by the RP for the purposes of GDA to provide me with adequate confidence that there are no fundamental design issues with respect to flooding.

4.5.5.3 BSX: HIC (Criterion C)

589. The safeguard building contains portions of the main steam lines (MSLs) and the main steam isolation valves (MSIVs). The RP has designated these components as HIC following challenges from ONR on their classification from both internal hazards (Ref. 141) and structural integrity (Ref. 166) perspectives. The impacts of internal hazards to HIC have been separately sampled as part of RO-UKHPR1000-046, 'demonstration that the risks to HIC components from internal hazards are reduced ALARP'. My assessment of the RP's RO-UKHPR1000-046 responses is presented in the RO-UKHPR1000-046 section of this report, but key points related to flooding are described below.

590. For flooding I am satisfied that the MSIVs are arranged on the upper levels of the BSA and BSB (+16.60m and +21.80m). From my assessment of the flood sources and the evidence provided by the RP, the most significant flood effects that could impact the HIC is from the failure of the main feedwater system ARE [MFFCS]. On this basis my conclusions from scenario IH-FL-BSX-03 are relevant as described in the section above.

591. Through my assessment of the layouts both the main feedwater lines (ARE) and the main steam lines enter the BSX at the same level, but both systems are in separate compartments. Therefore, it is my view that only flowing water would potentially impact the MSL by flowing into the compartment. Through my assessment of the BSB flooding scenario (IH-FL-BSX-03) I am content that the RP has demonstrated that, with the combination of the compartment volume and the engineered drainage features, the flood levels from failure of the main feedwater line cannot generate flood levels high enough to submerge the MSIVs and the main steam line itself. Therefore, for flooding I judge that the case presented by the RP is adequate for GDA.

4.5.6 Summary of Assessment and Affirmation of PCSR Claims

592. From my assessment of the RP's safety case, I have found that the principal safety measures for flooding are primarily the class 1 civil structures. These are passive structures, which I consider to be at the top of safety measure characteristics in line with SAP EKP.5 (Para 155). I have been satisfied that the RP has provided sufficient evidence to demonstrate that these divisional barriers claimed for flooding have adequate withstand and fulfil their safety functional requirements, and thereby satisfy SAPs EDR.2 and ESS.1 and EHA.15.

593. I am satisfied that the RP has identified additional measures such as isolation valves and operator action as defence in depth. These measures in some instances require further assessment and substantiation at the detailed design stage. However, their identification provides me with confidence that when substantiated there will be adequate systems in place to manage the risks from flooding and provide defence in depth in line with SAP EKP.5.

594. Overall, I judge that the RP has demonstrated that, for flooding, the current layout as assessed for the purposes of GDA provides adequate measures and segregation for internal flooding hazards, and in my view satisfies SAP ELO.4.

4.5.6.1 Affirmation of PCSR Claims for the Flooding Safety Case

595. This section provides a summary of my assessment of the principal claims associated with the internal flooding safety case.

- Sub-claim 3.2.2.SC19.2.7 (Flooding): The internal flooding sources are sufficiently identified.

596. Based on the evidence provided and assessed, I have judged that the RP has demonstrated that the principal flood sources have been identified. Evidence provided through RO-UKHPR1000-053 (Ref. 57), has given further confidence that the interrogation of the RP's source data has been systematic and therefore provides confidence in the outputs of the flooding assessment reports.

597. I am satisfied that the released flood volumes have been calculated applying conservative assumptions, taking the largest flood volumes and flow rates following a full guillotine pipe break. I judge this to be in line with relevant good practice (Ref. 7) and satisfies SAPs EHA.6 and EHA.15.

- Sub-claim 3.2.2.SC19.2.8 (Flooding): After the safety assessment, the safety measures to mitigate the consequences of internal flooding are identified and properly classified.

598. The analyses carried out by the RP based on the identified flood sources have in my opinion adequately identified the barriers that are required to provide the required withstand to ensure that the effects from flood waters are retained within one train, thus satisfying SAPs EHA.6 and EKP.15.

599. The RP has clearly identified areas of exception to segregation and assessed the potential impacts of flooding spreading between redundant safety trains. It has identified suitable and sufficient SSCs to minimize the impacts of flooding. Minor shortfalls have been observed and I have raised Assessment Findings where appropriate.

600. The RP has provided limited justification for the impacts to HIC in the BRX and BSX from flood effects. However, I have been satisfied that the risks are negligible and the integrity of the HIC would be maintained in the event of flooding.

- Sub-claim 3.2.2.SC19.2.9 (Flooding): The safety measures for internal flooding are sufficiently substantiated.

601. The principal safety measures for flooding largely related to the various barriers. The RP provided sufficient evidence through the demonstration of flood height and through its barrier substantiation reports to substantiate that the identified barriers are able to deliver their safety functions, thus satisfying SAPs EKP.4 and EKP.3.

4.5.7 Flooding Safety Case Strengths

602. Through my assessment recorded above, I have noted the following strengths in the RP's internal flooding safety case.

- The RP has demonstrated that the flooding methodology is consistent with relevant good practice.
- The RP has demonstrated adequate application of this methodology.

4.5.8 Outcomes

603. Through my assessment of the RP's internal flooding safety case I have been satisfied that the RP has provided adequate evidence to underpin its flooding analysis for the

purposes of GDA. The RP has demonstrated that hazard identification and screening has been applied in line with its assessment criteria (A, B and C). I also note that the RP has implemented modifications to the firefighting system in the BSC to eliminate a flooding risk to the MCR.

604. Following my assessment, I have identified several areas of improvement through a mix of Assessment Findings and minor shortfalls. My Assessment Findings relate to findings associated with the flooding analysis methodology, including sensitivity analysis, delivery of safety functions during flooding, barrier penetration substantiation, and analysis of flood hazards from the passive heat removal system.

4.5.9 Conclusions

605. My assessment of the generic UK HPR1000 internal flooding safety case has been informed by several submissions, RQs, and ROs. The breadth and depth of my assessment has been focused on the key risk areas and the quality of evidence provided.

606. Although several Assessment Findings have been raised, for the purposes of GDA I am content that the principal risks from flooding have been identified and understood.

607. Therefore, based on the outcomes of my assessment of the RP’s internal flooding safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and have raised Assessment Findings accordingly. I do not judge that these gaps are significant enough to prevent issue of a DAC, as I am content that they can be addressed by the licensee at detailed design.

4.6 Hazard Assessment – Dropped Loads

4.6.1 Principal Claims from the Generic UK HPR1000 Dropped Loads Safety Case

608. The generic UK HPR1000 dropped loads safety case for the sample buildings (BRX, BFX and BSA/BSB/BSC) is comprised of the following documents:

- Dropped Loads Safety Assessment Report for Reactor Building, (Ref. 167).
- Dropped Loads Safety Assessment Report for Fuel Building, (Ref. 168).
- Dropped Loads Safety Assessment Report for Safeguard Buildings, (Ref. 169).
- List of Segregation Areas and Exception to Segregation Areas, (Ref. 29).
- Reinforced Concrete Barrier Substantiation Report for BRX, (Ref. 83).
- Reinforced Concrete Barrier Substantiation Report for BFX, (Ref. 97).
- Classification of the Typical Cranes, (Ref. 170).
- ALARP Assessment of the Spent Fuel Delivery Process, (Ref. 171).

609. The principal claims for the dropped loads safety case for the generic UK HPR1000 design are defined within the pre-construction safety case report (PCSR) Chapter 19 Internal hazards (Ref. 3). These principal claims are:

- **Sub-claim 3.2.2.SC19.2.13 (Dropped Loads):** The dropped loads sources are sufficiently identified.
    - Argument 3.2.2.SC19.2.13-A1 (Dropped Loads): The lifting devices are sufficiently identified.
- **Sub-claim 3.2.2.SC19.2.14 (Dropped Loads):** After the safety assessment, the safety measures to mitigate the consequences of dropped loads are sufficiently identified and properly classified.

  - Argument 3.2.2.SC19.2.14-A2 (Dropped Loads): Where there are exceptions to segregation, safety measures are identified to ensure that sufficient SSCs are available, during and after dropped loads, to deliver the safety functions.
  - Argument 3.2.2.SC19.2.14-A3 (Dropped Loads): Dropped loads do not cause unacceptable damage to HIC.
  - Argument 3.2.2.SC19.2.14-A4 (Dropped Loads): The safety measures to mitigate the consequences of dropped loads are classified in accordance with the methodology of safety categorisation and classification.

- **Sub-claim 3.2.2.SC19.2.15 (Dropped Loads):** The safety measures to mitigate the consequences of dropped loads are sufficiently substantiated.

  - Argument 3.2.2.SC19.2.15-A1 (Dropped Loads): The floors claimed as barriers are substantiated.
  - Argument 3.2.2.SC19.2.15-A3 (Dropped Loads): Validation of lifting procedure execution and lifting route planning can contribute to avoiding unacceptable consequences highlighted by the safety assessment.

4.6.2 Dropped Loads Methodology Assessment

610. The RP's dropped loads analysis methodology is based on identifying and assessing bounding cases. The submissions define criteria to enable a set of bounding dropped load challenges to be identified and then taken forward for more detailed analysis.

611. The RP's methodology identifies that the dropped load assessments should consider the following types of drops:

- Collapsed structures: the collapse of part of the building structures due to structural failure.
- Falling objects: heavy items of plant equipment dropped from significant height.
- Dropped loads: assumed to occur as a result of a lifting device failure if the lifting devices can no longer control the loads.

612. The methodology also identifies the need to consider the impact of tipping and swinging loads where applicable.

613. The methodology includes the following key assumptions:

- Dropped loads are postulated from every lifting or handling device but only for one device at a time.
- Dropped loads are postulated to occur during normal operation (for example, power operation or shutdown (including EIMT activities)) of the plant.
- Dropped loads are considered as hard objects and the potential energy is fully transferred into kinetic energy.
- Dropped loads are assumed to directly result in damage and unavailability of all equipment in the affected area.

614. This type of bounding approach, including the assumptions, is consistent with ONR GDA guidance to requesting parties (Ref. 1) and I consider it appropriate for the GDA stage of the design development.

615. The following safety objectives are identified by the RP for the dropped loads assessment:

- Dropped loads should not result in the failure of any fundamental safety function.

- Dropped loads should not cause Design Basis Condition three or four or Design Extension Conditions (DEC) where practicable (even if this occurs, delivery of the fundamental safety functions should be ensured),
- There are no cliff edge effects due to dropped loads.
- The risk from dropped loads is reduced to be as low as reasonably practicable (ALARP).
- Dropped loads should not cause damage to High Integrity Components (HIC).
- The civil structures identified as a barrier to dropped loads should be adequately substantiated as being robust to the bounding dropped loads.
- Dropped loads should not undermine the stability or integrity of buildings important to safety.

616. These safety objectives meet the expectations of SAPs EHA.1 (identifying and characterising hazards) and EKP.1 (provision of an inherently safe design) and hence I consider them appropriate for GDA.

617. The RP's process for applying the methodology involves the identification of potential sources of dropped loads, including the failure of lifting devices and the collapse of structures. The consequence analysis focusses on the impact on the identified target structural elements or plant and equipment, considering both global and local effects. The RP's screening analysis assumes that all items of plant and equipment located within the vicinity of the dropped load are lost.

618. ONR expectations with regard to nuclear lifting operations are outlined in ONR NS-TAST-GD-056 Nuclear Lifting Operations (Ref. 10). The RP's methodology (Ref. 172) references relevant RGP as identified within NS-TAST-GD-056 as applicable to the design of nuclear lifting equipment and operations. It is therefore my judgement that the methodology has been developed based on appropriate codes and standards.

619. The RP's methodology is focused on demonstrating that the plant can withstand the worst case dropped load impacts. It therefore focusses on protection measures, such as physical barriers, and on the redundancy built into the generic UK HPR1000 design, as opposed to preventative measures that prevent or reduce the likelihood of dropped loads. In my judgement this approach is sufficient for the purposes of GDA, as the detailed design of the lifting equipment has not yet been completed. However, my expectation is that the detailed design of the lifting equipment will confirm that suitable and sufficient SSCs have been incorporated into the design of the lifting equipment to prevent or reduce the risk of dropped loads to a level that is ALARP. This will be followed up as part of normal regulatory business at the detailed design stage.

620. Sub-section 5.1 of the RP's methodology (Ref. 172) identified the RP's dropped loads assessment assumptions. While these assumptions generally appear logical, I raised the following queries through RQ-UKHPR1000-1038 (Ref. 173).

- Radiological consequences of dropped loads – It was not clear how the RP's assessment on divisional barriers addressed operator radiological doses associated with potential dropped loads events.
- Consequential hazards – It was unclear how dropped loads would be screened without understanding the potential impact of consequential hazards.
- Common cause events – A seismic event could potentially cause failure of all non-seismically qualified lifting equipment and structures, potentially in multiple divisions. It was not clear how the RP's methodology addressed this. I have also assessed the RP's seismic events leading to internal hazards in the combined and consequential hazards sub-section 4.9.3.2 of this report.

621. The RP's response (Ref. 173) clarified that the radiological consequence of dropping a spent fuel assembly was already considered in the reactor building dropped loads assessment, that the remaining radiological inventory is mainly concentrated in the

primary circuit, and that no dropped loads were identified that could result in drops into the reactor pit. The RP also noted that Large-Break-LOCA was considered to be the bounding case for radiological releases. In my judgement the RP has derived relatively high radiological dose consequences which are not likely to be challenged by further analysis, however, the RP's response on its own does not provide sufficient evidence that the methodology adequately considers the radiological consequences in selection of the bounding cases to meet the expectations of SAPs EHA.6 and FA.1. I consider this a minor shortfall that does not affect the outcome of my GDA assessment.

622. In response to RQ 1038 (Ref. 173), the RP confirmed that consequential hazards were considered in the combined hazards assessment which included seismically induced dropped loads, and that the failure of non-qualified structures in a seismic event were considered in the Earthquake Safety Evaluation Report. This is discussed further in the combined hazards section below (see sub-section 4.9).

623. In RO-UKHPR1000-053 (Ref. 174), I asked the RP to provide sample hazard analyses which included dropped load scenarios. My review of the response to RO-UKHPR1000-053 (Ref. 57) identified that further queries were needed in relation to the RP's application of its dropped loads methodology. This specifically related to dropped load impacts in areas of the plant, such as the fuel route or operating deck, where there are single train safety systems that are not HIC and may not have redundancy. Hence, I raised further queries in RQ-UKHPR1000-1721 (Ref. 175) and RQ-UKHPR1000-1418 (Ref. 176) relating to the reactor building and fuel building dropped loads assessment reports respectively.

624. In response to RQ-UKHPR1000-1721 (Ref. 175), the RP stated that the single train items listed are located on the operating deck and cannot be impacted by dropped loads from the polar crane. Furthermore, the RP stated that the single train systems are generally part of the containment or pressure boundary; their loss would result in a design basis fault and there are SSCs provided to protect against these faults which have been designed not to be susceptible to dropped loads.

625. In my judgement the evidence provided by the RP in response to RQ-UKHPR1000-1721 (Ref. 175) sufficiently addresses the safety case gap identified for the purposes of GDA. However, the potential for dropped load impact on single train systems, and the associated arguments have not been fully captured within the GDA dropped loads safety case. To meet the expectations of EHA.3 and EHA.6, at detailed design, I expect the safety case to be further developed to clearly identify and analyse all design basis events. Based on my assessment I am satisfied that this can be considered a minor shortfall for the purposes of GDA.

626. Following my assessment of the RP's dropped loads methodology, I have considered how the RP has applied this methodology during the assessment of the principal buildings in the generic UK HPR1000 design within the nuclear island. My assessment is presented in the following sections.

4.6.3 BRX: Assessment of Reactor Building Dropped Loads Safety Case

627. In the Reactor Building Dropped Loads Assessment report (Ref. 167) the RP identified a total of 24 individual lifting devices located in the reactor building. These consist of the 200t Reactor Building Polar Crane, the refueling machine, and 22 monorail lifting beams located throughout the building to facilitate maintenance activities during outages.

628. The polar crane is located above the operating deck in BRX, and is used to undertake all the significant lifting operations required during outages including:

- RPV head assembly.

- Multiple-Stud Tensioning Machine (MSTM).
- Internal missile protection removal slab.
- Reactor coolant pump motor.
- Pool slot gate.

629. The refueling machine is located above the reactor pool and is primarily used for fuel loading and unloading during reactor refueling outages.

630. Of the 22 monorails, 19 are located within the inner containment (BRX) to facilitate the maintenance of valves, pumps, heat exchangers etc. The three remaining monorails) are located in the reactor building annulus (BRB) for maintenance of the Secondary Passive Heat Removal System (ASP [SPHRS]).

631. It is a fundamental assumption of the RP's dropped load analysis (Ref. 172) that the majority of the maintenance activities are carried out at specific maintenance activity windows based on specific operating modes of the plant, for example when the reactor is shut down for an outage. On this basis the dropped loads from maintenance hoists are largely discounted by the RP as any safety related equipment that may be impacted will not be required to provide its safety function during the outage. To gain better understanding of the RP's dropped loads management I raised RQ-UKHPR1000-0688 (Ref. 177). The RP's response to RQ-UKHPR1000-0688 (Ref. 177) confirmed its lifting strategy and that it has in place optimised lifting schedules to reduce SSCs within a lift path. The RP also stated (Ref. 177) if lifts are required to be made when the plant is in operation, it would put in place administrative procedures to protect the nuclear safety functions. Based on the RP's responses to my queries, I am satisfied that for the purposes of GDA, reasonable assumptions for the assessment of dropped loads have been applied.

4.6.3.1 BRX: Bounding Cases for Barrier Assessment (Criterion A)

632. The RP identified the following bounding case related to criterion A (Ref. 167):

- IH-DL-BRX-01 – Drop of RPV head assembly from the Polar Crane onto reactor cavity during refuelling outage.

633. The Reinforced Concrete Barrier Substantiation Report for BRX (Ref. 83) presented the substantiation of the base of the reactor pool against the RPV Head Drop. The RP used LS-DYNA to model the impact on the reactor pool, in combination with acceptance criteria related to the principal compressive strain of concrete and the tensile strain of reinforcing steel taken from IAEA Safety Report No. 87 (Ref. 178). LS-DYNA is a computational fluid dynamic modelling tool commonly used across the UK nuclear industry and in my judgement is suitable for the analysis undertaken by the RP.

634. The RP selected allowable strain values for design extension events (DEEs), which are greater than those allowable in design basis events. However, application of inconsistent criteria may lead to non-conservative decisions at detailed design. It is therefore my opinion that the analysis should be updated, at detailed design, to use the design basis event success criteria to be consistent with the expectations in ONR SAPs EHA.5 and EHA.19. Each internal hazard design basis event should be derived, and analysis of the design basis events should assume the event occurs simultaneously with the facility's most adverse permitted operating state. I have therefore raised the following Assessment Finding to ensure the licensee applies appropriate criteria in this regard. This Assessment Finding also applies to the fuel building reinforced concrete barrier substantiation assessment (Ref. 97).

> AF-UKHPR1000-0069**:** The licensee shall, in the analysis of dropped loads for the detailed design, utilise criteria associated with design basis events for compressive

strain and tensile strain in reinforced concrete structures.

635. The RP's assessment of the impact on the reactor pool identified that the impact area will be in the plastic failure state and that leakage could not be ruled out. The RP argued that even conservatively assuming that the water escapes from the reactor pool there will still be a minimum of 3.2m of water above the fuel, and between the fuel and the RPV flange. While it is conceded that there will be an elevated dose rate in the reactor building, it is argued that this will be detected by the Plant Radiation Monitoring System which will alarm, and the operators will evacuate.

636. I raised RQ-UKHPR1000-1038 (Ref. 173) to query dropped loads in the reactor building including the radiological consequences. In response, the RP stated that following loss of the water from the reactor pool, the maximum dose rate would be 0.3mSv/hr. This would exceed the radiation alarm levels in the area, facilitating evacuation in 10 minutes, equating to a total dose of 0.05mSv. Drop of the RPV head would be a significant revealed event, hence the RP claimed that evacuation time was reasonable, and even if this was conservatively increased to half an hour the dose would be 0.15mSv. On this basis the RP considered that the drop of the RPV head resulting in loss of the reactor pool inventory was tolerable as a low frequency event.

637. In my judgement this is an obvious revealed event and hence I have confidence that the operator will evacuate promptly. However, the RP has not provided detailed analysis to support the maximum dose rate of 0.3 mSv/hr which is central to its claim. Hence this needs full analysis during the site-specific project phase when operating procedures and actions will be fully developed. This concern is also included in the Assessment Finding raised below.

638. This scenario is not explicitly addressed as an initiating event in the reactor building internal flooding safety assessment (Ref. 148), which considered that the potential flood volume is bounded by IH-FL-BRX-01.

639. Combined hazards are not considered in the reactor building dropped loads assessment, and therefore the RP has not given further consideration to the consequential flooding scenario following an event in which the base of the reactor pool may be breached. Consequential flooding as a result of a dropped load has been screened out as a potential hazard combination in the combined hazards assessment report, and this is discussed further in Sub-section 4.9 of this report. In my judgement, whilst the evacuation time appears reasonable, the RP has not provided sufficient evidence to demonstrate that consequential flooding is tolerable to meet the hazard analysis expectations of SAPs EHA.6 and FA.7. The following Assessment Finding is therefore raised.

AF-UKHPR1000-0070**:** The licensee shall, as part of detailed design, demonstrate that the risks from consequential flooding in the event of drop of the reactor pressure vessel head on the reactor pool structure have been reduced to as low as reasonably practicable.

640. I queried the potential for swinging loads to impact barriers in RQ-UKHPR1000-1038 (Ref. 173) for the reactor building (and also RQ-UKHPR1000-0961 (Ref. 179) for the safeguards building), and I requested further evidence from the RP as to how the potential for swinging load impacts on barriers was limited by the design. The RP provided clarification on how the potential horizontal swinging load distances had been calculated in the response to RQ-UKHPR1000-0961 (Ref. 179). Additional information relating to how the traverse speed of loads is limited was provided in the response to

RQ-UKHPR1000-1418 (Ref. 176) (raised to query the RP's consideration of dropped loads in the fuel building).

641. The RP's final response to RQ-UKHPR1000-1038 (Ref. 173) (and RQ-UKHPR1000-1418 (Ref. 176)) stated that the motor power was selected to match the design load and therefore any potential overspeed would be limited.

642. I accept that, given the distance from the barriers and the speeds involved, the potential impacts on barriers from swinging loads are likely to be well within the capability of the barrier. It is, however, not clear that the cases considered by the RP bound all potential faults. However, responses provided by the RP to ONR's RQs on this topic supplement the dropped load assessment report, and I now consider the RP to have provided ONR with sufficient confidence that swinging loads from mechanical handling equipment in the reactor building do not pose a significant challenge to the civil structures. I consider the assessment of swinging loads as adequate for the purpose of GDA.

643. Overall, for the purposes of GDA, I judge that the RP has provided sufficient confidence that the impact from dropped loads to barriers within the reactor building have been identified and consequences can be controlled. Through my assessment I have identified two Assessment Findings for the licensee to address, however, in my view these do not undermine my judgement regarding the adequacy of the analysis provided by the RP.

4.6.3.2 BRX: Exception to Segregation (Criterion B)

644. The RP identified the following bounding cases related to Criterion B. All three bounding cases involve drops from monorails.

- IH-DL-BRX-02 - Drop of PTR valve onto other PTR valves during maintenance in refuelling outage.
- IH-DL-BRX-03 - Drop of RCV high pressure decompression valve onto redundant RCP safety sensors during maintenance in refuelling outage.
- IH-DL-BRX-04 - Drop of Containment Cooling and Ventilation System draught fan onto redundant RCP pressuriser pressure and level instrumentation during maintenance in refuelling outage.

645. The RP's assessment for Criterion B focused on areas where there are perceived exceptions to segregation and therefore a single dropped load could potentially affect multiple trains. In identifying exceptions to segregation, the RP not only considered rooms that contain lifting equipment and equipment from more than a single train, but also considered equipment located in the room below.

646. For both IH-DL-BRX-02 and IH-DL-BRX-03, the RP's analysis (Ref. 167) identified that a dropped load could potentially impact on PTR valves or RCP safety related sensors from more than one division. However, in both cases the RP argued that the dropped loads are associated with maintenance activities that are only undertaken during outages, hence the RP concluded that the consequences of failure of the impacted equipment were acceptable.

647. In the case of IH-DL-BRX-04, the SSCs potentially affected (i.e. the RCP pressuriser instrumentation) are one level down from where the lifting activities are performed and therefore claimed to be protected by the floor (i.e. the concrete slab).

648. The 'Reinforced Concrete Barrier Substantiation Report for BRX' (Ref. 83) presented the substantiation of the floor between the lifting operation and the potential target plant. This assessment applied the R3 Impact Assessment Procedure (Ref. 44) and demonstrated that the associated utilisation factors were very low, and therefore the

floor should withstand the drop and no scabbing or perforation will occur which would present risks to the instrumentation.

649. In my judgement the RP's arguments presented for the three bounding cases are appropriate. Additionally, the use of R3 to assess the barrier performance meets my expectations.

650. During my assessment of the RP submissions and associated discussions I identified that the design of the maintenance monorails did not include any requirement for seismic qualification. I raised RQ-UKHPR1000-1038 (Ref. 173) to ask the RP whether the potential for coincident seismic induced dropped loads or collapse in multiple divisions had been considered.

651. The RP's response (Ref. 173) included confirmation that for all the lifting devices currently without seismic classification, seismic calculations would be performed to ensure that the collapse of the lifting devices would not occur during earthquake. I raised an additional RQ (RQ-UKHPR1000-1470 (Ref. 180)) requesting confirmation of how this requirement had been captured and incorporated into the GDA design. In response to this RQ the RP confirmed that cranes installed on the nuclear island, irrespective of their function, will maintain their integrity during a design basis earthquake event and will have a minimum seismic design requirement of SSE2 if they have the potential to impose an unacceptable impact on SSE1 SSCs. The RP outlined the requirements set out in Methodology of Safety Categorisation and Classification (Ref. 181), which will be applied to crane systems. The RP also confirmed that all steel structures installed on the nuclear island are designed according to ANSI/AISC 690 standard and with a minimum SSE2 seismic design requirement. This requirement has now been captured within the safety case and is documented in the structural analysis and design method statement (Ref. 39). I am content that the RP has adequately responded to my query.

652. As part of RO-UKHPR1000-055 (Ref. 110) and RQ-UKHPR1000-1721 (Ref. 175) I requested further clarification of how the potential for seismically induced internal hazards, including dropped loads, had been considered in the assessment and of the generic UK HPR1000 design. In response the RP produced the 'Earthquake Induced Dropped Loads Effects Safety Evaluation Report (based on the Fuel Building and Safeguard Building B) (Ref. 182). In that document the RP confirmed that further analysis of the failures of non-seismically qualified cranes will be undertaken during the site-specific stage.

653. In my judgement this approach of seismically qualifying the lifting equipment to prevent collapse or drop is good practice. However, it is at present a GDA assumption and evidence to support the seismic qualification has not yet been provided. It will therefore be necessary for the licensee to demonstrate that this equipment is adequately qualified against the site seismic profile during the site-specific phase. Whilst I note that equipment qualification is a matter for detailed design, the internal hazards consequence analysis of dropped loads impacts onto SSCs because of seismic events also need to be assessed. However, to meet the expectations of ONR SAPs EKP.1 and EQU.1 at detailed design, site specific information is required for layouts and for the seismic hazard itself. Further analysis will be required, and it is my view that this can be considered normal business.

654. Another fundamental assumption in the response to RO-UKHPR1000-055 (Ref. 182) is that all internal steel structures are seismically qualified and out of scope for GDA. Given the set requirements and statements that the cranes and structures will be SSE2, I agreed that these would not be in the scope of RO-UKHPR1000-055, and that for GDA, the dropped loads assessment would not require analysis of the collapse of these structures. However, to meet the expectations of ONR SAPs EKP.1, EKP.2 and EQU.1 at detailed design, when site specific layouts and information are available,

further analysis will be required to confirm that adequate space is available within the buildings to accommodate these seismically qualified structures and that their failure does not impact nuclear safety. I consider this to be normal business.

655. Overall, for the purposes of GDA, I judge that the RP has provided sufficient evidence that the impact from dropped loads to 'exception to segregation' areas within the reactor building have been identified and that the consequences can be controlled. I consider the need for further analysis related to the seismic qualification of lifting equipment and steel structures to be normal business resolved at detailed design.

4.6.3.3 BRX: HIC (Criterion C)

656. The RP identified the following bounding case scenarios applicable to Criterion C (Ref. 167).

- IH-DL-BRX-01 - Drop of RPV head assembly (from Polar Crane) onto the reactor cavity during refuelling outage.
- IH-DL-BRX-05 - Drop of RCP motor (from Polar Crane) onto RCP casing and flywheel during maintenance in refuelling outage.
- IH-DL-BRZ-06 - Drop of pressuriser manway cover (from monorail) onto pressuriser or surge line during maintenance in refuelling outage.

657. The dropped load assessment identified that there were no potential dropped loads that could impact the remaining HIC located in BRX (Steam Generators and the Main Coolant Line).

658. IH-DL-BRX-01 considered the potential drop of the RPV head onto the reactor vessel. The ability of the RPV to withstand the impact is justified in the RPV Head Drop Analysis report (Ref. 183).

659. The reactor building dropped load assessment identified the potential for the RPV head to be dropped onto the main steam line, which is a HIC. However, the RP argued that the RPV head is lifted in outages when the main steam line is out of service and therefore not performing the function for which it is designated as HIC, consequently loss of the main steam line can be tolerated, and assessment of the consequences of the potential impact is not necessary.

660. The RP presented similar arguments for IH-DL-BRX-05 and IH-DL-BRX-06, relating to the potential for dropped load impacts on the RCP casing and flywheel and pressuriser, as these maintenance lifts are also carried out during outages.

661. The RP assessment identified a number of locations where monorail lifting beams were situated above HIC in the reactor building. However, the RP's submissions stated that no lifting operations will be undertaken in BRX while the reactor is operating; all lifting operations will be undertaken during maintenance and refueling outages when the reactor is in the cold shutdown, defueled state. Hence the RP concluded that this means there is no potential for dropped loads on HIC during normal operation and that the monorails are provided to facilitate maintenance of the HIC so potential drops are limited to components of the high integrity systems themselves, which will already be out of service.

662. I raised RO-UKHPR1000-046 (Ref. 88) for the RP to address consideration of HIC resilience against internal hazards challenges. My assessment of the RP's response to RO-UKHPR1000-046 is detailed in this report (see sub-section 4.12.5). In that section I report my sampling and judgements on the adequacy of the RP's analysis of impacts to the RPV head, and also impacts onto high integrity functions which the RP argued could only occur during shutdown operations.

4.6.3.4 BRX: Damage to Fuel Assembly (Criterion D)

663. Criterion D is an additional criterion that specifically related to dropped load scenarios that have the potential to cause damage of the fuel assembly. This criterion only applies where fuel assemblies are located, namely the BRX and the BFX.

664. The RP identified the following bounding case scenario applicable to Criterion D:

- IH-DL-BRX-07 - Drop of fuel assembly (from the refuelling machine) in reactor pool during handling in refuelling outage.

665. The RP considered drop and damage of a single fuel assembly in the reactor pool as the bounding case for potential damage to fuel assemblies in the reactor building. This scenario is bounded by the fuel handling accident, presented in 'On-site Radiological Consequence Evaluation for Fuel Route PIE' (Ref. 184). This report (Ref. 184) calculated a significant unmitigated dose to operators assuming a 10-minute evacuation time. The source term used assumed damage to 17 fuel rods and conservatively assumed the immediate release of fission products into the pond water.

666. The RP identified IH-DL-BRX-07 as an infrequent fault in Appendix C of the reactor building dropped load assessment (Ref. 167) . The RP reported that the radiological consequences were below the BSL of 200mSv identified in Target 4 of the ONR Safety Assessment Principles (SAPs) (Ref. 2).

667. I queried the basis of the dropped load frequencies in RQ-UKHPR1000-1038 (Ref. 173) and the RP responded that the frequencies were based on single failure proof and non-single failure proof mechanical handling equipment taken from sub-section 3.4.6 of NUREG-1738 (Ref. 185).

668. While I accept that it is likely that the dropped load frequency for this scenario can be shown to be below $1x10^{-3}$ pa, this has not been demonstrated during GDA. Further analysis will be required during the detailed design when the detail of the manual handling equipment and operations will be developed. Given the potentially high radiological consequences quoted by the RP my expectation is that at detailed design the licensee will develop the safety case to address this hazard.

669. I noted that this was the only dropped load scenario identified by the RP as giving rise to radiological consequences. Hence, as part of RO-UKHPR1000-053 (Ref. 174), I requested clarification on any other dropped load scenarios where radiological consequences were assumed to bounded by IH-DL-BRX-07. In response (Ref. 57), the RP confirmed that no additional dropped loads have been identified anywhere in the reactor building with the potential to result in anything other than relatively insignificant radiological consequences. Given the relatively high radiological consequences quoted by the RP for IH-DL-BRX-07 I am content that this response is acceptable for GDA.

670. Based on the assessment provided and noting the minor shortfalls identified, I judge that the RP's assessment of dropped loads within the reactor building with the potential to result in fuel damage is adequate for the purposes of GDA.

4.6.4 BFX: Assessment of Fuel Building Dropped Loads Safety Case

671. The RP identified a total of 38 individual lifting devices located in the fuel building (Ref. 168). These consist of the 130t Spent Fuel Cask Crane, the 1t Spent Fuel Pool Crane, the 10t Auxiliary Crane and 35 monorail lifting beams located throughout the building to facilitate maintenance activities during outages.

672. Key considerations of the generic UK HPR1000 design and safety case for this building are:

- The Spent Fuel Cask Crane is used to lift the spent fuel casks between the PMC Transport Room and the cleaning pit and loading pit. Import and export of the spent fuel casks to and from the fuel handling hall is via the hoisting pit, which represents the highest potential lift of a fully laden spent fuel cask.
- The Auxiliary Crane is used for importing new fuel casks and the movement of new fuel assemblies to the new fuel elevator at the edge of the spent fuel pool, which transfers the fuel assemblies into the spent fuel pool. The Auxiliary Crane shares the same rails as the spent fuel crane and is able to traverse the hoisting pit and new fuel area.
- The Spent Fuel Pool Crane is used to move spent fuel assemblies within the spent fuel pool and transfer them between the spent fuel pool and the cask loading pit and transfer pit. The spent fuel pool crane is operated above the spent fuel pool. The RP noted the importance of the maximum lift height design limit to ensure that the spent fuel remains below the water level in the spent fuel pool at all times.
- Fuel handling activities may be carried out in the fuel handling building when the reactor is at power or shutdown. A fundamental assumption of the RP's dropped load case stated that maintenance activities which may impact on any of the systems important to safety located in the fuel building are only undertaken during reactor outages.

4.6.4.1 BFX: Bounding Cases for Barrier Assessment (Criterion A)

673. The RP's case (Ref. 168) did not identify any divisional barriers that may be impacted by drops or swinging loads from any of the lifting equipment in the fuel building. The structures that may be impacted were identified as the foundation raft and the base of the Spent Fuel Pool. The foundation raft effectively forms part of the building containment boundary, whereas integrity of the Spent Fuel Pool base is necessary to retain the water in the pool which provides shielding and cooling to the spent fuel.

674. The RP's Fuel Building Dropped Loads assessment (Ref. 168) identified three bounding cases relating to potential impacts on these barriers, these are:

- IH-DL-BFX-01 – Drop of Steam Generator Blowdown System Heat Exchanger onto building foundation raft.
- IH-DL-BFX-02 – Drop of Spent Fuel Cask in hoisting pit with potential damage to fuel building foundation raft and fuel assemblies.
- IH-DL-BFX-03 – Drop of new fuel assembly into the spent fuel pool.

675. The steam generator blowdown system heat exchanger was identified by the RP as the bounding case potential dropped load from a monorail in the fuel building. The combination of the weight of the heat exchanger and the potential drop height results in an impact energy much greater than other dropped load scenarios.

676. The floor of the room (BFX2085ZRM) of which scenario IH-DL-BFX-01 is based, is 2.2m thick and the global assessment in the Reinforced Concrete Barrier Substantiation Report for BFX (Ref. 97) calculated a utilisation factor of 0.02. The impact was therefore shown to be well below the capacity of the barrier.

677. As discussed previously the RP had not adequately considered swinging loads and I challenged this in in RQ-UKHPR1000-1038 (Ref. 173) for the reactor building (and also RQ-UKHPR1000-0961 (Ref. 179) for the safeguards building), and I requested further evidence in RO-UKHPR1000-055 (Ref. 110). In response to RO-UKHPR1000-055 (Ref. 182), the RP provided the potential impact volumes based on the calculated swing with and without sliding; the worst-case swing with sliding was 1.139m and swing without sliding was 0.529m. The methodology applied by the RP was based on ASCE 4-16 Chapter 11 (Ref. 186). I judge that this is an appropriate approach and

standard, recognised for the seismic analysis of safety related structures and consideration of swing loads, as the minimum and maximum sling lengths were used.

678. In respect to IH-DL-BFX-01, the RP indicated that a number of important safety systems could be impacted by swinging loads. The RP argued that the potential loss of the equipment only affected one train and / or it was not performing its safety function during maintenance or shutdowns, and therefore the equipment was not in service and its loss due to impact could be tolerated. I am content that this argument is adequate for the purposes of GDA.

679. IH-DL-BFX-02 considers the potential drop of a spent fuel cask in the hoisting well from a maximum height of 18.3m. The RP stated that the integrity of a spent fuel cask cannot be ensured in this scenario, hence reducing the lift height as well as other potential measures would be studied through optioneering.

680. The RP's ALARP review of the spent fuel process (Ref. 171) presented, in my view an adequate set of options to; eliminate the need to lift the spent fuel cask; reduce the lift height, or; mitigate the consequences of a potential drop. The RP's evaluation of the benefits and disbenefits of implementing the identified options are reasonable and its preferred solution adequately addressed the concerns relating to dropped loads. I note that the overall option selected by the RP is intended to address a broader range of issues and may introduce additional challenges. However I am satisfied that these will not impact the dropped loads case (e.g. additional operational challenges).

681. The identified preferred option for implementation included installing impact limiters in the loading pit, the cleaning pit (to be re-designated as the transit platform) and the base of the hoisting pit. The modification proposed that the cask sealing activities will be completed on a cask stand installed in the loading pit, which removes the requirement to undertake them in the cleaning pit. In addition, the modifications indicated that the cleaning pit will be re-purposed as a transit platform to provide a stepped lift path for the spent fuel cask and the bottom lowered to the +9.50m level, or roughly half the total cask drop height from the fuel handling hall. The addition of an impact limiter to the base of the transit platform provides the dual benefit of protecting the base of the transit platform and ensuring the cask integrity is maintained in the event of a dropped load. The cask will be lowered over the transit platform before being traversed into the hoisting pit and lowered the final ~10m. The impact limiters installed in the loading bay will prevent the floor of the PMC transport room failing, and that the cask integrity is maintained in the event of a dropped load.

682. The detailed design of the cask and impact limiters will be undertaken post-GDA, supported by appropriate analysis to demonstrate the spent fuel cask withstand and adequate performance of the impact limiters. I have therefore raised the following Assessment Finding to ensure appropriate regulatory oversight of these activities, particularly with respect to analysis of design basis events and identification and classification of SSCs and categorisation of their safety functions (SAPs EHA.5, EQU.1, ECS.1-2).

> AF-UKHPR1000-0071: The licensee shall, as part of detailed design, demonstrate that the internal hazards arising from the fuel cask handling operations are reduced to as low as reasonably practicable. This should include but not be limited to, substantiation of the impact limiter design.

683. The Reinforced Concrete Barrier Substantiation Report for BFX (Ref. 97) also identified the bases of the loading pit and cleaning pit as potential targets of a drop of the spent fuel cask from the Spent Fuel Cask Crane.

684. Impact on the base of the cleaning pit was not explicitly assessed in the barrier substantiation report. The report stated that the drop onto the bottom of the loading pit is from around twice the height of the cleaning pit drop (13.50m as opposed to 6.80m) and that the base of both pits is of similar construction. However, the drop in the cleaning pit is through air rather than water and therefore the two drops are not directly comparable. I judge that this is not a significant issue for GDA given that the RP has demonstrated the withstand of similar barriers against equivalent or greater challenges in the barrier substantiation report (Ref. 97).

685. The RP identified IH-DL-BFX-03 (drop of a new fuel assembly from the Auxiliary Crane into the spent fuel pool) as the bounding case for potential impacts on the bottom of the spent fuel pool.

686. The RP used LS-DYNA to model the impact on the spent fuel pool. As I stated in my assessment of the reactor building case, LS-DYNA is a recognised tool for this purpose. The adequacy of the RPs claims for the structural performance under these loads is assessed in detail by the ONR civil engineering assessment (Sub-section 4.5.5 (Ref. 49)). Furthermore, I note that the RP has committed to conduct further sensitivity studies at the site-specific stage to demonstrate that the single loading location chosen and presented in GDA is suitably bounding. The further work required for this is captured in Assessment Finding AF-UKHPR1000-0221 (Ref. 49). In addition, to ensure that the appropriate assessment criteria are applied, Assessment Finding AF-UKHPR1000-0069 is also relevant here.

4.6.4.2 BFX: Exception to Segregation (Criterion B)

687. The RP identified five exception to segregation areas in the fuel building in the List of Segregation Areas and Exception to Segregation Areas (Ref. 29). The report considered each area in turn, sentencing the potential for equipment from more than a single safety train to be impacted by a dropped load event. The RP ruled out the vulnerability of each ‘exception to segregation’ area in the BFX based on the following statements:

- The APG [SGBS] valve room – there is no lifting equipment located in the room or the room above.
- The RRI [CCWS] piping area – there is no lifting equipment located in the rooms or the rooms above.
- The PTR [FPCTS] piping area – dropped loads only have the potential to impact on the train A PTR pipework.
- The ventilation systems area – the Safeguard Building Controlled Area Ventilation System, Annulus Ventilation System, and Containment Sweeping and Blowdown Ventilation System are arranged in the ventilations systems area and no lifting equipment is present in any of these rooms or the rooms above.
- Fuel handling and storage area - PTR sensors and pipework used for SFP level and temperature measurements are located around the perimeter of the SFP. The RP assessment identifies the shortest distance between two pipes from different safety trains is 1.58m, fuel assemblies are handled vertically hence there is no potential for both these pipes to be damaged by the drop of a single fuel assembly.

688. The RP concluded that there are no exceptions to segregation that are a concern for dropped loads in the fuel building. In my judgement the arguments provided are adequate and reasonable for the purposes of GDA.

4.6.4.3 BFX: HIC (Criterion C)

689. The RP specified that there are no HIC located in the fuel building and therefore no bounding cases were identified associated with this criterion (Ref. 168). I have sampled HIC assessments, notably for RO-UKHPR1000-046 (see sub-section 4.11 of this report) and I have not identified anything to challenge this position.

4.6.4.4 BFX: Damage to Fuel Assembly (Criterion D)

690. The RP identified the following bounding case scenarios applicable to Criterion D (Ref. 168):

- IH-DL-BFX-02 - Drop of Spent Fuel Cask in hoisting pit with potential damage to fuel building foundation raft and fuel assemblies.
- IH-DL-BFX-04 - Drop of spent fuel assembly into the spent fuel pool.

691. The RP did not discuss radiological consequences of IH-DL-BFX-02 in the fuel building dropped load assessment. Furthermore, the RP considered that failures of the fuel cask cannot be tolerated. The RP identified this as a gap in the dropped load assessment for the fuel building (Ref. 168), stating that optioneering would be undertaken to review the substantiation requirements and to reduce the potential drop height.

692. I sampled the RP's 'ALARP Assessment of the Spent Fuel Delivery Process' (Ref. 171) and confirmed that the radiological consequences of the spent fuel cask drop had not been assessed. Instead, the RP had focused on options with the potential to ensure that the cask containment is maintained. The RP considered that the design of the cask and canister to be used for spent fuel operations were outside the GDA scope. For the purposes of the optioneering assessment, the RP assumed that a drop height of 10m or more was likely to be beyond the withstand of typical cask designs.

693. As discussed for criterion A, the ALARP Assessment report (Ref. 171) presented a relatively comprehensive set of options to eliminate the need to lift the spent fuel cask, reduce the height to which it must be lifted, or to sufficiently mitigate the consequences of a potential drop. As discussed above in my assessment for BFX criterion A, the RP's preferred option included the installation of impact limiters in the loading pit, the cleaning pit (to be re-designated as the transit platform), and the base of the hoisting pit. In principle, my judgement is that the proposed solution of combining the cask withstand with a compressible buffer material is an appropriate means of ensuring that the cask integrity is maintained in the event of a dropped load.

694. Further consideration of the consequences of the drop of the spent fuel cask and the design of the impact limiters was provided by the RP in response to RO-UKHPR1000-056 (Ref. 187), which was raised in relation to on-site consequences of the fuel route PIEs. This provided further details of the proposed design of the impact limiters.

695. The design proposed by the RP for the impact limiters in its response to RO-UKHPR1000-056 (Ref. 187) comprised of deaerated concrete bricks sandwiched between two concrete slabs. I accept that the deaerated concrete bricks will provide some energy absorption once the upper concrete slab is breached, however it is not clear how this arrangement will protect the cask against the initial shock impulse when it impacts the slab. I have assessed the proposed changes to address the shortfall (discussed further in sub-section 4.11 of this report), noting that the fuel handling parameters including the cask design and the handling operations procedures are not fully defined. I note that the UKABWR GDA considered a similar drop hazard relating to the spent fuel cask where optioneering identified, as the preferred option, an engineered impact limiter at the bottom of the lifting shaft, in combination with the cask withstand. This is discussed in the ONR ABWR Step 4 Internal Hazards Assessment

Report (Ref. 188). In my judgement that use of an impact limiter is a feasible option which can be developed in conjunction with the detail of the fuel cask and fuel handling operations during detailed design.

696. I am therefore content that the solution identified in the RP's ALARP assessment of the spent fuel delivery process (Ref. 171) is adequate for the purposes of the GDA dropped loads assessment, noting that my Assessment Finding AF-UKHPR1000-0071 requires resolution.

697. The RP identified the drop of a single fuel assembly in the spent fuel pool from the spent fuel pool crane (IH-DL-BFX-04) as the bounding case for potential damage to fuel assemblies in the fuel building. The potential unmitigated dose to operators was calculated by the RP based on a 10-minute evacuation time and a source term that assumes damage to 17 fuel rods and the immediate release of fission products into the pond water.

698. The RP identified IH-DL-BFX-04 as an infrequent fault as the initiating event frequency is less than $1x10^{-3}$pa. As the potential consequences are above the SAPs target 4 Basic Safety Level (BSL), I would expect the hazard frequency to be demonstrated to be below $1x10^{-4}$ pa in line with Target 4 of the SAPs (Ref. 2).

699. As identified in the discussion of IH-DL-BRX-07 in the reactor building (see Sub-section 4.6.3.4), I queried the basis of the drop frequencies in RQ-UKHPR1000-1038 (Ref. 173) (point 7). The ONR Mechanical Engineering team challenged the design of the spent fuel pool crane, as part of RO-UKHPR1000-014 (Ref. 189) and a further cross cutting RO was raised RO-UKHPR1000-056 (Ref. 190), to address shortfalls identified with the safety case for the equipment identified to handle spent nuclear fuel, and the risks associated with fuel handling. The generic UK HPR1000 design initially adopted an overhead travelling crane, which is not an approach typically used in the UK for fuel handling operations. In response to these ROs, the RP has proposed a substantial redesign of the fuel handling arrangements.

700. The final design of the crane and operations in this area will clearly impact on the potential dropped load frequency and therefore, as the crane design is subject to change, further internal hazards assessment will be required during detailed design. This will be addressed by resolution of Assessment Finding AF-UKHPR1000-0071.

701. I judge that the assessment provided by the RP of dropped loads within the fuel building is adequate for the purposes of GDA, noting that I have raised Assessment Finding AF-UKHPR1000-0071 requiring further analysis to be completed by the licensee at detailed design.

4.6.5 BSX: Assessment of Safeguard Building Dropped Loads Safety Case

4.6.5.1 BSX: Bounding Cases for Barrier Assessment (Criterion A)

702. The RP stated in the dropped loads assessment for the Safeguard Buildings (Ref. 169) that only the foundation raft may be affected by dropped loads, as it assumed that loads drop vertically to the floor. The RP separately considered swinging effects for lifting devices located close to divisional barriers. The RP also identified 148 monorail lifting devices in the safeguards building (Ref. 177).

703. The RP identified the following bounding case scenario for impacts to barriers in the safeguards building (Ref. 169):

- IH-DL-BSX-01 – Dropped loads which may impact the foundation barrier.

704. The RP's assessment in (Ref. 169) considered two initiating events leading to IH-DL-BSX-01. In both cases the RP identified that barrier substantiation was required to demonstrate whether the foundation raft can withstand the dropped loads effect. The barrier substantiation report (Ref. 101) applied a method from the R3 Impact Assessment Procedure to assess the potential for perforation or scabbing to occur as a result of the impact. I am satisfied that the RP provide sufficient evidence, including adequate analysis, to confirm that the identified bounding case dropped load impact onto the foundation raft will not result in significant damage to the barrier and therefore satisfies SAPs EHA.1 and EHA.6.

705. As noted previously, I raised queries on the modelling of swinging loads impacting barriers in RQ-UKHPR1000-0961 (Ref. 179) for the safeguards building (and also RQ-UKHPR1000-1038 (Ref. 191) for the reactor building and RQ-UKHPR1000-1418 (Ref. 176) for the fuel building). The RP's responses (Ref. 179) to my queries for the modelling of swinging loads have been adequate for the purposes of GDA.

706. In my judgement, the assessment in the dropped load assessment report, in combination with the responses provided by the RP to the RQs raised, provide sufficient confidence that swinging loads from the mechanical handling equipment in the safeguards building do not pose a significant challenge to the civil structures. I am therefore content that the assessment of swinging loads is adequate for the purpose of GDA.

4.6.5.2 BSX: Exception to Segregation (Criterion B)

707. The RP's assessment (Ref. 169) identified two exception to segregation areas in the Safeguard Building, these are:

- Main Control Room in BSC.
- Main Steam Line (VVP [MSS])/ Main feedwater flow control system ARE [MFFCS] pipes and valves (train B and train C) in BSB.

708. In (Ref. 169) the RP identified the following bounding case scenario for criterion B.

- IH-DL-BSX-02 – Dropped Loads which cause the loss of more than one safety train.

709. The RP's assessment (Ref. 169) considered the bounding case of dropped loads during lifts of the VVP2220VV-actuator. The RP's analysis addressed the potential for the dropped load to penetrate through the service room floor into the room, containing safety equipment below. The RP's functional analysis (Ref. 169) concluded that perforation or scabbing of the service room floor will not occur and hence that the safety equipment in the room below will not be damaged. I am content that the evidence presented is adequate for GDA.

4.6.5.3 BSX: HIC (Criterion C)

710. In dropped loads safety case for the safeguard buildings (Ref. 169) the RP identified the main steam lines as potential HIC and hence the following bounding case scenario was identified.

- IH-DL-BSX-03 – Main Steam Line Impacted by Dropped Loads.

711. The RP's assessment of this scenario relied on lifting operations only being carried out during outage maintenance activities, during which the main steam lines will not be functional or required to maintain safety.

712. As discussed above I raised RO-UKHPR1000-046 (Ref. 155) on the subject of the designation and assessment of HIC against internal hazards challenges. My

assessment of the RP's response to RO-UKHPR1000-046 is detailed in this report in sub-section 4.11 of this report and hence is not discussed further here.

713. In my judgement, based on the information provided in the RP's assessment and the response to RO-UKHPR1000-046, I am content that the RP has provided an adequate assessment of dropped loads impacts to HIC in the safeguard buildings for the purposes of GDA.

4.6.6 Summary of Assessment and Affirmation of PCSR Claims

714. My assessment of the dropped loads assessment reports identified a number of areas where further clarification was required, hence I raised corresponding RQs and ROs. In the majority of cases the additional information provided in response is considered sufficient for the purposes of GDA. Where gaps remain, I have identified them as minor shortfalls and Assessment Findings.

715. The main shortfalls I identified during the assessment generally related to the lack of evidence to support the bounding cases and conclusions drawn. However, when I challenged this through RQs and RO-UKHPR1000-UKHPR1000-0053, the further evidence provided by the RP for specific samples was sufficient to provide additional confidence in the conclusions presented.

716. In my judgement none of the above issues are insurmountable, and suitable solutions are not precluded by the GDA design. Where appropriate I have raised Assessment Findings to ensure that these issues are addressed during detailed design. I am therefore content that solutions to these shortfalls that reduce risk to ALARP can be identified and implemented during the detailed design.

4.6.6.1 Affirmation of PCSR Claims for the Dropped Loads Safety Case

717. This section provides a summary of my assessment of the principal claims associated with the internal dropped loads safety case.

- **Sub-claim 3.2.2.SC19.2.13** (Dropped Loads): The dropped loads sources are sufficiently identified.

718. Based on the evidence provided and assessed, the RP has demonstrated that the principal dropped loads scenarios have been identified, noting that evidence provided through RQs, RO-UKHPR1000-046 and RO-UKHPR1000-053 has given further confidence in this regard. The RP has identified potential areas of exception to segregation and assessed the potential dropped loads impacts. This satisfies SAPs EHA.1 and EHA.19.

- **Sub-claim 3.2.2.SC19.2.14** (Dropped Loads): After the safety assessment, the safety measures to mitigate the consequences of dropped loads are sufficiently identified and properly classified.

719. Through my assessment I have been satisfied that the RP's methodology and analysis for dropped loads is adequate. Through its analysis the RP has identified appropriate safety measures in particular civil barriers, which in my view have been adequately classified, satisfying SAPs EKP.5, EHA.4, EHA.6 and FA.8.

- **Sub-claim 3.2.2.SC19.2.15 (Dropped Loads)**: The safety measures to mitigate the consequences of dropped loads are sufficiently substantiated.

720. I considered that the analyses carried out by the RP has adequately justified that the identified barriers will provide the required withstand to ensure that dropped loads impacts are retained within one safety train. This satisfies SAPs FA.8, ECS.2 and ECS.3.

4.6.7 Dropped Loads Safety Case Strengths

721. Through my assessment recorded above, I have noted the following strengths in the RP's internal dropped loads safety case:

- The RP has adopted appropriate standards and relevant good practice.
- The RP has adequately implemented its methodology.
- The RP has provided positive responses to the ONR queries.

4.6.8 Outcomes

722. Through my assessment of the RP's internal dropped loads safety case, I have been satisfied that the RP has provided adequate evidence to underpin its dropped loads analysis for the purposes of GDA. The RP has demonstrated that hazard identification has been applied in line with its assessment criteria (A, B and C).

723. Following my assessment, I have identified several areas of improvement through a mix of Assessment Findings and minor shortfalls. My Assessment Findings relate to applying appropriate analysis criteria to determine failure, the consequences of RPV head drop to the reactor pool structure and the modifications to the BFX for spent fuel cask handling operations.

4.6.9 Conclusions

724. My assessment of the generic UK HPR1000 internal dropped loads safety case has been informed by several submissions, RQs and ROs. The breadth and depth of my assessment has been focused on the key risk areas and the quality of evidence provided.

725. Although several Assessment Findings have been identified, I am content that the principal risks from dropped loads scenarios have been identified and understood for the purposes of GDA.

726. Therefore, based on the outcomes of my assessment of the RP's internal dropped load safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and have raised Assessment Findings accordingly. I do not judge that these gaps are significant enough to prevent issue of a DAC, as I am content that they can be addressed by the licensee at detailed design.

4.7 Hazard Assessment – Internal Missiles

4.7.1 Principal Claims from the Generic UK HPR1000 Internal Missiles Safety Case

727. The generic UK HPR1000 internal missiles safety case for the GDA sample buildings (BRX, BFX and BSA/BSB/BSC) is comprised of the following principal documentation:

- GHX00100041DOZJ03GN The Internal Missiles methodology report (Ref. 192).
- GHX84200043DOZJ03GN Internal Missiles Safety Assessment Report for Reactor Building, Rev. A (Ref. 193).
- GHX84200046DOZJ03GN Internal Missiles Safety Assessment Report for Fuel Building, Rev. A (Ref. 194).
- GHX84200036DOZJ03GN Internal Missiles Safety Assessment Report for Safeguard Buildings, Rev. A (Ref. 195).

728. The principal claims for the internal missile safety case for the generic UK HPR1000 design are defined within the RP's pre-construction safety case report (PCSR) Chapter 19 Internal hazards (Ref. 3). These claims are stated as:

- Sub-claim 3.2.2.SC19.2.16: The internal missile sources are sufficiently identified.

  - Argument 3.2.2.SC19.2.16-A1: Equipment is identified as potential internal missile sources regardless of its classification except for equipment designed as HIC.

- Sub-claim 3.2.2.SC19.2.17: After the safety assessment, the safety measures to mitigate the consequences of internal missiles are sufficiently identified and properly classified.

  - Argument 3.2.2.SC19.2.17-A1: In segregation areas, safety measures are identified to ensure that the consequences of any internal missile are limited to one train of the systems delivering the safety functions through use of barriers.
  - Argument 3.2.2.SC19.2.17-A2: Where there are exceptions to segregation, safety measures are identified to ensure that sufficient SSCs are available, during and after an internal missile, to deliver the safety functions.
  - Argument 3.2.2.SC19.2.17-A3: An internal missile does not cause unacceptable damage to HIC.
  - Argument 3.2.2.SC19.2.17-A4: The safety measures to mitigate the consequences of internal missiles are classified in accordance with the methodology of safety categorisation and classification.

- Sub-claim 3.2.2.SC19.2.18: The safety measures to mitigate the consequences of internal missiles are sufficiently substantiated.

  - Argument 3.2.2.SC19.2.18-A2: Walls/ floors/ additional local partitions which are claimed as barriers to deliver the function of internal missile protection are also substantiated to withstand the loads imposed by internal missiles.

4.7.2 Internal Missiles Methodology Assessment

729. The RP’s internal missiles methodology (Ref. 192) aims to demonstrate that the following general principles of design protection against internal missiles (Ref. 27):

- Internal missiles should not result in the loss of any fundamental safety function of nuclear power plants.
- Internal missiles should not cause Design Basis Condition (DBC) 3 or 4 or Design Extension Condition (DEC) where practicable.
- Internal missiles should not cause damage to High Integrity Component (HIC).
- The habitability of the Main Control Room (MCR) should be ensured in the event of an internal missiles so far as reasonably practicable.
- The availability and the accessibility of the remote shutdown station should be ensured in case the MCR is unavailable.
- There is no cliff edge effect due to an internal missile event, and
- The risk from internal missiles will be reduced to ALARP.

730. The RP’s methodology provided a structured approach for the assessment of internal missile hazards. The RP’s assumptions included some conservatisms, such as equipment located in the impact areas for internal missiles was assumed to fail, initial kinetic energy of rotating equipment was totally converted to translation kinetic energy, and no energy reduction was claimed for perforation of the casings. The RP also made a conservative assumption in that the analysis considered that missile fragments from

pumps and other rotating equipment would not be retained by the equipment casing. In my judgement the RP's principles and assumptions meet ONR expectations specifically with respect to FA.1 and FA.7 (ensuring the consequences are analysed and risks reduced to ALARP) and EKP.1 (ensuring the design is inherently safe).

731. The RP's methodology included a section on the review and screening of internal missiles sources. This section reviewed the potential for missiles to be generated from high energy fluid systems, rotating equipment, and the Control Rod Drive Mechanism (CRDM).

732. The methodology addressed the potential for high energy valves to fail and generate missiles. However, no justification is provided to indicate why some missile sources (such as HIC) are not including in the assessment scope. I am content that HIC should not fail under normal operating conditions and hence should not generate missiles. However, this should be explicitly identified and substantiated in the safety case. Additionally, valves with two or more fastening measures for removable parts were screened out as missile sources by the RP. In my judgement, this places a requirement on the fastening measures, and it is important that these are designated as safety features with suitable classification and engineering substantiation of their effectiveness to prevent or mitigate missiles. Hence, it is not clear whether all systems with the potential to generate missiles are bounded by this approach. This does not meet the expectations of ONR SAPs EHA.1 and EHA.19 related to identification and screening of internal hazards. I have included this shortfall in the Assessment Finding raised below.

AF-UKHPR1000-0072: The licensee shall, as part of detailed design, demonstrate that the risks from internal missile hazards screened out based on restraints are reduced to as low as reasonably practicable. This should include, but not be limited to, substantiation of the restraint systems.

733. The RP identified two critical welds for the Control Rod Drive Mechanism (CRDM) pressure housing assembly whose failure may generate internal missiles, and provided the following (paraphrased) discussion of the considerations for the bounding case.

> "If the joint between the rod travel housing and the latch housing fails, the rod travel housing and drive rod assembly can be ejected. Calculations show that the missile from ejection of a drive rod assembly has both a larger ejection velocity and a smaller impact area than the missile from ejection of a rod travel housing. On the assumption of more energy acting on a smaller area it is likely to be more damaging. Therefore, the ejection of drive rod assembly is the bounding case for missiles in this case"

734. I have assessed the RP's analysis. Whilst the scenarios identified are reasonable in terms of defining the bounding cases for potential missiles generation, no further evidence or justification is provided, such as reference to the calculation results using SSC design and layout information. Whilst there is a potential safety case gap where possible missile generation hazards may not have fully been bounded, I am content that the case selected is challenging and further justification would require detailed design considerations and will be influenced by licensee choices. Further justification and evidence is therefore required to meet the expectations of ONR SAPs EHA.1, EHA.6 and EHA.19. once future design decisions are made. However, I judge the current case is adequate for the purposes of GDA.

735. The RP's preliminary consequences analysis distinguished between rooms containing redundant equipment, and rooms that don't contain redundant safety equipment. In my judgement a review should be undertaken at detailed design to ensure that room

layout changes have been considered with respect to the location of redundant equipment. This is expected as part of normal regulatory business.

736. The RP's assessment considered rotating equipment and conservatively assumed that plant is operating at maximum speed when failure occurs. It also assumed that three equal sized fragments were generated which is in agreement with recommendations in the R3 methodology (Ref. 44).

737. The RP presented different approaches to calculate the kinetic energy for missiles from valves, vessels and the CRDM. The RP assumed vertical and horizontal missiles from valves are continuously accelerated up to a maximum speed either limited by the maximum flight length or the jet velocity, whatever value is smaller. The RP assumed normal operating conditions in the calculation of the kinetic energy for CRDM missiles. For velocity calculations the RP assumed the missile did not continue to accelerate after ejection.

738. The RP's calculation of missile mass and impact area considered the specific valve size and type, I judge that these are reasonable and conservative approaches in line with ONR SAPs EHA.1 and EHA.19.

739. In summary, following my assessment of the RP's internal missiles methodology I have been satisfied that for the purposes of GDA that the RP's methodology is adequate. I have considered how the RP has applied this methodology, noting the Assessment Finding raised during my assessment of the principal buildings in the generic UK HPR1000 design. My assessment is presented in the following sections.

4.7.3 BRX: Assessment of Reactor Building Internal Missiles Safety Case

740. The RP's internal missiles assessment (Ref. 193) followed the assessment methodology (Ref. 192). The RP identified internal missile bounding cases based on criteria A, B and C.

741. The missile source from rotating equipment with the maximum impact energy and with the missile target being the thinnest barrier it could impact was selected by the RP as the first bounding case (Ref. 193). The RP selected further bounding cases for other rotating equipment missile sources where the barrier thickness for potential targets is smaller.

742. I raised a number of queries related to the bounding case selection in RQs (RQ-UKHPR1000-1031 (Ref. 196), RQ-UKHPR1000-1037 (Ref. 197)). I then raised RO-UKHPR1000-053 (Ref. 174) to provide further clarity and to address gaps in the safety case analysis (see sub-section 4.11.2). The RP produced the reports 'Justification of Internal Hazards for the Sampled Areas' (Ref. 57) and 'Room Datasheet for the Sampled Areas' (Ref. 77) in response. The room datasheets (RDS) (Ref. 77) provided a list of all equipment, including missile sources, for each room of the RO-UKHPR1000-053 sample areas. This information was complemented by 2D drawings of the sample rooms (Ref. 78) which provided evidence and verification for the location steps of this bounding case selection process. The response to RO-UKHPR1000-053 (Ref. 57) provided further narrative and analysis to justify that the bounding cases identified as representative of the internal hazards in the reactor building are sufficiently justified. This satisfies SAPs EHA. 2, 6, 14 and 19.

743. The RP stated within its safety case (Ref. 193) that the accumulators were the only vessels that would be assessed as potential missile sources in the BRX. It documented the detailed safety assessment of the accumulators in the report 'Accumulators Failure Consequence Analysis Report' (Ref. 198).

744. This report (Ref. 198) stated that the accumulator postulated gross failures are assessed based on a systematic consideration of the direct and indirect failure consequences, and provided evidence that missile trajectory is vertical. The RP concluded that the direct and indirect consequences of the accumulator gross failure were acceptable. In RQ-UKHPR1000-1037 (Ref. 197), I queried the RP's assumptions on missile trajectory. In response the RP confirmed that this is vertical. No bounding case for vessels as missile source were defined because the consequences from accumulator failure were considered acceptable. Nevertheless, the accumulator failure should be added to the criterion A cases for assessment during detailed design when the plant layout will be known, and the licensee can consider the potential location of SSCs with respect to missile sources. I consider this a minor shortfall in line with ONR SAP EHA.1 that can be addressed at the detail design. Similar information will also be required at detailed design to support the assessment of all potential internal missile scenarios. This will be followed up as part of normal regulatory business.

745. The RP's assessment of internal missiles in the reactor building (Ref. 193) included several supplementary assumptions in line with its methodology (Ref. 192) which, paraphrased, include:

- Internal missiles impact is perpendicular to the target (the worst scenario).
- Ricochet of missiles is generally not considered due to the decrease of energy following the initial impact.
- For vertical upward valve missiles, the pressure at which fluid expels the missile is assumed to be constant.
- The ceilings of the room where valves are located are claimed as internal missiles barriers unless the substantiation result shows that the barriers cannot withstand the internal missiles loads, then the upper ceiling will be taken into consideration.
- Vessels are most likely to fail at welds.
- For CRDM:
  - The coolant discharge area is small which means that the coolant pressure can be assumed to be constant before the missile is totally separated from the stationary component and the coolant pressure will quickly decrease to atmospheric pressure following missile generation.
- For rotating equipment:
  - The fragment from rotating equipment, except for turbines, is assumed to be potentially ejected in any direction.
  - Initial kinetic energy (kinetic energy = translational energy + rotational energy) of the ejected sector is totally converted to impact energy of the missiles.
  - No energy is expended in deforming the missiles as they perforate the casing.
  - Missile energy is not reduced due to friction, air resistance and gravity.
  - For the rotating elements, such as discs or wheels, it is conservatively assumed that three equal sized fragments are generated.
  - For the rotating elements like blades, it is assumed that one of the blades can form a missile with high translational energy.

746. I judge that the above assumptions are adequate and are in line with ONR SAPs EKP.1, EKP.2 and EKP.3.

4.7.3.1 BRX: Bounding Cases for Barrier Assessment (Criterion A)

747. The RP identified bounding case internal missiles scenarios for criterion A by considering the impact energy of potential missiles and the location and size/thickness of barriers and applying the internal missiles methodology (Ref. 192). The following bounding case scenarios were identified.

- Six cases for valves (IH-IM-BRX-01 to IH-IM-BRX-06).
- Two cases for CRDM (IH-IM-BRX-11 and IH-IM-BRX-12).
- Two cases for rotating equipment (IH-IM-BRX-13 and IH-IM-BRX-14.

748. I selected the cases IH-IM-BRX-01, IH-IM-BRX-04 and IH-IM-BRX-06 in the resolution of RO-UKHPR1000- 53 (Ref. 174) to provide evidence for the bounding approach. In response the RP provided further evidence concerning the missile and barrier characteristics for the bounding cases including missile impact energy, missile mass, missile force area, nose shape factor, and barrier thickness.

749. The RP undertook consequence analysis (using layout information from the 3D model) for the scenarios where the barrier is considered to fail, (IH-IM-BRX-01, IH-IM-BRX-02, IH-IM-BRX-04). In these cases, the RP assumed that the equipment located in the rooms above and under the barrier (ceiling) also failed. In addition, the RP undertook further analysis to consider whether redundant trains of SSCs and other barriers could fail. The RP's analysis (Ref. 57) concluded that the consequences were tolerable, largely due to the limitation of effects to a single division and the prevention of any impact on the outer containment of the BRX.

750. The RP provided barrier substantiation in the report 'Reinforced Concrete Barrier Substantiation Report for BRX' (Ref. 83).

751. The RP did not assess consequential internal hazards caused by potential barrier failures. Furthermore, consequential failures caused by missiles from rotating equipment being ejected in any direction were also not assessed in the RP's internal missiles assessment (Ref. 193) or within the combined hazards assessment (Ref. 199). This is not consistent with the expectation of ONR SAPs EHA.1, EHA.3 and EHA.6. I have raised the following Assessment Finding for the RP to address this gap at detailed design when more detailed information about the site layout and location of all SSCs will be known.

> AF-UKHPR1000-0073**:** The licensee shall, as part of detailed design, demonstrate that the risks from consequential internal missile hazards are reduced to as low as reasonably practicable.

752. In summary, from my assessment of the bounding cases for the BRX I have been satisfied that the RP has identified appropriate bounding cases. However, I have identified shortfalls in the RP's safety case evidence and raised an Assessment Finding to address this. However, this shortfall does not undermine my view that the case is adequate for the purposes of GDA.

4.7.3.2 BRX: Exception to Segregation (Criterion B)

753. The RP's assessment for Criterion B focused on areas where there are exceptions to segregation where a single internal missiles source could potentially affect multiple trains of equipment. In identifying exceptions to segregation, the RP considered rooms that contain; valves, rotating equipment, CRDMs, equipment from more than a single train, and equipment located in adjacent rooms.

754. The RP considered three bounding cases against Criterion B, IH-IM-BRX-15, IH-IM-BRX-16, and IH-IM-BRX-17 (Ref. 193). All three cases related to missiles from failure of rotating equipment, and the RP did not identify any bounding cases for missiles from failure of valves or from the CRDM that could impact more than one train of safety system.

755. Through my assessment, I am satisfied that the RP provided adequate justification to demonstrate there were no bounding cases related to either valves as missile sources, or the CRDMs impacting redundant SSCs based on barrier substantiation and physical separation. In addition, the RP considered potential deviations of up to 10-degrees from vertical ejection. I judge this meets the expectations of SAPs EHA.6 and EHA.7 and is adequate for the purposes of GDA. This should be reviewed during detailed design when the layout of the building is fully developed. This may be followed up as part of normal regulatory business.

756. The RP's selected bounding cases addressed scenarios with the potential for internal missiles to penetrate a barrier and impact an SSC in an adjacent room. The RP provided further evidence of substantiation of the barrier within the barrier substantiation report (Ref. 83) which demonstrated that the impact energy of the missiles is insufficient to cause failure of the claimed barriers. I reviewed the information provided and, in my judgement, I am satisfied that this analysis is sufficient for GDA purposes.

4.7.3.3 BRX: HIC (Criterion C)

757. The RP identified the following bounding case scenarios applicable to Criterion C (Ref. 193):

- Four cases for valves (IH-IM-BRX-07 to IH-IM-BRX-010).
- No case for CRDM.
- Six cases for rotating equipment (IH-IM-BRX-18 to IH-IM-BRX-23).

758. The RP's internal missiles assessment considered the potential for internal missiles to impact HIC located in BRX which include the Reactor Pressure Vessel head, the Steam Generators, the Main Coolant Line, the Main Steam Line, the Pressuriser, and the Reactor Coolant Pumps.

759. As discussed in Sub-section 4.11 of this report, I raised RO-UKHPR1000-046 (Ref. 88) to request further information regarding the substantiation of HIC against internal hazards loads. The RP's response to RO-UKHPR1000-046 (Ref. 155) confirmed that HIC were substantiated against the loads from internal missiles for the selected sample cases and that the structural integrity of the HIC would be preserved. Following my assessment of the presented evidence (Ref. 155) as detailed in the RO-046 section of this report, I am content that the expectations of ONR SAPs EHA.6 and EKP.5 have been satisfied.

760. I also selected IH-IM-BRX-07 (valve missiles impacting the steam generator) as a sample area in RO-UKHPR1000-053 (Ref. 174). In response (Ref. 57), the RP provided further evidence concerning the missile characteristics for the bounding case and the bounded cases. The RP evaluated the potential impact of the bounded missiles on the steam generator and compared impact energies with the bounding case. I sampled this response and judged that the RP's assessment meets the expectations of ONR SAPs EHA.1 and EHA.6.

761. In summary, I judge that the RP has provided sufficient evidence of an adequate hazard identification and screening process for the internal missiles hazards in the Reactor Building BRX in line with ONR SAP EHA.1 and EHA.19. I judge that the

scenarios identified for further analysis are adequate and provide confidence that the principal risks to BRX from internal missiles were captured.

4.7.4 BFX: Assessment of Fuel Building Internal Missiles Safety Case

762. The RP's assessment of the fuel building missiles safety case is presented in the 'Internal missiles safety assessment report for fuel building' (Ref. 194). The claims arguments and evidence for the internal missiles assessment of the BFX presented by the RP were very similar to those presented for the assessment of the BRX. The RP noted that there were no HIC identified in the BFX.

4.7.4.1 BFX: Bounding Cases for Barrier Assessment (Criterion A)

763. The RP identified the following bounding case for criterion A for the different missile sources (Ref. 194).

- One case for valves (IH-IM-BFX-01).
- One case for rotating equipment (IH-IM-BFX-02).

764. The bounding case for internal missiles from valves IH-IM-BFX-01 was selected by the RP because this valve has the highest impact energy, and the targeted barrier is a ceiling with the smallest thickness in the BFX building of 500mm. The RP selected IH-IM-BFX-02 as the bounding case for internal missiles from rotating equipment because this equipment has the highest impact energy, and the targeted barrier is a wall with a thickness of 400mm which is the smallest wall thickness that can be affected by missiles from rotating equipment.

765. The safety assessment for the selected cases provided sufficient information concerning the missiles characterisation and the barriers to be substantiated. The barrier substantiation itself was provided in the BFX barrier substantiation report (Ref. 97). The calculation results presented show that the barriers can withstand the load from the missile in both cases and no further consequence analysis is undertaken. I reviewed the information provided and in my judgement this analysis is in line with SAPs EHA.1 and EQU.1 and sufficient for GDA purposes.

4.7.4.2 BFX: Exception to Segregation (Criterion B)

766. The RP identified five potential exception to segregation areas in the fuel building in the 'List of Segregation Areas and Exception to Segregation Areas' (Ref. 29). The RP considered each of these exception to segregation areas to identify whether there was the potential for equipment from more than a single safety train to be impacted. In identifying exceptions to segregation, the RP considered; rooms that contain valves, rotating equipment, equipment from more than a single train, and equipment located in adjacent rooms (Ref. 194).

767. The RP confirmed that SSCs from different safety trains are separated within the BFX building and selected three bounding cases for this criterion, all related to rotating equipment, IH-IM-BFX-03, IH-IM-BFX-04 and IH-IM-BFX05 (Ref. 194).

768. The RP provided a rationale for excluding valves as internal missile sources affecting exception to segregation SSCs which relied on the substantiation of barriers and physical separation due to plant locations relative to the building layout. In addition, the RP considered missiles with a deviation of up to 10-degrees from vertical ejection. I judge the arguments provided to be reasonable for GDA purposes, however this should be reviewed during detailed design when the layout of the building is fully developed. This may be followed up as part of normal regulatory business.

769. I reviewed the RP's assessment of the bounding cases selected. I noted that all the bounding cases selected were similar as they all addressed scenarios with the

potential for internal missiles to penetrate a barrier and impact an SSC in an adjacent room. The RP provided further evidence of substantiation of the barriers in (Ref. 83) which confirmed that the impact energy of the missiles was insufficient to cause failure of the barriers and hence the barriers were substantiated to withstand the missile. In my judgement this analysis is in line with SAPs EHA.1 and EQU.1 and is sufficient for GDA purposes.

4.7.4.3 BFX: HIC (Criterion C)

770. The RP specified that there are no HIC located in the fuel building (Ref. 194) and therefore no bounding cases were identified associated with this criterion. I have not identified anything to challenge this position during my assessment of the fuel route internal missiles assessment.

4.7.4.4 BFX: Review Findings – Non-Barrier Structures

771. In my sampling of the RP's internal hazard assessments, including the internal missile assessment (Ref. 194), I determined that the RP had not considered internal hazard impacts on non-barrier structural elements. In my judgement these impacts could result in consequential hazards not bounded by the examples presented by the RP. I consequently raised RO-UKHPR1000-054, (Ref. 98) seeking further justification of the internal hazard loads applied for non-barrier structures for civil engineering analysis and focusing on rooms within BFX.

772. In response (Ref. 58), the RP presented a systematic, comprehensive approach that clearly characterised the loads to be used within the civil engineering for the selected rooms. In my judgement the application of the process for identification, data collection, and analysis of internal missile hazards as well as the derivation of bounding design basis loadings is appropriate and meets the expectations of ONR SAPs EHA.1, EHA.2 and EHA.6.

773. The RP's response to RO-UKHPR1000-054 (Ref. 58) also confirmed that, for the selected rooms considered in the RO sample, all barriers could withstand the load from internal missiles. Through my assessment of the RO-UKHPR1000-054 evidence I am satisfied that the RP has demonstrated that the internal missiles safety case can be fully developed at the site-specific project stage to include the considerations of all impacts to non-barrier structures.

4.7.5 BSX: Assessment of Safeguard Building Internal Missiles Safety Case

774. The claims and arguments for the internal missile assessment of the Safeguard Buildings BSX presented by the RP (Ref. 195) are very similar to those presented for the assessment of the Reactor Building BRX (Ref. 193).

775. The RP presented sub-claims to mitigate the consequences from internal missiles in the BSX buildings (Ref. 195). The Safeguard Buildings include three completely independent sub-buildings (namely Safeguard Building A (BSA), Safeguard Building B (BSB), Safeguard Building C (BSC)) corresponding to the three divisions of safety systems respectively. BSC is located between BSA and BSB and the walls between the sub-buildings are divisional barriers.

776. The RP performed data collection and the identification of internal missiles for all components in all Safeguard Buildings covered by the evaluation scope described in the methodology report (Ref. 192). The following aspects were identified by the RP as being pertinent to the assessment:

- The valve with the maximum impact energy for a barrier of lesser thickness was selected as the bounding case.

- It was assumed that the ceilings would potentially experience the most challenging load, as valves with significant mass will be installed vertically. As a result, missiles will preferentially eject in the vertical direction.
- The missile source from rotating equipment in Safeguard Building BSC with the maximum impact energy and its thinnest barrier was selected as a bounding case.
- In the Safeguard Buildings BSA and BSB the equipment will be symmetrically arranged and therefore only BSB was assessed.
- Safeguard Building BSC bounding cases were only considered where the rotating equipment had potentially larger kinetic missile energy then in safeguard buildings A and B.

4.7.5.1 BSX: Bounding Cases for Barrier Assessment (Criterion A)

777. The RP identified the following bounding cases for criterion A by applying the bounding case selection methodology (Ref. 195):

- Two cases for valves (IH-IM-BSX-01 and IH-IM-BSX-02).
- Two cases for rotating equipment (IH-IM-BSX-06 and IH-IM-BSX-07).

778. The two bounding cases for valves were located in the Safeguard Fuel Buildings BSA and BSB (symmetry of the equipment in the buildings).

779. The selected bounding cases for valves required substantiation of the roof of the buildings (barrier) against the missile load. Both cases bound potential valve missile scenarios in the BSC building.

780. The safety assessment for the selected cases provided information concerning the missile characterisation and the barriers to be substantiated. The RP provided the barrier substantiation in the report ‘Reinforced Concrete Barrier Substantiation Report for BSX’ (Ref. 101) which confirms that the barriers can withstand the load from the missile and no further consequence analysis is performed. I reviewed the information provided and in my judgement this analysis is in line with SAPs EHA.1 and EQU.1 and is sufficient for GDA purposes.

4.7.5.2 BSX: Exception to Segregation (Criterion B)

781. The RP identified the following cases for the different missile sources for criterion B (Ref. 195):

- None for valves.
- Two cases for rotating equipment (IH-IM-BSX-08 and IH-IM-BSX-09).

782. As a precaution, the SSCs of the three safety trains were arranged in the three different BSX buildings. One exception was the VVP [MSS] / ARE [MFFCS] area (train B and C in BSB), and the other exception was the Main Control Room Air Conditioning System (DCL) with its three trains in the BSC building.

783. Based on my assessment of the internal missiles analysis for the safeguard Buildings (Ref. 195), I considered that there may be additional instrumentation and control (I&C) equipment as well as electrical equipment located in exception to segregation areas, which is not currently listed, as information on these systems is limited given the level of design development at GDA. This will require further review during detailed design and may be followed up as part of normal regulatory business.

784. As discussed in paragraph 4.7.3.2 the RP provided justification for excluding valves as missile sources. I judge the arguments provided are adequate for GDA purposes, however these may require review during detailed design when the layout of the

building is fully developed. This may be followed up as part of normal regulatory business.

785. The 3D model described in its analysis report (Ref. 196) is intensively used in the analysis. The screenshots presented within the RP's analysis (Ref. 195) provided limited information, hence, to ensure the underpinning of all internal missiles safety analysis, further data and 3D drawings should be provided to aid the analysis at the site-specific project stage. This may be followed up as part of normal regulatory business.

786. IH-IM-BSX-08 addressed the potential for a cooling fan unit in Room BSB3324ZRM of BSB, to impact the main steam pipelines in train C. This scenario may lead to the loss of two trains of the main steam lines and hence required the target (VVP3130TY) to be substantiated against the missile impact. The RP's assessment identified this gap and proposed that optioneering solutions be captured in the 'ALARP Demonstration Report for Internal Hazards' (Ref. 33). However, when I assessed (Ref. 33) this optioneering information was not included, hence a gap in the safety case remains. I raised RO-UKHPR1000-046 (Ref. 88) specifically to address shortfalls in the RP's safety case for the impact of internal hazards on HIC. In sub-section 4.11 of this report, I discuss the RP's submissions for sample areas to resolve RO-UKHPR1000-046. The RP submissions do address the potential impacts to the main steam line, although not specifically for this scenario, and this shortfall is captured as part of Assessment Finding AF-UKHPR1000-0077. I have however gained confidence from the RP's substantiation of the MSL (Ref. 89) and the proposal to reorient valves such that the missile trajectory can be directed away from the MSL (Ref. 155). Hence, I have confidence that the licensee can resolve these issues.

787. For the second bounding case (IH-IM-BSX-09) the missile source and the target SSCs (pressure sensors for redundant safety trains) were located in different rooms separated by a barrier (ceiling). The RP substantiated the barrier to withstand the load from the missile, thus preventing the missile from impacting the SSCs. The RP's analysis indicated that for this case the impact energy was too low to cause barrier failure, and the barrier substantiation was sufficiently documented in the 'Reinforced Concrete Barrier Substantiation Report for BSX' (Ref. 101). I reviewed the information provided, and in my judgement this analysis is in line with SAPs EHA.1 and EQU.1 and is sufficient for GDA purposes.

4.7.5.3 BSX: HIC (Criterion C)

788. The RP identified the following bounding cases for the different missile sources with respect to criterion C (Ref. 195). These bounding cases were included as part of assessment of impact to the main steam lines in response to RO-UKHPR1000-046 (Ref. 89).

- Three cases for valves (IH-IM-BSX-03 to IH-IM-BSX-05).
- Four cases for rotating equipment (IH-IM-BSX-10 to IH-IM-BSX-13).

789. The RP's selection of missiles from valves also included valve missiles impacting HIC with a 10-degree deviation from the vertical ejection, based on the information from the 3D model. The RP also addressed the potential for missiles to impact HIC in adjacent rooms based on the information from the 3D model. Hence the RP's assessment considered the impact of missiles on all identified HIC in the safeguards buildings, i.e. main steam lines and main steam line isolation valves.

790. I reviewed the RP's substantiation of HIC against missile loads, provided in response to RO-UKHPR1000-046 MSL assessment (Ref. 89) and associated ALARP review (Ref. 155). Through my assessment I have been satisfied that the RP has demonstrated that the integrity of the HIC when subject to internal missiles hazards,

including the RO-UKHPR1000-046 sampled areas. My detailed findings from RO-UKHPR1000-046 and the substantiation of HIC is provided in sub-section 4.11 of this report.

791. Overall, in my judgement the RP has provided sufficient evidence of an adequate hazard identification and screening process for the internal missile hazards in the Safeguard Buildings BSX.

792. The internal missile safety assessment report, in combination with additional information which has been provided as a response to RQs and ROs, provide an adequate assessment of the internal missile hazard safety case for the Safeguard Buildings BSX.

793. On the basis that the Assessment Findings identified above can be resolved at detailed design, I judge that the assessment provided by the RP of internal missiles within the safeguards building is adequate for the purposes of GDA.

4.7.6 Summary of Assessment and Affirmation of PCSR Claims

794. My assessment of the internal missiles assessment reports identified a number of areas where further clarification was required, hence corresponding RQs and ROs were raised. In the majority of cases I was satisfied the additional information provided by the RP in response was adequate for the purposes of GDA. Where safety case gaps remain, I have captured these as Assessment Findings.

795. The main shortfalls identified during the assessment generally related to the lack of evidence to support the RP’s bounding cases and conclusions drawn. However, when I challenged this through RQs and RO-UKHPR1000-046, the RP provided adequate evidence for specific samples giving me sufficient confidence in the conclusions presented.

4.7.6.1 Affirmation of PCSR Claims for the Internal Missiles Safety Case

796. This section provides a summary of my assessment of the principal claims associated with the internal missiles safety case.

- Sub-claim 3.2.2.SC19.2.16 (Internal Missiles): The Internal Missiles sources are sufficiently identified.

797. Based on the evidence provided and assessed, I conclude that the RP has demonstrated that the principal internal missiles scenarios have been identified. Evidence provided through RQs and RO-UKHPR1000-046 has given further confidence. This satisfies SAPs EHA.1, EHA.19 and EHA.14.

- Sub-claim 3.2.2.SC19.2.17 (Internal Missiles: After the safety assessment, the safety measures to mitigate the consequences of internal missiles are sufficiently identified and properly classified.

798. Through my assessment I have been satisfied that the RP’s methodology and analysis for dropped loads is adequate. Through its analysis the RP has identified appropriate safety measures in particular civil barriers, which in my view have been adequately classified, satisfying SAPs EKP.5, EHA.4, EHA.6 and FA.8. This in my view provides sufficient confidence that the most significant missile risks are retained within one safety train.

- Sub-claim 3.2.2.SC19.2.18: The safety measures to mitigate the consequences of internal missiles are sufficiently substantiated.

799. I have been satisfied that for the purposes of GDA the RP has provided sufficient evidence, for the purposes of GDA, that the identified safety measures have been substantiated. This is presented in the relevant barrier substantiation reports and the various responses to RO-UKHPR1000-046.

4.7.7 Internal Missiles Safety Case Strengths

800. Through my assessment recorded above, I have noted the following strengths in the RP's internal missile safety case.

- The RP has applied its methodology adequately for the assessment of missile hazards.
- The RP has adequately demonstrated HIC integrity where required.
- The RP has adequately identified and substantiated barriers to ensure missile effects are limited to one train.

4.7.8 Outcomes

801. Through my assessment of the RP's internal missiles safety case, I have been satisfied that the RP has provided adequate evidence to underpin its missile hazard analysis for the purposes of GDA. The RP has demonstrated that hazard identification has been applied in line with its assessment criteria (A, B and C).

802. Following my assessment, I have identified several areas of improvement through a mix of Assessment Findings and minor shortfalls. My Assessment Findings are associated with demonstrating the risks to HIC are reduced ALARP (as per RO-UKHPR1000-046 findings), justification of screening out specific valve designs for analysis and consideration of consequential internal hazards.

4.7.9 Conclusions

803. My assessment of the generic UK HPR1000 internal missiles safety case has been informed by several submissions, RQs and ROs. The breadth and depth of my assessment has been focused on the key risk areas and the quality of evidence provided.

804. Although several Assessment Findings have been identified, I am content that the principal risks from internal missiles scenarios have been identified and understood for the purposes of GDA.

805. Therefore, based on the outcomes of my assessment of the RP's internal missiles safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and have raised Assessment Findings accordingly. I do not judge that these gaps are significant enough to prevent issue of a DAC, as I am content that they can be addressed by the licensee at detailed design.

4.8 Hazard Assessment – High Energy Pipe Failure

4.8.1 Principal Claims from the Generic UK HPR1000 HEPF Safety Case

806. The generic UK HPR1000 HEPF safety case for the sample buildings (BRX, BFX and BSA/BSB/BSC) is comprised of the following documents:

- HEPF methodology report (Ref. 200).
- CAMPHOR validation and verification report (Ref. 201).
- Pressure and temperature analysis after HEP breaks in Reactor building (Ref. 202).

- Pressure and temperature analysis after HEP breaks in Fuel building (Ref. 203).
- Pressure and temperature analysis after HEP breaks in safeguard buildings (Ref. 204).
- Reactor building HEPF safety assessment report (Ref. 205).
- Fuel building HEPF safety assessment report (Ref. 136).
- Safeguard buildings HEPF safety assessment report (Ref. 140).
- Case analysis of typical high energy mechanical penetrations (Ref. 206).

807. The principal claims for the HEPF safety case for the generic UK HPR1000 design are defined within the pre-construction safety case report (PCSR) Chapter 19 Internal hazards (Ref. 3). These principal claims are stated as:

- Sub-claim 3.2.2.SC19.2.10 (HEPF): The high energy pipe failures sources are sufficiently identified.
    - Argument 3.2.2.SC19.2.10-A1 (HEPF): The high energy pipe failures sources are sufficiently identified.
- Sub-claim 3.2.2.SC19.2.11 (HEPF): After the safety assessment, the safety measures to mitigate the consequences of high energy pipe failures are sufficiently identified and properly classified.
    - Argument 3.2.2.SC19.2.11-A1 (HEPF): In segregation areas, the consequences of any high energy pipe failures are limited to one train of the systems delivering the safety functions through use of barriers.
    - Argument 3.2.2.SC19.2.11-A2 (HEPF): Where there are exceptions to segregation, consequences of high energy pipe failures are mitigated through additional safety measures (for example, shields, restraints, geometrical separation) to ensure the delivery of the safety functions.
    - Argument 3.2.2.SC19.2.11-A3 (HEPF)：High energy pipe failure does not cause unacceptable damage to HIC.
    - Argument 3.2.2.SC19.2.11-A4 (HEPF): Additional safety measures (for example, relief devices) are used to control sub-compartment pressure, where the unmitigated effects challenge the integrity of barriers. The relief devices are used in Safeguard Buildings and Fuel Building. For Reactor Building, the containment is designed to withstand the pressure of steam release.
    - e) Argument 3.2.2.SC19.2.11-A5 (HEPF): The safety measures to mitigate the consequences of high energy pipe failures are classified in accordance with the methodology of safety categorisation and classification.
    - f) Argument 3.2.2.SC19.2.11-A6 (HEPF): Where required, SSCs important to safety are capable to operate following a high energy pipe failure in the resulted environmental conditions.
- Sub-claim 3.2.2.SC19.2.12 (HEPF): The safety measures to mitigate the consequences of high energy pipe failures are sufficiently substantiated.
    - Argument 3.2.2.SC19.2.12-A1 (HEPF): The safety measures have the capability of withstanding the load imposed by high energy pipe failures.

4.8.2 HEPF Methodology Assessment

808. This section details the findings from my assessment of the RP's methodology for the analysis of HEPF hazards (Ref. 200). The RP's methodology provides the basis for its identification, screening, and assessment of HEPF hazards within the generic UK

HPR1000 safety case. My assessment has been undertaken in line with ONR expectations set out in ONRs Safety Assessment Principles (Ref. 2) and TAG 14 (Ref. 7) which are benchmarked and consistent with relevant international standards for safety in the design of nuclear power plant including those from IAEA (Ref. 15) and WENRA (Ref. 60).

809. The RP's HEPF methodology defines (Ref. 200) HEPs as those pipes that have a maximum operating pressure greater than 1.9MPa gauge pressure or maximum operating temperature greater than 95ºC. The methodology also sets out the requirement to assess all potential HEPF consequences, namely pipe whip, jet impingement, blast, steam release, flooding, and changes in ambient conditions (for example, temperature, water spray).

810. The HEPF methodology report (Ref. 200) provided analysis methods specifically for pipe whip and jet impingement as well as defining the approach for combination of these hazards following a HEPF. The other analysis methods for those relevant hazards are covered in the following methodology reports:

- Blast is covered in the internal explosion methodology Report (Ref. 114).
- Steam release is covered in the guideline for thermal response analysis of sub-compartments (Ref. 207).
- Flooding effects are covered in the internal flooding analysis methodology Report (Ref. 144).
- Changes in ambient conditions from pipe failures (within a compartment) are also captured in the qualification process for equipment which defines the approach for SSC substantiation (Ref. 208).

811. My assessment of the various hazard methodologies is detailed in the relevant sections of this assessment report. Based on the above I am content that the scope and definition of HEPF effects are consistent with relevant good practice such as R3 (Ref. 44) and IAEA SSG 64 (Ref. 15). I am content that the RP has methodologies for all key hazards, thereby meeting SAPs EHA.1 and 19. I note that the detailed qualification of SSCs against some of the hazard challenges from HEPF, such as high temperature and pressure, are out of scope for GDA. This is because the selection of SSCs is subject to licensee choices at the detailed design stage, and therefore I have not assessed this aspect further. Notwithstanding this, I have assessed the RP's claims made on the withstand of key SSCs within the safety case, which include barriers and HIC from HEPF effects.

812. According to the HEPF methodology (Ref. 200), the RP applied two key screening criteria for the identification of HEP hazard sources:

- Small piping with diameter smaller or equal to a pipe diameter of 25mm (DN25) had been screened out by the RP as potential sources of damage.
- The development of a blast wave was only screened for analysis for coolant temperatures of 300°C or higher.

813. In my view the RP's approach is adequate for the purposes of GDA. It allows it to focus on the most challenging hazards that could impact a barrier, SSC or HIC. The screening out of pipes smaller than 25mm in diameter (DN25) is unlikely to result in a significant hazard being missed at this stage. As the final pipe layout is a matter for detailed design and the licensee, it is my expectation that failure of any pipes, including medium and small diameter pipes, can be considered at detailed design.

814. For the criterion relating to the blast screening, I have already highlighted my reservations about this approach in the explosion section of this report detailed above. I have raised an Assessment Finding AF-UKHPR1000-0061 for this to be addressed, which is also relevant to the HEPF assessments.

815. I have assessed the RP’s guidelines for the analysis of the thermal response of a compartment following a HEPF (Ref. 207). I judge that the document is adequate for providing guidance to suitably qualified and experienced personnel undertaking analysis of mass and energy release rates; this includes how the boundary conditions are assumed to provide a conservative calculation of the differential pressure in the sub-compartments. My detailed assessment of the adequacy of the code used for this analysis is presented in sub-section 4.8.3 below.

816. The RP’s methodology (Ref. 200) provides the key design principles that its HEPF analysis should demonstrate to support the principal claims stated in sub-section 4.8.1. These are:

- HEPF should not result in the failure of any fundamental safety function of nuclear power plants.
- HEPF should not cause a Design Basis Condition (DBC) 3 or 4 or Design Extension Condition (DEC).
- HEPF must not cause damage to High Integrity Components (HIC).
- The habitability of the Main Control Room (MCR) should be ensured in the event of a high energy pipe failure so far as reasonably practicable. The availability and the accessibility of the remote shutdown station should be ensured in those cases where the MCR may not be available.
- There are no cliff-edge effects due to HEPF.
- The risk from HEPF is reduced to be ALARP.

817. I am satisfied that these principles provide a good basis to develop a HEPF analysis. I judge that the principles are consistent with relevant good practice as defined in technical assessment guide TAG-14 (Ref. 7) and the SAPs (Ref. 2),in particular SAP ELO.4, which sets out the expectation that the design and layout of the site, its facilities (including enclosed plant), support facilities and services should be such that the effects of faults and accidents are minimised.

818. The RP’s HEPF methodology (Ref. 200) defined the following assumptions in the assessment of HEPF:

- HEPF are postulated to occur during normal operation.
- Two or more simultaneous independent HEPF are not considered.
- HEPF can occur in any high energy pipe, except for HIC.
- HEPF is assumed to be a gross failure of the pipe, leading to a double ended guillotine break.
- For impacted pipes of smaller nominal pipe size, irrespective of pipe wall thickness, gross failure is considered.
- For impacted pipes of larger or equal nominal pipe size gross failure is not considered, but with equal or thinner wall thickness, leakage is considered for global effects.

819. I have assessed these assumptions and I note the following findings on the key aspects:

- It is my view that the stated assumption that the HEPF can only occur during normal operation is not fully aligned with ONR guidance. It is ONRs expectation that the safety case demonstrates sufficient control of radiological hazards at all times, thus any period where risk is elevated, (such as energising a pipe for testing or for accident response) must be subject to a specific demonstration that risks are reduced to ALARP, as per SAP NT.2. This generally applies for DEC systems. Although the RP had stated that DEC systems are out of scope for GDA, I have been satisfied that analysis of such systems that could impact key SSCs have been identified and analysed for the purposes of GDA, including the VDA [ASDS] system. My assessment of this system is detailed in the explosion sub-section (4.4.5.1 and 4.4.5.3) of this report, as explosion is the principal hazard following its failure.

- For all the pipe systems identified as a HEP, the RP approach was to take the maximum pressure and temperature of the pipe as the initial conditions for analysis purposes. This is in-line with SAP EHA.5 that states the most adverse permitted operating states should be assumed.
- I am content that the RP's approach (bounding case for barriers and case-by-case consideration of exception to segregation areas and HIC) is appropriate and that the relevant loads have been subject to combined and consequential hazard analysis.
- I am satisfied that HEPF can be considered as an infrequent fault, if the pipe has an adequate classification attached. Therefore, the independent simultaneous failure of two adequately classified pipes will have a low probability, and if outside the design basis criteria may be screened out; this approach satisfies SAP EHA.19 and FA.6.
- A significant assumption in the RP HEP analysis methodology is that gross failure will not occur in HIC. The reliability of HIC is specifically assessed by the ONR structural integrity team (Ref. 209). Where a HIC is adequately substantiated (in line with SAPs EMC.1 to 3), I am content that gross failure can be discounted from the design basis. ONR SAP EMC.3 does set out the expectation that the safety case should provide evidence to demonstrate that the necessary level of integrity has been achieved for the most demanding situations identified. This includes a detailed design loading specification covering normal operation, faults, and accident conditions including plant transients and internal and external hazards. This aspect has specifically been addressed through the RO-UKHPR1000-046 (Ref. 88) demonstration that the risks to HIC from internal hazards are reduced ALARP. My assessment of the response to RO-UKHPR1000-046 is presented in the RO-UKHPR1000-046 section of this report (Sub-section 4.11).
- It is my view that the application of a double ended guillotine break assumption is conservative and in line with relevant good practice ONR TAG-14 (Ref. 7) and IAEA-SSG64 (Ref. 15).
- The assumptions regarding possible consequential effects such as pipe on pipe impact are based on experiments as detailed in US NRC NUREG 0800 (Ref. 210) . It is my opinion that care needs to be taken applying such assumptions. This is because the simplicity of the application does not consider additional factors, such as consideration of the additional mass or an elbow on the whipping branch, in which case gross failure of the impacted pipe of larger or equal nominal pipe size should be considered as stated in IAEA SSG-64 (Ref. 13), and should be addressed on a case by case basis if specific withstand claims are to be made. I note that whilst the RP listed these assumptions, it seldom applied them. I nevertheless sampled the scenario of the main feedwater and main steam line pipes striking each other and this is reported below.

820. The RP has considered the consequential failure of pipework within one division as a combined hazard and therefore has not included this as part of the HEPF assessment reports. My judgement on the RP's combined hazards case, including consequential pipework failures, is detailed in sub-section 4.9 of this report. For 'exception to segregation' areas the RP considered that all piping of the same size within the influence zone of one HEPF would suffer consequential failure, which I judge to be conservative. Finally, the RP assessed pipe whip or jet impacts onto HIC through calculation for any individual impact case regardless of the relative size of the impacting pipe or HIC. In these cases, the RP regarded the whipping pipe as a hard missile and considered the maximum impact energy by choosing the maximum length of the pipe whip arc. Although the identification of the maximum length and arc to define the pipe whip energy is a conservative approach, I note that the conservatisms

may not allow for the effect of additional masses or elbows on the whipping branch; this may result in a higher load due to increased stiffness, which is especially relevant if impacting another SSC.

821. The placement of valves and elbows is subject to detailed design choices; however their placement should allow for the associated hazards to other SSCs. Given that pipe-to-pipe interaction has been assessed including pipe whip, I am content that there is not a significant risk gap here. Further choices by the detailed designer will influence further analysis work and therefore I regarded this as a minor shortfall of the HEPF methodology report.

822. The next stages of the RP's HEPF methodology described the principal steps of its analysis; that is the identification of high energy pipes (HEP), their location and influence zones from pipe whip and jet impact, and the identification of targets. The RP then followed a simple preliminary analysis or, if it deemed it necessary, a more rigorous analysis of impacts and withstand of a barrier or other SSCs. The key elements in the safety analysis are highlighted here:

- For segregated areas, the RP's methodology set the requirement to demonstrate that the effects of HEPF would be contained within one division by calculating the impact onto the divisional barriers and substantiating their withstand against the combined hazard loading from the bounding HEPF.
- For the 'exception to segregation' areas, the RP's methodology required that a preliminary safety analysis is undertaken assuming that all SSCs (and their safety function) within an influence zone are lost. This includes undertaking a functional analysis to establish whether sufficient SSCs will remain available following HEPF to satisfy the safety objectives and maintain nuclear safety.
- If, following its HEPF analysis, the RP deemed it necessary that an SSC withstand needed to be claimed, the methodology stated that the HEPF effects such as pipe whip and jet impact loads were to be calculated and compared to the withstand of target SSCs to substantiate their survival. If the safety objectives could not be satisfied, the methodology stated that the plant layout was either to be modified to separate HEP and target SSCs, or protective measures were to be installed like pipe whip restraints, shielding, or guard pipes following an ALARP review. For HEPF effects other than pipe whip and jet the withstand of SSCs may be improved by equipment qualification. However, this will be influenced by licensee choices in equipment selection.
- The RP's methodology expected that the most adverse break location would be selected independently of weld locations or changes in geometry and the most adverse location would be selected for any resulting plastic hinge.
- The RP's methodology expected moderate energy pipes, whose pressure and/or temperature is marginally below the 2.0MPa threshold (1.9MPa), to be considered on a case-by-case basis if a moderate energy pipe was identified as a potential hazard with respect to RP's 3 criteria approach.

823. It is my judgement that the RP's approach to HEPF analysis as described above is consistent with the claims, arguments and evidence presented in PCSR chapter 19 (Ref. 3). I am satisfied that the analysis methods are consistent with the guidance defined in relevant good practice such as R3 (Ref. 44) using several conservative assumptions; for example, the application of instantaneous and steady thrust forces based on maximum pressure and temperature in the pipe, neglecting friction and energy consumption by plastic deformation of the impacting pipe.

824. The RP's design requirements for the divisional barriers are specified within specific civil engineering design documents (Ref. 39) that set out the barrier structural requirements in terms of strength for global effects and serviceability for local effects like cracking or scabbing. The RP's analysis assesses the barriers performance against the civil criteria (such as scabbing) to determine the withstand of the claimed

barriers against the HEPF loads. The analysis and substantiation of the barriers is demonstrated by the use of relevant methods from dedicated codes used for concrete structures in nuclear power plants for global mechanical and thermal effects (ACI 349-M (Ref. 40)), and Euro codes (Ref. 41) as well as empirical models for local impacts according to R3 (Ref. 44). Details of these approaches are described by the RP in the structural analysis method statement (Ref. 39). The withstand of equipment other than barriers against HEPF effects like steam, spray, and flooding are determined by equipment specification. I judge that to be an acceptable approach using standards that are relevant for nuclear installations. The withstand of piping against pipe whip and jet impact is determined by R3 methods which I also consider adequate (Ref. 44). In conclusion, I consider that the RP's methodology adequately conformed with relevant good practice for the determination of the withstand of barriers and SSCs against HEPF effects.

825. The RP's analysis approach for cliff-edge effects is also described in its methodology and is largely based on the application of the various assumptions as defined in the analysis approach. I have already stated that I am satisfied with these assumptions. However, it is my view that although application of the RP's analysis assumptions will provide a conservative analysis, it does not fully demonstrate that an adequate cliff edge analysis is undertaken.

826. As per my findings in the flooding section, the requirements to demonstrate hazard resilience, and an understanding of the safety cases' reliance on the underpinning data and sensitivity in variation of assumptions, is not clearly defined within the methodology. I therefore judge that the current approach to cliff edge effects does not satisfy SAP EHA.7. It is my view that the licensee will need to consider how the variation in its assumptions may impact its safety case and ensure that appropriate and sufficient sensitivity analysis is undertaken. This is captured in Assessment Finding AF-UKHPR1000-0065.

827. In summary, I judge that the RP's HEPF methodology provides an adequate basis for application of its HEPF analysis. I have identified one minor shortfall and an Assessment Finding; however, I judge these not to be significant enough to undermine the overall adequacy of the assessment methodology. Therefore, I judge that for the purposes of GDA the RP's methodology is adequate for the analysis of HEPF in line with SAPs EHA.1, EHA.3, EHA.6, EHA.14 and FA.7.

4.8.3 Assessment of the CAMPHOR Code

828. CAMPHOR is an in-house sub-compartment analysis code used by the RP to simulate the pressure and temperature responses inside PWR compartments following a high energy line break. The RP also applied this code to analysis of accidents which involve high energy pipe failure, such as Loss of Coolant Accident (LOCA), Steam Line Break (SLB) accident, etc. An overview of the different physical models and correlations incorporated in CAMPHOR was provided in the code validation and verification report (Ref. 201).

829. The CAMPHOR code is described by the RP as a multi-node code which can simulate multi compartments by modelling one compartment or several compartments as a single node. Adjacent nodes may be connected by vents. It requires the input of a Mass and Energy Release (MER), computed by a different code named, LOCUST, and provides a conservative evaluation of the peak pressure in each sub-compartment that can be used to assess the mechanical stresses applied to the walls. CAMPHOR output can also be used to derive ambient conditions following a high energy pipe failure. The results serve as a basis for equipment qualification in the affected compartments.

830. The RP's code validation report (Ref. 201) states that the code uses a quasi-steady-state approximation to represent accident transients using well-known models and

hypotheses. Air, steam, and water in each physical compartment are represented as a single control volume, and these compartments are linked by flow paths which may have resistance; the compartments are assumed to be in thermal equilibrium during accident transients. The mass and energy change in each control volume at current time are calculated based on a previous time step under the assumption of vent flows under constant state. The thermodynamic state of each compartment is determined on the thermal equilibrium assumption. The state of vent flows between adjacent compartments for the next time step is updated according to the current thermodynamic state of each compartment. The flow is seen and solved in the network of compartments as one dimension.

831. As part of my assessment, I elected to sample the CAMPHOR code validation evidence to obtain confidence in the RP's application of it to the generic UK HPR1000 design. I sampled the following areas:

- Adequacy of models.
- Adequacy of the validation and verification.
- Adequacy of the application of the code for HEPF assessment.

832. My assessment has been based on the following guidance:

- ONR technical assessment guide on the validation of computer codes and calculation methods (Ref. 8).
- ONR SAPs (Ref. 2).
- IAEA Specific safety guide on deterministic safety analysis for nuclear power plants (Ref. 211).
- USNRC transient and accident analysis methods (Ref. 212).

833. As part of my assessment I raised several queries relating to the various models applied through RQ-UKHPR1000-0826 (Ref. 213), RQ-UKHPR1000-1436 (Ref. 214) and RQ-UKHPR1000-1471 (Ref. 215). From assessment of the RP's responses to the above queries I concluded the following:

- The models adopted in CAMPHOR have been based on models that are routinely used in sub-compartment analysis. This includes the models for key phenomena including mass energy conservation, heat conduction and transfer. These models are required to simulate the conditions expected from a HEPF break.
- The application of a model (Moody) developed for steam-water mixtures to steam-air conditions provided conservative results when compared to other standards such as the USNRC standard review plan (Ref. 216).
- The scope of the model is adequate for the purposes of assessing the conditions following a HEPF steam release. Following queries raised in RQ-UKHPR1000-0423 (Ref. 217), the RP confirmed (Ref. 217) that the code is limited to the analysis of steam effects.
- The Mass Energy Release (MER) input required for a CAMPHOR analysis is computed by the separate code LOCUST. I am satisfied that the RP has adequately defined the required inputs from LOCUST, however it was unclear how this transfer of data was provided from the CAMPHOR documentation (Ref. 201). I raised RQ-UKHPR1000-1436 (Ref. 214), to get further information on the RP's processes to manage the data transfer between LOCUST and CAMPHOR. The RP response to RQ-UKHPR1000-1436 (Ref. 214) clarified the quality assurance process for the data transfer, stating that the data inputs are subjected to two independent checks, which, for the purposes of GDA, I judge to be adequate.
- The RP has demonstrated the applicability of the code (the range to which the code can be applied), but the complete demonstration with respect to the actual temperatures and pressures analysed has not been adequality presented.

However, I judge this to be an issue with the RP's reporting rather than the models used and I am content that this can be addressed as part of normal business.

834. Overall, I am satisfied that the scope and models adopted by the RP are adequate and I am satisfied the RP has provided sufficient evidence to demonstrate that the models are fit for purpose (Ref. 24); thus I have confidence that the analysis outputs from the code are adequate for the purposes of this GDA assessment. Through my assessment I have identified some areas where the safety case would benefit from additional evidence to underpin the code more robustly, and therefore the current body of evidence does not wholly satisfy the intent of SAPs AV.4 and AV.5 related to the documented evidence to underpin a code. I judge these as minor shortfalls. These include:

- The applicability range of CAMPHOR is not fully covered by the verification and validation (V&V) evidence. The correlations and models used in CAMPHOR are well known, and the literature is already extensive on these, however this is not adequately presented in the V&V report (Ref. 201).
- Some of the models used are not fully documented.
- The wall condensation model assumes that the steam in the compartment is in saturated conditions. In cases in which the steam is superheated, a fraction of the liquid water present on the wall will re-evaporate. Relevant good practice (Ref. 218) advises to correct the mass of condensate by a factor 0.92. This cannot be done in the current CAMPHOR model.
- The V&V report (Ref. 201) describes explosion venting membranes/bursting discs as 'Key phenomena'. However, no further description of the associated model, nor any V&V evidence is given elsewhere in the document.

835. CAMPHOR is a bespoke tool that the RP had developed for the analysis of steam release. In the areas that I sampled, I was satisfied that the CAMPHOR code either used recognised models or, where modifications were applied, they did not result in non-conservative results. Furthermore, I note that the licensee may choose to utilise a different analysis tool which would be subject to regulatory scrutiny at its time of use.

4.8.4 BRX: Assessment of Reactor Building HEPF Safety Case

836. The RP's BRX HEPF safety analysis report (Ref. 205) provides a brief overview of systems important to safety as well as a description of their basic layout across the BRX. The HEPF analysis report also included the Secondary Passive Heat Removal System (ASP [SPHRS]). ASP is designed to provide decay heat removal during DEC-A accidents when the Emergency Feedwater System ASG [EFWS] fails. I consider the inclusion of the ASP system within the screening for HEPF to be positive, as the RP had previously stated that DEC-A systems were generally out of scope for GDA.

837. The general layout of the reactor building consists of three primary loops that are separated from each other by substantial walls with a thickness of 1000mm. These walls are partial walls, protecting the components from direct HEPF impact of the other loops, yet allowing the flow of steam and flooding water within the inner containment. That means that the BRX is not fully segregated by divisional barriers, but primarily relies on spatial separation for global effects, with some physical segregation for pipe whip impacts and other more local effects provided by barriers within the secondary shielding walls.

838. The BRX HEPF report (Ref. 205), also sets out the principles implemented in the BRX design (which are also relevant to the other buildings sampled) governing the prevention of HEPF. These principles are:

- Pipes are designed in accordance with appropriate design codes such as RCC-M (Ref. 80).
- Minimising the number of welds.
- Inspections helping early detection of leaks.

839. It is my opinion that these measures are in accordance with relevant good practice such as IAEA SSG-64 (Ref. 15). However, it is my view that the provision of leak detection should also be implemented so far as is reasonably practicable to reduce reliance on inspections. This will provide additional defence in depth and complement the goal of early detection of leaks. I judge this to be a gap against SAP EKP.3 (defence in depth) in the definition of prevention measures. As leak monitoring is an important measure to prevent the escalation to pipe breaks, and it is for the licensee at detail design to determine the most appropriate systems to achieve this and take due account of the hierarchy of measures (SAP Para 155), I consider this a minor shortfall.

840. The primary protection measures claimed in the HEPF report are the substantial reinforced concrete barriers and secondary shielding walls. Other measures, such as pipe whip restraints, and pressure release devices, are claimed as and when required. In line with SAP ELO.4, optimisation of layout, I am content that these measures are appropriate and consistent with the plant layout as presented through the placement of the various barriers.

841. As well as the three primary cooling loops, the redundant trains of safety systems are typically arranged in different sectors of the Reactor Building. Redundant trains are usually physically segregated by divisional barriers. However, the HEPF analysis report (Ref. 205) stated, that there are some exceptions to segregation areas where direct hazard effects across trains are possible.

842. The BRX is fundamentally split into the BRA (main reactor hall) and BRB (annulus). Within the BRB area there are multiple penetrations where safety systems transit through the external wall into the corresponding safety train supporting buildings, principally BSA/BSB/BSC and BFX.

843. The BRB is a compact region where failure of a HEP could impact other SSCs whose role is to support the various SSCs within the main reactor hall (BRA). Within the BRB the pipes are contained inside mechanical penetrations for passing through the area and into the connecting buildings. These mechanical penetrations mitigate failure of the HEP. To determine the adequacy of the generic penetrations design requirements I raised RQ-UKHPR1000-1541 (Ref. 219) to obtain clarity on the generic penetration design assumptions.

844. My assessment of the RP's response to RQ-UKHPR1000-1541 (Ref. 219) included assessment of its revised generic design report for typical mechanical penetrations (Ref. 206). In this report (Ref. 206), the RP described the design requirements and assumptions for mechanical penetrations of medium and high-energy piping through the containment. The RP stated that the penetrations design would be based on the design and construction code RCC-M (Ref. 80). To provide further confidence in its approach, the RP presented detailed examples for particular penetrations including the main steam line (MSLs) and the main feedwater (ARE) lines. Because the RP stated that the MSLs penetration are classified as HIC, the RP provided detailed analyses of the failure of the ARE pipe and the impact on the penetration within which it sits. The RP has classified the ARE mechanical penetration as mechanical class 2 according to RCC-M.

845. The RP's penetration withstand analysis (Ref. 206), following the ARE failure was conducted using finite element analysis. Three break locations were considered by the RP; the weld of the ARE pipe with the penetration inside the annulus; outside of the penetration on the BRX side, and; on the BSX side. The analysis included the jet and

whip effects on the ruptured pipe end and the pipe loads from the other side. In all three cases the results show that the maximum stresses on the penetrations remain lower than 83 % of the allowable loads according to RCC-M, service level D - the level for faulted conditions.

846. From my assessment I was satisfied that the evidence provided by the RP was adequate and its analysis satisfied my expectations in line with SAPs EHA.6 and AV.2. The classification of the penetrations is adequate, given that the main feedwater line is a safety classified 1 pipeline. This satisfies my expectation for such a device and is in line with relevant good practice for secondary systems, thereby satisfying SAP ECS.1 and ECS.3. In my view, the RP has applied conservative boundary conditions and the results are in line with the applied structural code. The RP has demonstrated margins compared to the allowable stress (17% and more). Given the fact that high stresses are concentrated in a very small region of the penetration as shown by the results, I am satisfied that both the design and the justification are acceptable for the purposes of GDA.

4.8.4.1 BRX: Bounding Cases for Barrier Assessment (Criterion A)

847. The BRX HEPF analysis report (Ref. 205) documents the application of the RP’s HEPF methodology (Ref. 200) to determine the bounding cases. The hazard identification process had been performed in three steps with the findings from each step documented in the HEPF analysis report (Ref. 205):

- Step 1: Data collection and identification of high energy pipes (data are maximum pressure and temperature during normal operation, diameter, wall thickness, fluid state, location).
- Step 2: Identification of potential impact (pipe whip, jet impingement, steam release if T >95ºC, flooding, and blast wave if T >300ºC)
- Step 3: Identification of bounding cases.

848. From my assessment of the evidence to demonstrate that step 1 had been adequately undertaken, I found that the evidence to underpin the collection and identification of the HEPs was not complete. I sampled the systems identified by the RP and concluded that that the lists presented did not contain all the main high energy pipe systems. Evidence to underpin the hazard identification and screening was also not available. For example, there were no room data sheets or detailed drawings available to support the lists of piping in the different rooms. I raised a Regulatory Observation, RO-UKHPR1000-053 (Ref. 174) and I selected series of sample areas to give confidence that the appropriate evidence was available for the identification and characterisation of potential HEPF. These sampled areas were:

- Room BRA3133ZRM focusing on the combined hazard impact on the containment wall BRI3101VB following failure of feedwater pipe ARE3440TY.
- Review of all HEP in room BRA3730ZRM as multiple systems exist and it is not considered an exception to segregation area.
- Rooms BRA2101ZRM and BRA2104 review of all HEP to demonstrate that the bounding cases are fully bounding.
- Failure of the ARE system in the BRB.

849. The RP’s response to RO-UKHPR1000-053 and the sampled areas was presented in its RO-UKHPR1000-053 analysis report (Ref. 57), room data sheets (Ref. 77) and detailed design drawings (Ref. 78), which were provided to underpin the data collected.

850. I assessed these submissions and concluded that they provided a systematic identification of all potential HEPF sources and effects on SSCs within the rooms in the sampled area. The RO-UKHPR1000-053 analysis report (Ref. 57) also presented

further analysis of the HEPF effects on the relevant SSCs considered, including a comprehensive review of the effects on the barriers claimed as providing protection against the effects of HEPF. Following my assessment I was satisfied that the evidence provided in the RO-UKHPR1000-053 report (Ref. 205) was adequate to address my sample queries and provide confidence in the main HEPF report (Ref. 205) satisfying my expectations in line with SAPs EHA.6.

851. As a further confirmatory check to test the adequacy of the hazard identification process, I sampled a number of the room datasheets (Ref. 77). My assessment of the datasheets confirmed that at all high energy pipework larger than 100mm nominal diameter had been identified and tabulated in annex D of the RO-UKHPR1000-053 report (Ref. 57). However, I noted that some of the smaller pipe sections listed in the room datasheets 2101 and 2104 (Ref. 77), were not included in the annex D (Ref. 77). These piping sections where:

- RCP1115TY (DN50, 17.13 MPa, 343 °C) in room BRA2101ZRM.
- RCV7414TY (DN50, 17.13 MPa, 100 °C) in room BRA2104ZRM.

852. I note that these pipes had actually been identified as potential flood sources in the internal flooding assessment report (Ref. 148), and are listed in the room data sheets (Ref. 77), therefore I am content that the pipes have been captured from the reference design. However, following my assessment of the BRX HEPF report (Ref. 205) and the RO-UKHPR1000-053 report (Ref. 57), I note that these pipes do not figure in the reports. While I acknowledge that these are relatively small diameter pipes and I am satisfied will not challenge the RP’s conclusions regarding the withstand of the barriers nor of the HIC, I judge that this is a shortfall with the consistency of the case and completeness of the data with respect to the identification of hazards. I consider this a minor shortfall in the documented evidence, as it does not wholly satisfy the intent of SAP EHA.1, which may be addressed at the detailed design stage.

853. Notwithstanding the above, I have confidence that the most challenging HEP cases have been identified. It is my view that at detailed design the impact of small-bore piping is considered as part of the layout considerations to minimise their effects, which I consider should be addressed as part of normal business.

854. For step 2 of the RP’s assessment approach, the RP applied a screening process regarding HEPF consequences, which I have discussed in detail in the methodology section. My main challenge remained the conservativeness of the RP’s 300°C blast criterion. As documented in my explosion assessment (sub-section 4.4), I found that this criterion did not fully account for the influence of pipe (or vessel) diameter.

855. It is my opinion that this shortfall does have an impact on the HEPF assessment, which should adopt conservative and justified assumptions for the blasts effect from HEPF. For HEPF failures, although blast can be a significant hazard it is often bounded by more dominant hazards from the pipe whip and jet loads, however the contribution of blast loads (in terms of damage to local structures such as pipe restraints) cannot be ignored. Noting that blast has been analysed for the most significant pipes, I am content that the issue with the blast criteria does not significantly challenge the conclusions made in my HEPF assessment. It is nevertheless important that the licensee ensures that this is addressed at detailed design when addressing Assessment Finding AF-UKHPR1000-0061.

856. The RP selected bounding cases based on the magnitude of each effect on the barriers. This step considers pipe whip impact energy, jet thrust force, energy of blast wave, differential pressure due to steam, and flooding level.

857. Whilst the majority of the HEPF consequences were calculated by the RP, for flooding it assumed a 10m flood height at the lowest levels and no flood loading at higher levels

in the BRX. Following my assessment of the flooding case I am satisfied that this does not lead to any significant shortfalls as the flood depths are so low in the BRX above the +0.00m level.

858. The RP's analysis of HEP sources identified 11 bounding cases by comparing the combined loads on barriers and the thickness of the barriers. The RP selected IH-HEPF-BRX-01 to IH-HEPF-BRX-04 as these pipes can impact claimed internal containment barriers. The RP also selected IH-HEPF-BRX-05 to IH-HEPF-BRX-11 as they can impact divisional barriers. For all 11 cases, the withstand of the barrier concerned was assessed by the RP and documented in the barrier withstand report (Ref. 83) according to the methods assessed earlier.

859. The RP's analysis predicted scabbing in 5 out of the 11 cases. I noted that in all the cases a margin larger than 50 % against perforation is reported by the RP (Ref. 83) along with a very large margin against global failure of the barriers, which I would expect as the pipe whip is a local effect. Following the identification of these cases I found that none of the cases which resulted in scabbing were regarded by the RP as a bounding case. This is because for the cases with scabbing, the RP argued that the layout of the rooms adjacent to the hazard had been reviewed by the RP to determine if the impact of the concrete missile induced by the scabbing could impact any SSCs important to safety. The RP stated (Ref. 205) that in all 5 cases the RP either identified no SSCs important to safety or only one SSC that belonged to the same division as the failing pipe. Thus, the RP stated that if the safety function was lost additional trains remained to provide the function. The RP concluded that for these cases the safety function could be ensured, and the localised failure of barrier was acceptable. As a result of sentencing these cases, other scenarios became the HEPF bounding cases.

860. For the purposes of GDA, I am satisfied that the RP has provided sufficient confidence that the claimed barriers have an adequate global withstand against the identified bounding cases and are adequate safety measures. The selection of bounding cases has been demonstrated to be adequate and I have been satisfied that all HEP that might have a significant impact on the barriers have been identified. I am therefore able to judge that the RP has demonstrated that adequate segregation is provided from the claimed barriers satisfying SAPs ECS.1 and ELO.4 and that adequate analysis has been undertaken to demonstrate their withstand, satisfying SAPs ECS.3 and EHA.6.

861. However, some barriers may experience scabbing in the event of pipe failure, and whilst the RP has provided arguments why this is acceptable, it is my view that the licensee should consider further measures to ensure the claimed barrier maintains its integrity as far as is reasonably practicable. This shortfall is already captured within the barrier methodology review in sub-section 4.4.

4.8.4.2 BRX: Exception to Segregation (Criterion B)

862. According to the general layout of the plant, redundant trains may only be impacted by HEPF within the identified exception to segregations areas providing that the principal divisional barriers can successfully deliver their safety functions. The findings from the RP's review of the SSCs of redundant trains with the BRX (Ref. 205) that could potentially be impacted by HEPF is described below:

- The piping related to the steam generator blowdown system (APG) in rooms BRA1731/2131ZRM: All three trains of APG enter the BRX in room BRA1731ZRM and go up to room BRA2131ZRM. In BRA2131ZRM the pipe APG3104TY may be hit by the jet of pipe APG1104TY, this scenario is coded by the RP as IH-HEPF-BRX-12. In the same location, failure of a pipe connected to the safety injection system (RIS) could impact all the APG lines by the pipe whip of one of three lines of RIS piping. These additional cases are coded by the RP as IH-HEPF-BRX-13 to 15 for each potential pipe impact.

- Valves of the Fuel Pool Cooling and Treatment System (PTR) in BRA2113ZRM: There are 4 different PTR valves connected to the reactor cavity, the RPV internals storage pool, the reactor pool, and IRWST. The only HEP identified by the RP in that room is APG2104TY that runs in the same room but is stated by the RP to be located sufficiently far from the valves and is positioned at much higher elevation. Therefore, the RP does not assume any simultaneous impact from the failure of APG2104TY onto the valves.
- Pressure sensors of the reactor coolant pumps in BRA2131/2132/2133ZRM: In each of these 3 rooms the RP identified that there are four sensor channels related to one pump. The RP stated that these sensors are designed to fail safe. The sensors for the other pumps are in the other rooms belonging to the other loops. Therefore, the RP claims that only the sensors of one loop can be impacted simultaneously by one HEPF, which the RP considered acceptable.
- Pressure and level sensors of the pressuriser in BRA2633ZRM: the RP considered through its assessment that these sensors cannot be impacted by HEPF as the RP stated that there are no HEP in the room and other HEP sources are considered by the RP to be sufficiently far away as to not present a challenge.
- Pressure and level sensors of the steam generators are located in various rooms: the RP stated that these sensors are designed to fail safe, so the RP argues that the fundamental safety functions are still available in case of their failure and therefore their failure is acceptable. Furthermore, the RP highlighted that redundant trains are spatially separated and located in different rooms. Therefore, the RP concluded that the redundant trains cannot be impacted simultaneously by one HEPF.

863. On the findings detailed above, I have assessed the evidence provided in the analysis report (Ref. 205) and I am satisfied that the RP conclusions are acceptable in all the areas except in the APG piping area. I therefore sampled this area further to determine how the RP addressed the hazards identified related to the APG system.

864. For the APG piping area the RP identified the need for a modification to address the shortfalls in this room. The modification involved moving one of the isolation valves on each APG train upstream of the consequential failure location of the APG pipes and adding a second isolation valve closer to the steam generator of that train. By implementing the modification, the RP could then effectively isolate the steam generators from the postulated break locations of the APG lines; this ultimately avoids the steam generators running empty under accidental conditions. By this modification the RP claimed to have eliminated the existing gap and considered that consequences of HEPF in this area were acceptable.

865. To ensure that I understood the basis of the modification and how it was implemented, I raised RQ-UKHPR1000-1338 (Ref. 191) for the RP to evidence the modification. In response to the RQ, the RP provided further details of the modification of the APG valves (Ref. 191); this included provision of the RP’s various modification sheets documenting the process. The response to RQ-UKHPR1000-1338 (Ref. 191) provided me with confidence that the APG modification (M22) is adequate, had been sufficiently implemented within the generic UK HPR1000 design, and as a result any failures would be limited to one steam generator. This satisfies my expectations in line with SAPs ECS.2 and ELO.4.

866. I judge that the RP has adequately applied the HEPF methodology for the identification and assessment of HEPF in exception to segregation areas. The assessment of the evidence has provided me with sufficient confidence that the HEPF consequences are tolerable, and adequate for GDA. Therefore I am satisfied that the RP’s case meets the

expectations in SAPs EHA.6 (Analysis), FA.2 (identification of faults), FA.4 (fault tolerance) and ELO.4 (minimisation of the effects of accidents).

4.8.4.3 BRX: HIC (Criterion C)

867. The following systems and components within the BRX upon which the RP has made a highest integrity claim are: the reactor pressure vessel (RPV), steam generators (SGs), pressurizer (PZR), main coolant lines (MCLs), reactor coolant pump casing and flywheel, and the main steam lines (MSLs).

868. The RP has undertaken detailed review of the potential HEPFs that could impact these components in response to RO-UKHPR1000-046 (Ref. 88). My assessment of the RP's response is detailed in the RO-UKHPR1000-046 section of this report. A short summary of the RP's key findings from the RO-UKHPR1000-046 report (Ref. 155) is provided here:

- The RP stated that the RPV cannot be affected by HEPF. The RP stated that the design is such that no other HEPs are located in the RPV cavity other than the MCL. Because the MCL is also claimed as HIC the RP has discounted its failure.
- All pipe whip scenarios impacting on the MCL have been claimed by the RP to have been eliminated through layout measures.
- The RP stated that there are no HEPFs that could create blast on the SGs.
- The RP identified several HEPFs that can impact the PRZ. The RP claims withstand for all the scenarios as well as providing options to address the pipe whip hazards.
- The RP highlighted that the MSLs are installed at elevations above +17.5m. The RP stated that there are no HEPs in these areas that can affect the MSLs. Therefore, the RP concluded that MSLs are not affected by HEPF.
- For the RCP casings and flywheels, the RP stated that following review it identified no HEP that may whip on the RCPs.
- For steam release, the RP stated that there are pressure relief channels for all rooms in which HIC are located, so the RP considered that pressure within the HIC compartments would remain at acceptable levels. Flood levels are considered insignificant by the RP due to the flow paths to the bottom of the containment building.

869. My assessment of the RP's optioneering process for the ALARP assessment presented in the RO-UKHPR1000-046 response (Ref. 155) concluded that the process appears transparent and feasible. The RP's proposed solutions have led to significant improvements in hazard and risk reduction. Withstand of the HIC have been substantiated with methods (Ref. 143) which align to relevant good practice such as R3 (Ref. 44) and RCCM (Ref. 80). The separate assessment of the withstand against blast waves and the other HEPF effects I consider acceptable so long as the target is not damaged by the blast wave, which the RP's calculations show should be the case. Furthermore, I am satisfied that, due to the open nature of the reactor hall, there are sufficient openings to provide venting to control sub-compartment pressures following a HEPF. Therefore, for the purposes of GDA, I am satisfied that an adequate approach has been demonstrated to identify and assess the consequences to HIC within the BRX.

870. In summary, following my assessment of the HEPF within the BRX and taking account of the work undertaken by the RP in response to RO-UKHPR1000-046 (Ref. 155) and RO-UKHPR1000-053 (Ref. 57) I am satisfied that the RP has demonstrated a systematic review of HEP hazards based on a room-by-room assessment approach. Following the additional analysis work undertaken by the RP in response to RO-UKHPR1000-046 (Ref. 155) and RO-UKHPR1000-053 (Ref. 57), I have been encouraged that for HEPF no additional cases had emerged. Therefore, I judge that

the HEPF review undertaken by the RP is adequate for the purposes of GDA and satisfies SAPs EHA.1 and EHA.4.

4.8.5 BFX: Assessment of Fuel Building HEPF Safety Case

871. The BFX HEPF report (Ref. 136) provides a brief overview of systems important to safety as well as a description of their basic distribution and/or location. The HEP are all arranged in the lower levels, that is below level +4.50 m and comprise the following systems:

- Steam Generator Blowdown System (APG [SGBS]).
- Extra Cooling System (ECS [ECS]).
- Fuel Pool Cooling and Treatment System (PTR [FPCTS]).
- Emergency Boration System (RBS [EBS]).
- Chemical and Volume Control System (RCV [CVCS]).
- Nuclear Sampling System (REN [NSS]).

872. The fuel building is divided into three independent zones each accommodating one of the redundant trains of the systems important to safety. These zones are segregated by divisional barriers. All the systems are segregated except in the APG valve room (BSA1531ZRM) and RRI piping area. The APG valve room is discussed in sub-section 4.8.5.2 of this report.

873. Regarding the RRI piping area: while the Component Cooling Water System RRI [CCWS] is identified by the RP as important to safety, it is a moderate energy system (design parameters $T \leq 90$ °C, $p \leq 1.35$ MPa, and up to DN350 (Ref. 58)). Therefore, the RP has not included it as a source for HEPF. Furthermore, the RP stated that there is no other high energy pipework in this RRI piping area. Therefore, the RP considered this system out of the HEPF assessment scope and not discussed further in the report (Ref. 136) I judge that this is acceptable for the purposes of GDA.

874. The assumptions applied by the RP in the identification of HEPF hazards sources are the same as applied for the BRX, described above. Overall, I deem the assumptions conservative and adequate, except for the assumptions relating to blast as previously presented in this report. However, there are a small number of subtle differences:

- The RP considers the external containment wall (thickness 1500 mm) as robust enough to withstand any HEPF without further analysis.
- For the assumptions regarding steam pressure, the RP refers to the report ‘Pressure and Temperature Analyses after High Energy Pipe Breaks in Fuel Building’ (Ref. 203). The only piping systems operating at $T \geq 95$ °C that may create steam pressure are the APG and REN systems. All REN piping have a very small diameter (DN8). In accordance with the general screening criterion, piping ≤ DN25 are discounted and therefore the REN system is not considered as a source of HEPF.
- A generic flooding level of 10m is assumed at the lower floors at -9.6m and -4.9m. A 2m flood height is assumed at higher floor levels. The latter is assumed to bound the flood water pressure as a design withstand value for structural loading above ground level. Nevertheless, a more conservative load of 5 m flood height was chosen as the decoupled load for use in the civil engineering analysis of these rooms as part of the analysis for RO-UKHPR1000-054 (Ref. 58).

875. Overall, I have been satisfied that the building layout is consistent with the general HEP safety principles as discussed in the BRX section and judged to be adequate. The claims on the robustness of the external containment I consider justifiable and acceptable for the purposes of GDA, particularly as withstand of the external containment has been demonstrated against the most onerous pipe failures in the BSX

assessment (Ref. 101) which I am satisfied bounds the sources in the BFX. The withstand of walls and barriers in the BFX against HEPF has been demonstrated in the barrier substantiation reports (Ref. 97), although the RP's analysis has identified that scabbing would occur in several instances. This is an issue I have noted within the barrier substantiation section of this report; the licensee should seek to eliminate this hazard so far as is reasonably practicable and this is captured in Assessment Finding UK-HPR1000-0056. I acknowledge that the RP has undertaken assessment of the adjacent compartments and concluded that there are no SSCs that could be damaged from missiles from the scabbing event. This provides me with confidence that, for the purposes of GDA, there is not a significant nuclear safety issue.

876. It is important to highlight that my assessment of the BFX has been based on the BFX design as per design reference DR2.1 (as detailed in section 3 of this report). However, during the GDA process a number of ROs were raised in other subject areas that have resulted in design changes to the BRX. These ROs were RO-UKHPR1000-14 (Ref. 189) and RO-UKHPR1000-056 (Ref. 190) that focused on the fuel route design. The outputs of these ROs could potentially challenge the validity of the HEPF analysis presented for GDA, as it is expected that redesign of some aspects of the BFX will be required, and therefore pipework may be rerouted in areas previously assessed. The extent to which the changes impact the current safety case will need to be revisited at detailed design by the licensee when more detailed design information is available. I expect this to be revisited as part of normal business as the updated BFX will require re-assessment from an internal hazard perspective.

877. The assumptions applied by the RP on the flood height for the HEPF analysis are consistent with the results of the internal flooding analysis in (Ref. 149). I note that for the BFX the RP has applied a more conservative flood height at higher building levels to be used for the civil engineering analysis. This increase in flood height provides confidence in the design of the building and satisfies ONR SAP FA.7 on the basis that the RP has used conservative assumptions.

878. Through my assessment of the generic UK HPR1000 design, I noted that the RP had not adequately demonstrated that it had determined the impact to load bearing structural walls other than the divisional barriers. I raised RO-UKHPR1000-054 (Ref. 98) to get confidence in the overall design of the UKHPR1000. I selected to sample the non-barrier structural elements in the fuel building directly below the spent fuel pond. I targeted this area as loss of internal structures could impact the fuel pond. I sampled the rooms on the three floors below the spent fuel pool. The main purpose of RO-UKHPR1000-054 was the identification of hazard sources and the provision of a series of bounding hazard loads that could be used in the civil substantiation of the inner compartment walls that are not divisional barriers. As per the other RO's, I requested further evidence to underpin the identification and data collection for each internal hazard within the sample area.

879. In the RP's response to RO-UKHPR1000-054 (Ref. 58), the RP described its process of determining the hazard loads for the civil substantiation of non-barrier elements. This approach used decoupled loads to provide conservative hazard loadings. Room data sheets (Ref. 58) and detailed design drawings (Ref. 78) were provided to underpin the evidence in the hazard analysis report. My assessment of these room datasheets confirmed that all HEP larger than DN25 had been identified as sources for HEPF in the BFX HEPF report (Ref. 136). This cross reference provided me with confidence that all potential source of HEPF in the BFX have been identified and I am content that the RP's identification, analysis, and data sources aligned with expectations within SAPs EHA.1, EHA.2, EHA.3 and EHA.5.

4.8.5.1 BFX: Bounding Cases for Barrier Assessment (Criterion A)

880. The RP hazard screening identified 16 bounding cases that can impact divisional barriers in the BFX. The bounding cases were selected by comparing the combined loads from the HEPF on the barriers as well as factoring the thickness of the barriers. For all these cases the withstand of the barrier concerned was analysed by the RP in the BFX barrier substantiation report (Ref. 97) according to the methods already discussed earlier in this report. From the results of this analysis (Ref. 97), scabbing was predicted in six out of these 16 cases. In all 16 cases, however, a margin larger than 50% against perforation and a very large margin against global failure of the barriers was reported. For the cases with scabbing, the RP checked the layout of the room adjacent to the scabbing barrier for any SSCs important to safety that could be damaged by the impact of concrete missiles induced by scabbing. The six bounding cases that resulted in scabbing were:

- IH-HEPF-BFX-01 - Pipe break of ECS1117TY- in room BFX1085ZRM impacting barrier BFX1010VB.
- IH-HEPF-BFX-02 - Pipe break of ECS2105TY- in room BFX1065ZRM impacting barrier BFX1052VB.
- IH-HEPF-BFX-03 - Pipe break of ECS2120TY- in room BFX1065ZRM impacting barrier BFX1052VB.
- IH-HEPF-BFX-04 - Pipe break of PTR2211TY- in room BFX1065ZRM impacting barrier BFX1052VB.
- IH-HEPF-BFX-05 - Pipe break of PTR2212TY- in room BFX1065ZRM impacting barrier BFX1052VB.
- IH-HEPF-BFX-06 - Pipe break of APG4301TY- in room BFX1596ZRM impacting barrier BFX1565VB.

881. I sampled all 6 cases listed above, and I was content that the evidence provided by the RP (Ref. 136) showed that there were no SSCs important to safety in the adjacent rooms. Therefore, the RP considered scabbing of the barrier acceptable in these cases, and the cases with the most onerous combinations of other effects were identified as the bounding cases to drive civil design. I have already highlighted my reservations with the scabbing of barriers, I have raised Assessment Finding UK-HPR1000-0056 to address this. It is my opinion that the procedure as described above, is adequate to identify those HEP that might have a significant impact on the claimed barriers in case of their failure. The approach to scabbing of barriers is in line with ACI 349-M (Ref. 40), but it is my view that options to eliminate scabbing hazards should be reviewed and provided so far as is reasonably practicable. I am content that the RP's conclusions are acceptable for the purposes of GDA, however further review of these scenarios should be considered by the licensee at the detailed design stage. This is also captured as part of Assessment Finding AF-UKHPR1000-0056.

882. I also sampled the adequacy of the case where the RP credits the pressure relief systems to limit the steam pressure following a HEPF. The bounding case IH-HEPF-BFX-09 is stated by the RP to result in the maximum predicted steam pressure on a barrier. In the scenario related to the pipe break of APG1106TY (SG blow down pipe) in BFX1531ZRM, the steam from the break is able to flow through two corridors to the heat exchanger room BFX1585ZRM, where it can flow up through a hoisting hole in the ceiling to BFX2085ZRM.

883. In BFX2085ZRM bursting disks are installed in a wall allowing the steam to be released to the outside. These disks are classified by the RP as safety class 1 SSCs that are designed to break at a pressure of 10 kPa. This is claimed by the RP to limit the differential pressure onto the barrier BFX1517VB to 17.72 kPa.

884. I sampled the available evidence associated with IH-HEPF-BFX-09, including review of the time pressure analysis of the steam flow paths (Ref. 203). The time pressure report

presented the pipe temperatures and, diameters, as well as the various compartment volumes required for the pressure analysis related to the steam paths, in addition to crediting the bursting disc in room BFX2085ZRM. From my assessment of the evidence, I am satisfied that the 17.72kPa differential pressure is appropriately substantiated. I have also sampled the substantiation of the barrier withstand. From my assessment of the barrier withstand report (Ref. 97) I am satisfied that it included all the relevant loadings consistent with the HEPF report (Ref. 97) and the withstand was appropriately substantiated in line with the ACI349M-13 methodology (Ref. 40). I judge that the RP has presented an adequate case for this sampled scenario. The RP has identified and located adequate safety measures including the appropriate categorisation of the safety measures, namely the class 1 bursting discs, to ensure the internal pressures do not challenge the class 1 barriers. I am satisfied that the classification of safety measures is in line with relevant good practice (Ref. 7), and therefore satisfies SAPs ELO.4, ECS.1 and ECS.2.

885. From my sample of bounding case IH-HEPF-BFX-14, I identified inconsistences with the RP's defined temperature data for the pipes supplying heat exchanger APG4310EX. I noted that the RP safety case stated different inlet and outlet temperatures in various tables in the BFX HEPF report (Ref. 136).

886. The temperature data of the pipes APG4302TY and APG4303TY vary as a result of one being an inlet and the other an outlet. The case IH-HEPF-BFX-14 is based on the pipe APG4303TY which assumes that the pipe is operating at 295ºC. Yet the pipe APG4303TY is also stated in the case to be the outlet of the heat exchanger, and as such it is likely that the pipe APG4303TY operates at around 60ºC.

887. This in my opinion may simply be a transcription error and it is likely that the wrong pipe designation has been identified, but the bounding case should be reviewed and, if necessary, reassessed for the inclusion of blast wave and steam pressures. It is my judgement from my understanding of the plant that no adverse effects would be identified, and as such does not impact my overall position for this case. Therefore I judge this to be a minor shortfall that can be addressed as part of normal business.

888. As stated earlier, I raised RO-UKHPR1000-054 (Ref. 98) to get confidence that the internal hazard loads on non-barrier load bearing elements are adequately conservative for use in the civil analysis for the structure. The RO-UKHPR1000-054 scope covered all internal hazards and for HEPF the following approach was adopted:

- The RP listed all the HEPs within the sample rooms, documented them in the room data sheets (Ref. 58), and underpinned this with the associated room drawings (Ref. 78).
- The same screening criteria as defined in the RP's HEPF methodology (Ref. 200) was applied.
- The RP analysed all relevant HEPF effects to determine a set of loads for each individual HEPF consequence (such as pipe whip and jet load) to be used as the hazard load for the civil analysis. In the first instance the RP used the bounding loads derived in the HEPF report (Ref. 136) and compared these to the derived HEPF loads from the RO-UKHPR1000-054 sample areas. If the RP identified a HEPF load that was not bounded by the loads from the HEPF reports (Ref. 136), the RP would adopt the largest load for the civil analysis.

889. From my assessment of the RP's approach and response to RO-UKHPR1000-0054 as defined above, I am satisfied that the RP has provided adequate evidence to underpin the screening, and I have confidence that all appropriate hazards from HEPF for load bearing non-barrier structural elements have been analysed.

890. From the RP's hazard review, as part of RO-UKHPR1000-0054 (Ref. 58) for the defined sample areas, the RP identified the HEPF loads and compared these loads

against the bounding case values derived in the BFX HEPF report (Ref. 136) for pipe whip (1353 kJ). This is considered the most challenging hazard load following a HEPF. Through this analysis the RP identified two rooms (BFX1044ZRM and BFX2024ZRM, figures 7 and 8) where the pipe whip energy was greater than the current bounding value contained in the BFX HEPF report (Ref. 136).

891. The RP's analysis concluded that for both rooms the pipe whip value was 3648.59 kJ, which is significantly greater than the values derived in the bounding cases against divisional barriers described above. The RP then applied this loading to the civil structure analysis which provided confidence that the most challenging loads in the building have been used.

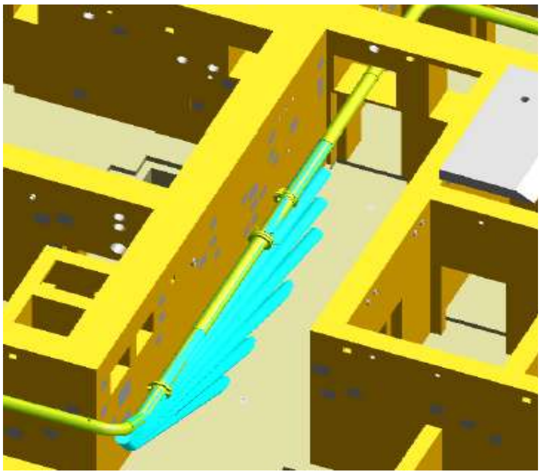

Figure 7: Trajectory of pipe whip in BFX1044ZRM

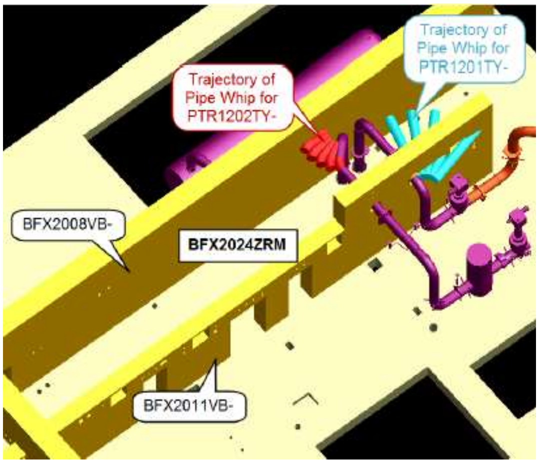

Figure 8: Trajectory of pipe whip in BFX2024ZRM

892. Through my assessment of the RP's response to RO-UKHPR1000-054 (Ref. 58), I am satisfied that the RP provided sufficient evidence to address the additional hazards from HEPF that could impact non-barrier walls identified within the BFX, exceeding the current bounding cases loads for barrier walls defined in the HEPF report (Ref. 136). The full analysis of these loads on these non-barrier elements was out of the scope for GDA. However, the response to RO-UKHPR1000-054 (Ref. 58) has provided assurances that the preliminary structural substantiation results indicated that the barriers had a global withstand and therefore their safety functions would be delivered. The assessment of the effects of the loads to load bearing non-barrier civil structures

for the RO-UKHPR1000-054 has been addressed by the ONR civil engineering assessment (Ref. 49).

893. Overall, my sampling based on the evidence provided by the RP has provided sufficient confidence, for the purposes of GDA, that the claimed barriers have an adequate global withstand against the identified bounding cases. I am satisfied that the selection of bounding cases has been demonstrated by the RP to be adequate, and all HEP that might have a significant impact on the barriers have been identified. This satisfies SAPs EHA.1, EHA.6 EHA.19.

894. However, I have noted that some barriers will experience scabbing. Whilst I accept that the RP has provided arguments why this would be acceptable, it is my view that options to eliminate scabbing hazards should be reviewed and provided so far as is reasonably practicable. I am content that the RP's conclusions are acceptable for the purposes of GDA, however further review of these scenarios should be considered by the licensee at the detailed design stage. This shortfall is already captured within the barrier methodology review in sub-section 4.4.

4.8.5.2 BFX: Exception to Segregation (Criterion B)

895. Within the BFX the RP identified one exception to segregation area where the impact of a HEPF could impact multiple trains of systems. This area was the APG valve room (BSA1531ZRM).

896. Within the room there is one steam generator blowdown line and two isolation valves of each of the three trains are installed (Ref. 29). However as clarified in RQ-UKHPR1000-1338 (Ref. 191), the RP had identified this shortfall and as a result modified the APG system. This modification included moving one of the valves of each train to a separate room within the BRX and adding one more valve in each train in the BRX. With such an arrangement the RP claimed that the steam generators could still be isolated even if all three lines or valves in BSA1531ZRM failed (Ref. 136).

897. The APG modification, as discussed in sub-section 4.8.4.2 of my report, in my view provides adequate measures to reduce the impact of a single failure impacting multiple trains of the APG system. The RP's relocation of the isolation valves also provides additional segregation to ensure the APG functionality can be maintained and, in my view, provides an adequate level of mitigation. Based on my assessment I am satisfied that the modification of the APG system satisfies SAPs EHA.3 and FA.7 and I am satisfied that the RP has adequately demonstrated the use of DBA to inform safety engineering requirements and demonstrated fault tolerance, thus satisfying SAPs FA.9 and FA.4 respectively.

898. In summary, for the identified exception to segregation area in the BFX, the RP has implemented modifications to the layout of valves to provide greater resilience within the generic UK HPR1000 APG layout. I therefore consider this provides an adequate assessment.

4.8.5.3 BFX: HIC (Criterion C)

899. There are no HIC within the BFX, therefore no assessment has been undertaken.

4.8.6 BSX: Assessment of Safeguard Building HEPF Safety Case

900. The BSX HEPF (Ref. 140) report presents the high energy safety systems in BSA/BSB/BSC that meet the criteria described within the RP's HEP methodology (Ref. 200). There are eight key safety systems arranged in the mechanical area (at level -9.60m, -4.90m and +0.00m) of BSA, BSB and BSC, these are:

- ASG [EFWS] - Emergency Feedwater System.

- RIS [SIS] - Safety Injection System.
- EHR [CHRS] - Containment Heat removal system.
- RRI [CCWS] - Component Cooling Water System.
- ECS [ECS] - Extra Cooling System.
- RBS [EBS] - Emergency Boration System.
- REN [NSS] - Nuclear Sampling System.
- SIH [CRDS] - Chemical Reagents Distribution System.

901. At level +13.2m and 16.60m of BSA & BSB the following HEP systems are identified:

- ARE [MFFCS] – Main Feedwater flow control system.
- VVP [MSS] – Main Steam system (including Main steam lines (MSL)).
- VDA [ASDS] – Atmospheric Steam Dump System.

902. At level 16.6m (External to the BSX) the following HEP systems are identified:

- VPU [MSDS] - Main Steam and Drainage System.
- ARE [MFFCS] – Main Feedwater line.

903. The assumptions applied in the identification of HEPF hazards are the same as those applied for the BRX and BFX described above. Overall, I judged that the RP's assumptions are mostly conservative and adequate, except for the screening assumptions relating to blast which I have covered in detail in the explosion sections of this report (sub-section 4.4); the findings there are also applicable to HEPF, in particular AF-UKHPR1000-0061.

904. As in the BFX, the BSX report assumes the external containment wall of the BRX (thickness 1500 mm) to be robust enough and able to withstand any HEPF without further analysis. To get confidence in the validity of this assumption I raised RQ-UKHPR1000-1033 (Ref. 220). The RP's response (Ref. 220) asserted that the external containment is designed to withstand the impact load of an aircraft, which is extremely high, including the parts that are connecting to the Safeguard Buildings. The claims on the robustness of external containment as sufficient to protect against the smaller internal loads are in my view justifiable and acceptable for the purposes of GDA. I also have additional confidence as the most challenging hazard loads from HEPF have been substantiated against the withstand claims for the divisional barriers which mostly have a nominal thickness of 800mm, and thus there is significant additional margin on the BRX interface. I am content that detailed analysis for the purposes of GDA on this wall would not be proportionate and can be discounted for internal hazards aspects.

905. Overall, I am satisfied that the RP has demonstrated that the BSX building layout is consistent with its general HEPF safety principles as discussed in the HEPF methodology (Ref. 200), and defined within its design principles (Ref. 27). I am satisfied that the RP has demonstrated that all three safeguard buildings are clearly segregated by class 1 barriers and each building contains the required independent trains to provide the generic UK HPR1000 safety functions. This in my view provides good diversity and segregation through layout, thereby satisfying SAP ELO.4.

4.8.6.1 BSX: Bounding Cases for Barrier Assessment (Criterion A)

906. The RP's bounding case analysis focused on those HEPFs within the safeguards buildings that could impact divisional walls in line with its hazard assessment criterion A.

907. I sampled the RP's bounding case approach for the BSX and found that there was a lack of evidence to justify the bounding cases as I found variation in the pipe temperatures and pressures. I therefore raised RQ-UKHPR1000-1033 (Ref. 220). The

RP’s response to RQ-UKHPR1000-1033 provided assurance that the RP had accounted for maximum operation pressures and temperatures, and had undertaken an unmitigated analysis for pipe whip, jet, blast, and flooding. For steam release the RP confirmed that it had credited pressure relief panels, where relevant, as part of its analysis and confirmed that all divisional barriers are 800mm thick. The HEPF report (Ref. 140) highlighted the following bounding cases that impacted the divisional barriers:

- IH-HEPF-BSX-01 – Pipe RIS3420TY in room BSC1032ZRM impacting Barrier BSC1012VB. Case results in maximum jet force on barrier.
- IH-HEPF-BSX-02 – Pipe RIS1615TY in room BSA1527ZRM impacting barrier BSC1513VB. Case results in maximum jet force and steam release.
- IH-HEPF-BSX-03 – Pipe RIS1280TY in room BSA1527ZRM impacting barrier BSC1513VB. Case results in maximum pipe whip.
- IH-HEPF-BSX-04 – Pipe ASG2301TY in room BSB1523ZRM impacting barrier BSC1512VB. Case results in maximum energy and jet force on barrier.
- IH-HEPF-BSX-05 – Pipe VDA3210TY in room BSB3702ZRM impacting barrier BSC3718VB. Case results in maximum blast and differential pressure on the barrier.
- IH-HEPF-BSX-06 - Pipe VPU3101TY impacting BSC3337VB (outer wall of MCR). Case results in maximum jet load and maximum blast load.

908. I sampled cases IH-HEPF-BSX-01 to 05 to ascertain the adequacy of the bounding cases and to ensure appropriate loadings had been analysed by the RP. From my assessment I was satisfied that the RP had adequately documented its hazard identification process and derived appropriate loadings through its analysis (Ref. 140). I was satisfied that loadings had been adequately captured within the BSX barrier substantiation report (Ref. 101). In all of the sampled cases I have been satisfied that the RP’s analysis has adequately demonstrated that the claimed barrier walls had adequate withstand with margins demonstrated for scabbing, perforation, and global stability, and therefore have provided me with confidence that the barrier engineering safety functions are satisfied with respect to HEPF.

909. For the failure of some of the systems, the RP has also identified the requirement for pressure relief panels. The RP presented a list of all the credited class 1 pressure relief panels which are incorporated within the design (Ref. 140). I have sampled the adequacy of these panels and I requested additional information to understand the margins of the relief areas using RQ-UKHPR1000-1033 (Ref. 220). The RP’s response (Ref. 220) provided adequate evidence to demonstrate that the panels were adequately sized for the required minimum pressure relief. The RP also updated its hazard schedule to ensure the claims on the panels had been adequately captured. Furthermore, I sampled the pressure and, temperature analysis (Ref. 204) and was satisfied that the pressures claimed were consistent with the analysis. It is my view that the RP has adequately identified the need for safety measures to reduce the impact of compartment pressurisation following a HEPF. The application of pressure relief panels is in line with relevant good practice (Ref. 7) and they are appropriately classified. When combined with the class 1 barriers I judge that suitable safety measures have been identified, thereby satisfying SAPs EHA.6, EKP.3 and FA.7.

910. I have assessed case IH-HEPF-BSX-06 as part of my explosion assessment of scenario IH-EX-BSX-04, and it is captured in sub-section 4.4.5.2 of this report.

911. For the purposes of GDA, I am satisfied the RP has demonstrated that the failures of HEPF have been adequately identified and analysed for the BSX buildings. I am satisfied that the principal class 1 barriers have been adequately substantiated and therefore provide appropriate segregation and margins.

4.8.6.2 BSX: Exception to Segregation (Criterion B)

912. The RP stated that BSX has two exception to segregation areas as defined within the exception to segregation report (Ref. 29). These two areas are the MCR and the area in the BSB where the main steam line pipes (VVP[MSS]) and main feedwater pipes (ARE[MFFCS]) are located. It is stated in the BSX HEPF report (Ref. 140) that both these locations can be impacted by HEPF.

913. For the MCR, it is an RP requirement that the habitability of the MCR is ensured in the event of a HEPF (Ref. 27) . My assessment of the RP's list of HEP within the BSC confirmed that there are no HEPs that could impact the BSC within the building. There are, however, high energy pipes located outside the Safeguard Buildings (Steam lines of VPU [MSDS] and feedwater lines of ARE [MFFCS]) which may impact the external wall of the MCR. In total there are six high energy pipes which may impact the barrier BSC3337VB. The consequential effects and loads due to the failure of these pipes have been analysed by the RP, where it has determined that the VPU (main steam lines) provided the bounding hazard. This was identified as scenario IH-HEPF-BSX-06 and IH-EX-BSX-04. I have assessed this specific scenario in detail in sub-section 4.4.5.2 of this report and therefore it is not discussed further here.

914. For the area identified by the RP in the BSB, at level +13.20m to +20.80m both train B and train C of the Main Steam System (VVP [MSS]) and Main Feedwater Flow Control System (ARE [MFFCS]) are located. This area mainly contains redundant trains of main feedwater lines, main feedwater isolation valves, and main steam isolation valves. A general arrangement is illustrated below in figure 9:

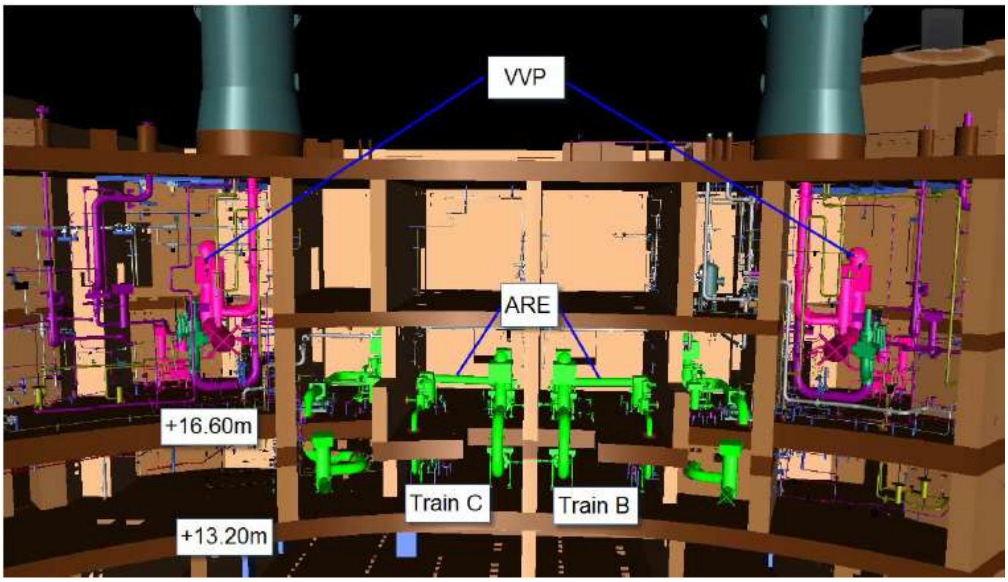

Figure 9: The elevation of VPP [MSS] / ARE [MFFCS]

915. For this location the RP identified the following bounding cases that impact the exception to segregation criteria:

- IH-HEPF-BSX-07 – Train B ARE Impacting Redundant Train C of ARE in BSB3628ZRM. The two trains are separated by a partial wall BSB3619VB.
- IH-HEPF-BSX-08 – Failure of ARE2510TY may impact redundant safety sensors in BSB3329ZRM by flooding.

916. For IH-HEPF-BSX-08, this scenario is the same as the flooding scenario IH-FL-BSX-03 and my findings following my assessment is reported in sub-section 4.5.5.2 of this report.

917. From my assessment of IH-HEPF-BSX-07, I noted that in the analysis of consequences, the RP makes no claims on the divisional barrier BSB3619VB (as shown in figure 10) segregating the two feedwater trains. Therefore, the RP assumes that following a pipe break of ARE2510TY in room BSB3628ZRM, the adjacent pipe ARE3510TY in room BSB3627ZRM would also be damaged.

918. It is also recognised in the BSX HEPF report (Ref. 140) that several redundant safety sensors would also be lost. A functional analysis was undertaken by the RP (Ref. 140) to demonstrate that loss of the two ARE systems would not impact plant safety and was tolerable. The functional analysis highlighted that the ARE [MFFCS] is not an engineered safety system as it is used in normal operation. The RP highlighted that if the two trains of ARE [MFFCS] are lost, the emergency feedwater system (ASG [EFWS]) is available (which is an engineered safety system). The RP stated that the ASG [EFWS] can be actuated to remove heat and bring the unit to safe state. There are three trains of ASG [EFWS] which are physically segregated and located in BSA, BSB and BSC respectively.

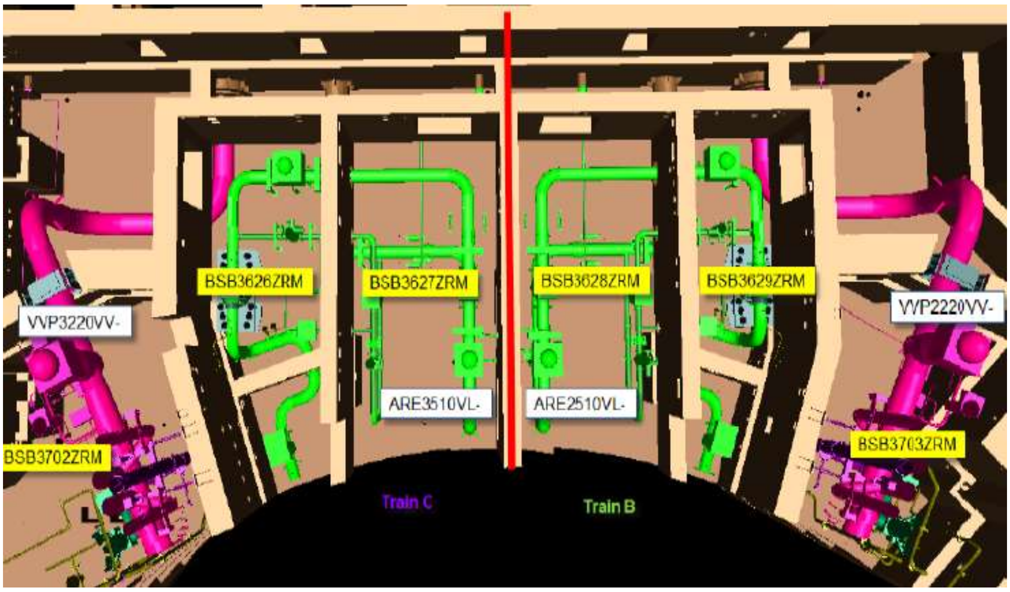

Figure 10: ARE [MFFCS] Train A and B exception to segregation area.

919. My assessment of the RP's functional analysis had provided me with some confidence that there are segregated and diverse safety systems available if the two systems failed. However, it was my observation that the RP's analysis had not assessed the physical impact of the ARE system to the actual building and the wider potential consequences such as overpressure. I also noted that the RP had sated that that barrier was considered as defence in depth in the hazards schedule (Ref. 92), however, the actual claim on the barrier was not clear particularly as the RP had already assumed it would fail.

920. It was my view that the loss and physical consequences of the two feed water systems concurrently would be significant. From my understanding of the plant, it was my view that the consequential hazards that would result from the failure of two ARE systems were significant, and as a result this was a shortfall against SAPs EHA.1, EHA.3

EHA.6 and FA.3. I therefore raised RQ-UKHPR1000-1542 (Ref. 221) to understand the significance to the building and address my concerns.

921. The RP's response to RQ-UKHPR1000-1542 (Ref. 221) conceded that the loss of these systems would be not acceptable. Therefore, in the RQ response the RP proposed a modification to increase the thickness of the dividing wall BSB3619VB. The RP stated that from an ALARP perspective the impact between the two pipes can be eliminated through increasing the thickness of the dividing wall. The RP stated that the wall thickness would need to be increased from 600mm to 900mm to eliminate the scabbing hazard and ensure that the wall does not fail. However, to provide additional margin, the RP committed to increase the thickness of the barrier to 1000mm (Ref. 222). This modification (M93) is captured within the internal hazards ALARP demonstration report (Ref. 33) and is stated to be completed and incorporated in the latest generic UK HPR1000 design reference (Ref. 6). I have assessed the details of the modification and I am content that this modification adequately addresses the shortfall I identified.

922. Following my assessment and queries, I welcomed the RP's positive response to address the shortfalls identified. Through the modification implemented by the RP, the hazard was eliminated and a robust segregation between the two feedwater lines demonstrated. I judge that the approach taken by the RP meets relevant good practice (Ref. 7) for scenario IH-HEPF-BSX-07 and satisfies SAPs EKP.3 and ELO.4.

923. I also undertook further assessment on the ARE system with respect to hazards from the jet loads from the HEP to other SSCs, such as the mechanical penetrations that enter the BRX. I noted that from my assessment of the main steam line consequences (Ref. 223), a jet load from the main steam line could result in the failure of the compensator element of the mechanical penetrations connecting the steam line to the reactor building. In this scenario the RP recognised that the failure of the compensator could lead to over pressurisation in the BRB area in the reactor building as documented in the RP's response to RQ-UKHPR1000-0925 (Ref. 141).

924. The main feedwater lines are operated at similar pressures as the main steam line. I therefore sought confidence that the compensator elements of the mechanical penetrations connecting the main feedwater lines would not be similarly damaged by a jet load from failure of the pipe. I raised RQ-UKHPR1000-1541 (Ref. 219) to query if the failure of the ARE and associated jet load could impact the compensator and result in the over pressurisation of the inner containment within the BRX.

925. The RP's response to RQ-UKHPR1000-1541 (Ref. 219) confirmed that the compensator could be destroyed under jet impact loads, and this would result in overpressure in the annulus and cause an excessive external load of inner containment. The RP confirmed that the inner containment would not withstand the overpressure. Therefore, in response the RP raised another design modification (M92) to address this shortfall (Ref. 224).

926. This modification is stated by the RP as the installation of anti-jet plates to protect the compensator from all HEPs as this shortfall would be relevant to all other HEPs (Ref. 225). This modification has been confirmed by the RP as completed in the internal hazards ALARP demonstration report (Ref. 33) and captured in the latest design reference (Ref. 6). However, the substantiation of these anti-jet plates should be assessed by the licensee at the detailed design to demonstrate that the plates are sufficiently robust, as the modification has been captured and already incorporated into the design, I am content that this can be followed up at detailed design.

927. In summary, for the exception to segregation areas in the BSX, I am satisfied that for the purposes of GDA, the RP has provided a demonstration that the risks from HEPF are reduced ALARP. The RP has implemented two key modifications that have

eliminated the hazard in one instance and mitigated the other to reduce the loads to SSCs. I have assessed the modifications and judged them to be adequate; substantiation of their design should be undertaken during the detailed design stage. I judge that the RP has demonstrated application of relevant good practice (Ref. 7) and satisfied the following relevant SAPs EKP.3, FA.7, FA.6, EHA.7, EHA.3 and EHA.6.

4.8.6.3 BSX: HIC (Criterion C)

928. During GDA, the classification of the main steam line and the main steam isolation valves within the BSX had not been clear and this resulted in significant scrutiny from the ONR Structural Integrity inspectors, as documented in the ONR SI Assessment report (Ref. 209). A HIC review by the RP's structural integrity team in response to RO-UKHPR1000-008 (Ref. 223) initially proposed that the main steam line in the BSX could be a structural integrity class 2 component. In response to the proposed classification, I raised RQ-UKHPR1000-0925 (Ref. 141) for the RP to clarify the consequences of the MSL failure. In its response to RQ-UKHPR1000-0925 (Ref. 141) the RP confirmed that the consequence from the main steam line failure is not acceptable and that the system would now be classified as a HIC component. As a result the hazards to the MSL within the BSX was included in the scope of RO-UKHPR1000-0046. Further information on the assessment of hazards to the MSL can be found in the RO-UKHPR1000-046 section of this report (sub-section 4.11).

929. Notwithstanding the above the RP identified two scenarios within the BSX HEPF report (Ref. 140) where the MSL would be impacted following a HEPF. These scenarios were:

- IH-HEPF-BSX-09 - pipe break of VDA2210TY- in room BSB3703ZRM, which may impact VVP2120TY (main steam line) / VVP2220VV (main steam isolation valve).
- IH-HEPF-BSX-10 - pipe break of ARE2510TY- in room BSB3324ZRM, which may impact VVP2130TY.

930. For IH-HEPF-BSX-09, the RP identified that the only effect to the MSL would be a blast load. This scenario has already been assessed in the blast section of this report (sub-section 4.4.5.3.) as scenario IH-EX-BSX-05. I noted that all three trains of the MSL are identical in terms of their size and components. However, as the three trains of MSL are in two different buildings, the rooms through which they pass are subtly different, in particular in relation to room volume. This is a key point as the identified explosion scenario is for a different room located in safeguard building A rather than safeguard building B. In this instance the RP highlights that the volume of the room in safeguard building A is smaller than the comparable location in safeguard building B. Therefore, I accepted that the analysis would be similar, and the case still bounding. I am satisfied that this scenario has been adequately addressed and is therefore not discussed further in this section.

931. For the scenario IH-HEPF-BSX-10, the RP stated that this scenario could be discounted on the basis that the ARE pipe was smaller in diameter than the MSL. As a result, the RP had screened out this scenario and conducted no further analysis nor provided any additional evidence to substantiate this claim.

932. From my assessment I judged that the evidence to support the RP's assertion for this scenario was not adequate. This is because the ARE pipe is a significant pipe with a thick wall and would result in a significant loading on the MSL. In addition, as part of the response to RQ-UKHPR1000-0925 (Ref. 141) the RP had stated that the combined hazard loads from the failure of the MSL and the consequential failure of ARE would not be acceptable in terms of overpressure, for the BSX civil structure. However, the RP had discounted consequential failure of the ARE following a MSL impact. This was because MSL was HIC, so its failure could be discounted, and since the RP

considered the ARE is of smaller diameter than the MSL, it assumed that the MSL would not fail from its impact from an ARE failure. It was the RP's view that the scenario did not require further analysis. I issued RQ-UKHPR1000-1235 (Ref. 226) to clarify this point.

933. In response to RQ-UKHPR1000-1235 (Ref. 226) the RP accepted that further measures could be put in place to protect the MSL from a potential pipe whip impact from the ARE. The RP proposed a further modification to the generic UK HPR1000 design through the installation of a restraint and wall in between the two pipe systems. I have reviewed the modification and I am content that it provides an adequate safety measure to mitigate the potential of pipe whip from the ARE pipe to the MSL. This modification (M86) has been captured in the ALARP demonstration report for IH (Ref. 33) for implementation in the generic UK HPR1000 design and is incorporated in the update design reference (Ref. 6).

934. In summary, I am satisfied that following my assessment, the RP has provided an adequate case for HEPF impacts on the MSL within the safeguards building. This is based on the implementation of the restraint and wall that will separate the main steam line from the main feedwater line. I judge that the implementation of the barrier and restraint is in line with relevant good practice (Ref. 7) and satisfies the following relevant SAPs EKP.3, FA.7, FA.6, EHA.7, EHA.3 and EHA.6.

4.8.7 Summary of Assessment and Affirmation of PCSR Claims

935. For HEPF, principal safety measures are primarily the class 1 civil structures; these are passive structures. In line with SAP EDR.2 it can be concluded that the RP has presented sufficient evidence that the barriers claimed for HEPF have adequate withstand against the identified HEPF loads, individually and in combination, and fulfil their safety functional requirements. This satisfies SAPs EHA.15, ESS.1. Therefore, sufficient segregation between SSCs important to safety has been demonstrated.

936. I have sampled the analysis code CAMPHOR and judged it adequate for the purposes of GDA. The code is underpinned by relevant codes and provides an adequate basis for assessing the temperatures and pressures following a HEPF. This satisfies SAPs AV.1, AV.2 and AV.3.

937. I am satisfied that the RP has identified additional measures such as bursting discs to provide appropriate pressure relief, and I have been satisfied that these have been adequately sized and classified. The RP has also implemented improvements in the segregation of HEP for the MSL and ARE systems. The RP has also identified the need for anti-jet plates which require further assessment and substantiation; however, their identification and inclusion in the design provides confidence within the scope of GDA that adequate systems exist to control the risks and providing defence in depth in line with SAP EKP.5.

938. Overall, I judge that the RP has demonstrated that, for HEPF, the current layout as assessed for GDA provides adequate measures and segregation to ensure that a design basis HEPF would not impact nuclear safety; this satisfies SAP ELO.4.

4.8.7.1 Affirmation of PCSR Claims for the HEPF Safety Case

939. This section provides a summary of my assessment of the principal claims associated with the internal HEPF safety case.

- Sub-claim 3.2.2.SC19.2.10 (HEPF): The high energy pipe failures sources are sufficiently identified.

940. Based on the evidence sampled, I am able to conclude that the RP has demonstrated that the principal HEP sources have been identified. Evidence provided through RO-UKHPR1000-053 has given confidence that the interrogation of the RP's source data has been systematic, this provides confidence in the outputs of the HEPF assessment reports.

941. From my assessment I am satisfied that the HEP systems identified by the RP has been adequately analysed and the largest loads for each individual hazard, pipe whip, jet impact, blast, temperature, pressure, and flooding have been appropriately calculated by the RP. I am satisfied that the RP has applied conservative assumptions and the analyses are in line with relevant good practice as detailed in my assessment satisfying SAPs EHA.1, EHA.2 and EHA.19.

- Sub-claim 3.2.2.SC19.2.11 (HEPF): After the safety assessment, the safety measures to mitigate the consequences of high energy pipe failures are sufficiently identified and properly classified.

942. The principal safety measures for HEPF are largely related to the various divisional barriers and bursting discs. Following my assessment, I am satisfied that the RP has provided sufficient evidence through the analysis of the HEPF loads and its barrier substantiation to justify the safety functional requirements on the identified barriers, thereby satisfying SAPs FA.6, FA.7 and ECS.1.

- Sub-claim 3.2.2.SC19.2.12 (HEPF): The safety measures to mitigate the consequences of high energy pipe failures are sufficiently substantiated.

943. Based on the evidence provided in the HEPF reports and RO-UKHPR1000-053 sample areas, I am satisfied that the analyses carried out by the RP based on the identified HEPF sources have adequately justified that the identified barriers will provide the required withstand to ensure that the effects from HEP are retained within one train. This satisfies SAPs ECS.2 and ECS.3.

4.8.8 HEPF Safety Case Strengths

944. Through my assessment recorded above, I have noted the following strengths in the RP's internal dropped loads safety case:

- The RP defined a HEPF methodology that is consistent with relevant good practice.
- The RP has demonstrated adequate application of this methodology.
- The three safeguard buildings are well segregated.
- The barriers claimed for segregation of the safeguard buildings are adequately substantiated.
- There are no SSCs in the BSX that will cause the loss of safety functions.

4.8.9 Outcomes

945. Through my assessment of the RP's HEPF safety case, I have been satisfied that the RP has provided adequate evidence to underpin its HEPF analysis for the purposes of GDA. The RP has demonstrated that hazard identification been applied in line with its assessment criteria (A, B and C).

946. Following my assessment, I have been satisfied that the RP has applied relevant good practice (Ref. 7) and the RP has adequality addressed the effects of HEPF both as individual hazards and in combination. The RP's methodology has been adequately applied to the principal sample buildings BRX, BFX and BSX and largely fulfilled my expectations for a HEPF analysis. However I have recognised that some gaps remain, and Assessment Findings have been highlighted. The Assessment Findings relate to

the screening of explosion sources and scabbing of civil structures. It is my judgement that none of these challenges the general layout of the plant and overall safety claims, and in my view can be addressed by licensee choices at detailed design.

947. During my assessment, the following modifications have been incorporated into the latest design reference (Ref. 6) by the RP to address identified shortfalls. I have judged the modifications to be feasible, and their implementation sufficient, for GDA.

- Modification (M22) to APG system to eliminate multiple loss of trains.
- Modification (M92) to install anti-jet plates to protect mechanical penetrations compensators from jet loads.
- Modification (M86) to install a wall and pipe restraint to segregate the MSL and ARE lines.
- Modification (M93) to increase barrier thickness in the BSB to segregate two ARE lines.

4.8.10 Conclusions

948. My assessment of the generic UK HPR1000 HEPF safety case has been informed by several submissions, RQs and ROs. The breadth and depth of my assessment has been focused on the key risk areas and the quality of evidence provided.

949. I am satisfied that the principal risks from HEPF have been identified and understood by the RP. The RP has identified the principal safety functions and substantiated the safety measures that deliver them within the scope of GDA.

950. Therefore, based on the outcomes of my assessment of the RP's HEPF safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and raised a number of Assessment Findings. I do not judge these gaps to be significant enough to prevent issue of a DAC, as I am content that they can be addressed by the licensee at detailed design.

4.9 Hazard Assessment – Combined Hazards Assessments

4.9.1 Combined Hazards Principal Claims

951. The principal claims related to hazard combinations in the PCSR include:

- Sub-claim 3.2.1.SC19.1: The individual internal hazards and hazard combinations that can potentially cause initiating faults and thus affect nuclear safety are sufficiently identified.
- Sub-claim 3.2.2.SC19.2.26 (Hazard Combinations): After the safety assessment, the safety measures to mitigate the consequences of hazard combinations are sufficiently identified and properly classified.
- Sub-claim 3.2.2.SC19.2.27 (Hazard Combinations): The safety measures to mitigate the consequences of hazard combinations are sufficiently substantiated.

952. The RP has addressed the potential for combined hazards in two separate reports the 'Combined Hazards Safety Assessment Report' (Ref. 227), and; the 'External Hazards Combination Safety Evaluation Report' (Ref. 228) implementing its combined hazard analysis methodology (Ref. 229).

4.9.2 Combined Hazards Methodology Assessment

953. The RP's Combined Hazards Methodology (Ref. 229) described the high-level approach chosen by the RP for combined hazards assessment in a three-step process, and follows guidance provided in IAEA-SSG 64 (Ref. 15):

- Identification of hazards types.
- Combined hazards screening.
- Hazard assessment.

954. The RP's hazard identification included distinguishing between three types of combined hazards: consequential, correlated, and unrelated (independent) combined hazards. I am satisfied this approach is in line with SAPs EHA.1 and EHA.6, regarding identification and characterisation of internal hazards/ hazard combinations and analysis of the consequential effects, and is in line with relevant good practice (Ref. 15).

955. The RP described the screening criteria for combined hazards as:

- Credible combined hazards due to probabilistic considerations.
- Credible combined hazards based on plant layout and design.
- Operating experience.
- Expert judgements.

956. The methodology (Ref. 229) used for independent internal hazards provided an identification and screening process which relied on consideration of the frequencies of each internal hazard, calculating the frequency of two or more independent hazards occurring simultaneously and comparing this combined frequency with a cut-off frequency of 10^{-7} per annum. For consequential and correlated internal hazards, the RP applied further hazard identification and screening processes following the primary hazard event to determine whether a combined internal hazard was credible. For example, in a dropped load event the area of the dropped load would be determined, the RP would then analyse the area to determine if other SSCs such as HEP could be impacted, and if so any hazards as a result of the SSC failure would be taken into account. I judge this an adequate approach for the purposes of GDA.

957. Based on the approach described above, it is my view that the RP's frequency argument for screening of independent internal hazards has some drawbacks if the number of combinations with one independent hazard (e.g. fire) is high and the frequencies of independent combinations are only slightly below the cut-off frequency. This potentially allows for several hazard combinations to be possible each with an occurrence frequency just below the cut-off but, where the total frequency of these combinations is significantly higher than 10^{-7} per annum, this could potentially result in cliff edge effects. To meet the expectations of ONR SAPs EHA.1, EHA.3 and EHA.4 and the Internal Hazards TAG (Ref. 7) it is my view that the RP should have considered and undertaken further sensitivity analysis for the potential combined hazards consequential effects close to the cut off frequencies, specifically to demonstrate there are no cliff-edge effects which are not otherwise captured in the safety case.

958. I discussed this issue with my ONR PSA specialist colleagues who confirmed that the RP's hazard PSAs had considered hazard combinations. My PSA colleague noted that the impacts of combined and consequential fires are proportionately addressed through the fire frequency calculations in the Fire PSA and accounted for in the overall risks for the generic UK HPR1000 design. In addition, the seismic risk insights report based on FCG3 seismic PSA has shown consideration of seismically induced fire and floods including HEAF fires. The ONR PSA assessment (Ref. 230), has provided me with confidence that these combinations have been addressed within the RP's safety case.

959. Following my assessment of the RP's methodology screening criteria, as described above, and taking account of the supporting information provided in PSA documentation, I am content that, for the purposes of GDA, this subject does not require further consideration. However, all potential hazard combinations and

reasonably practicable improvements to hazard resilience should be considered and assessed during the detailed design stage. However, I judge that this may be followed up as part of normal regulatory business.

4.9.3 Combined Hazards Assessment Reports

960. There are two key combined hazards reports that have informed my assessment. These are:

- The 'Combined Hazards Safety Assessment Report' (Ref. 227), which considers the hazard combinations initiated internally, i.e. where an internal hazard is the initiating event.
- The 'External Hazards Combination Safety Evaluation Report' (Ref. 228), which considers hazard combinations initiated offsite, i.e. where an external hazard is the initiating event. For the purposes of this internal hazards assessment report, only combinations from this analysis which can result in internal hazards are considered here.

4.9.3.1 Combined Hazards Initiated by Internal Hazards

961. The internal combined hazards analysis (Ref. 227) uses a 6-step approach to the hazard combinations

- Step 1: Hazard identification.
- Step 2: Screening and identification of hazard combination.
- Step 3: Identification of bounding load cases.
- Step 4: Impact assessment (consider whether the combined hazard is bounded by the single hazard assessment).
- Step 5: Functional analysis to assess suitability and sufficiency of safety measures.
- Step 6: Identification and review of protection measures.

962. The RP provided a description of the combined hazard sequences in its combined hazards report (Ref. 227). The RP's approach considered one (initial) equipment failure (and the resulting hazards) leading to just one other (secondary) equipment failure (and the resulting hazards). Domino effects such as tertiary event sequences (where the secondary equipment failure could lead to another equipment failure and resulting hazards), or where the first equipment failure could lead to more than one secondary equipment failure, were discounted based on the low conditional probabilities for additional equipment items being failed, combined with generally already low initiating frequencies for the initial events. The RP also considered cliff edge effects associated with this assumption. The RP has not provided any further substantiation of the claimed low conditional probabilities for additional equipment failures. I raised RQ-UKHPR1000-1495 (Ref. 231) to seek improved transparency of the initial identification, screening, and assessment of combined hazards.

963. The RP's response to RQ-UKHPR1000-1495 (Ref. 231) included tables giving additional information on the screening process and combined hazards assessment. In addition, the RP provided a detailed example of the screening process. This example provided more information on the first steps of the screening process and more details on the combined hazards load derivation.

964. As discussed earlier, domino effect sequences are excluded from further consideration in the RP's combined hazards report (Ref. 227). However, in response to RQ-UKHPR1000-1495, the RP provided an example indicating that all three lines of the Steam Generator Blowdown System APG could be lost simultaneously, thus representing a tertiary event sequence with three equipment failures. Whilst the RQ

response went on to confirm that a design modification (movement of isolation valves) has rectified this issue, similar anomalies may remain.

965. I have however gained some confidence from the RP's response to RO-UKHPR1000-053 (Ref. 57) that the necessary information to screen and assess combined hazards exists and can be assembled such that a complete and suitable combined hazards safety case can be achieved.

966. As noted in sub-section 4.11 of this report, I raised RO-UKHPR1000-054 (Ref. 98) to address my concern that the RP's analysis had not taken into consideration the impact of hazard loads on key internal non-barrier structural elements. In defining the sample areas for RO-UKHPR1000-054 I specifically targeted areas with the potential for highest consequences, that is the fuel building. I also raised two further RQs RQ-UKHPR1000-1722 (Ref. 232) and RQ-UKHPR1000-1724 (Ref. 233), requesting further clarity on the RP's response to horizontal missile hazards, dropped load combinations, and clarification of hazard sources present in rooms.

967. As a result of the RP's response to RO-UKHPR1000-054 (Ref. 58), RQ-UKHPR1000-1722 (Ref. 232) and RQ-UKHPR1000-1724 (Ref. 233), I have gained some confidence that the RP has been able to identify, characterise, and substantiate non barrier safety components for the sample areas. My civil engineering colleagues have addressed the implications of hazard combinations leading to impacts to the civil structure in the Civil Engineering Assessment Report (Ref. 49) and have raised an Assessment Finding AF-UKHPR1000-0215 requiring further substantiation of these barriers at detailed design. Hence in my judgement, whilst this leaves a gap in the safety case for structures and components not addressed in RO-UKHPR1000-054 (Ref. 58), I have confidence that the licensee will be able to adequately address this gap during detailed design when the detail of plant equipment and operating procedures will be known and hence the consequences can be reassessed on a case-by-case basis. I have included this concern in the Assessment Finding AF-UKHPR1000-0074 raised below in line with SAPs EHA.3, EHA.5, EHA.6, EHA.7 and EHA.18.

968. The RP's detailed assessment (Ref. 227) of combined hazards was limited to those buildings containing equipment with a safety function. The RP screened out buildings that contained no hazards that could impact nuclear safety functions in other buildings. In addition, any buildings/areas containing hazard sources negligible in terms of their potential impact on SSCs were screened out of the analysis (this refers to hazards where the RP judged that the magnitude of the impact on a barrier or HIC was such that it has no detrimental effect on functionality).

969. The RP's assessment generally considered combined hazards as follows:

- Buildings which contained dedicated hazard compartments to separate redundant divisions of SSCs that delivered critical safety functions, in other words segregated by robust construction such as concrete or steel.
- Buildings which contained exceptions to segregation, meaning areas where redundant divisions of SSCs were not segregated and instead were simply separated, or it was not possible to segregate/separate the SSCs.

970. The RP's combined hazards assessment (Ref. 227) considered the primary nuclear safety buildings; the reactor building BRX, the fuel building BFX, and the safeguard buildings BSX. The RP did not undertake a detailed combined hazard assessment for the remaining buildings within the GDA; instead the RP has assumed worst-case scenario (i.e. the total loss of all the SSCs in the building).

971. It is not clear from the RP's assessment (Ref. 227) exactly which buildings were screened out of its assessment. However, I would expect to see consideration of the combined hazards within other buildings which potentially contain hazards, such as

Emergency Diesel Generator Buildings. The RP’s assessment seemed to consider functional aspects only, such as loss of a complete system. This is valid in principle, for the purposes of GDA, as it provides confidence in the generic UK HPR1000 ability to maintain safety following loss of various systems. However, this is on the basis that the hazards (single or combined) cannot spread to adjacent buildings or do not lead to other detrimental effects, such as structural collapse of one building impacting adjacent buildings.

972. As discussed above, the Civil Engineering Assessment Report (Ref. 49) has considered the implications for combined hazards to impact the civil structure, and the RP’s response to RO-UKHPR1000-054 (Ref. 58) provided me with some confidence, for the purposes of GDA, that a suitable safety case can be made for the analysis of combined hazard loads. However, I judge that a gap remains in the safety case regarding the completeness of the combined hazards analysis as described above. This should be resolved at detailed design when the detail of plant equipment, layout and operating procedures will be known and hence the combined hazard consequences can be reassessed on a case-by-case basis. I have included this concern in Assessment Finding AF-UKHPR1000-0074 to address the requirements of SAPs EDR.2 EHA.6, EHA.7 and ELO.4.

973. The RP’s combined hazard analysis (Ref. 227) considered the following target types:

- Claimed barriers.
- Exception to segregation areas.
- HIC.

974. These target types were consistent with the RP’s single hazard assessments.

975. The RP claimed (Ref. 227) that the effects of combined hazards on exception to segregation areas were bounded by the single hazard assessments. The claim used consideration of functional arguments that sufficient lines of protection would remain, even with the loss of equipment in multiple divisions. On this basis the RP limited its combined hazard assessment target to rooms containing HIC or bordering a claimed barrier.

976. From my assessment of the RP’s approach, I was not satisfied that the RP had provided sufficient evidence to demonstrate that escalating event sequences were adequately prevented, or that the impacts of these event sequences did not compromise claimed barriers or HIC.

977. Combined hazards may have detrimental effects on other elements important to safety such as civil structures (walls, floor slabs or ceilings). It is my view that the RP’s analysis had not considered this in rooms other than those containing the defined target types. Damage or (partial) collapse of civil structures in other rooms may lead to escalating event sequences beyond the current analysis. This concern is similar to those I have identified previously in this section. I consider there to be a lack of evidence of analysis of escalation of events in other areas of the plant; this remains a gap in the current safety case which should be resolved at detailed design and is captured in my Assessment Finding AF-UKHPR1000-0074 in line with SAPs EHA.6, EHA.7 and EHA.18.

978. The RP’s combined hazards assessment (Ref. 227) described the main assumptions and considerations from the single hazard assessments which are discussed below. In my judgement the initial assumptions, which include the following points, are reasonable for GDA:

- The RP's HEPF reports assumed that the force is equal and opposite to the thrust force which accelerates a whipping pipe. Therefore, jet was considered as applicable in all combinations involving pipe whip.
- The RP's Internal flooding assessment reports provided lists of all flooding sources in the forms of pipework and vessels. This included high pressure sources, in which the temperature and pressure conditions are assumed by the RP to be the operating conditions listed in the HEPF reports.
- Steam hazards were assumed by the RP to be present in any room which contained a pipe holding water at or above 100°C (taken from the HEPF reports).
- All pipe whip hazards were assumed by the RP to be within rooms which the HEPF reports listed as containing HEPF sources. These only included pipe whip loads which could impact on divisional barriers, leading to cases listed where steam hazards were identified but pipe whip was not. In the absence of detailed 3D model information, the RP assumed that pipe on pipe impact scenarios could occur where there are multiple pipes within a given room.

979. Further RP assumptions and considerations were:

- Individual rooms were assumed by the RP to be sufficiently bounded within buildings considered in isolation i.e. room numbers reflect discrete volumes with distinct boundaries and not an extension of a larger volume. This included BRX although the RP noted that room boundaries may not be complete in BRX due to openings, e.g. for mechanical penetrations.
- The list of barriers and rooms adjacent to barriers, contained in the single hazard reports were considered as part of the combined hazards assessment.
- The RP assumed that the worst-case combined hazard loads in terms of impact on a barrier occur in rooms which bordered that barrier, i.e. spread of hazards from other rooms was not explicitly considered.
- In line with the internal missiles reports, the RP assumed that the orientation of valve type missiles was such that they will impact the slab (ceiling) of a particular room; i.e. they were unlikely to combine with jet or pipe whip effects on the same barrier section. The exception was where an explosion or blast occurred in the initiating hazard, and pipework failures (deformation or bending) could not be anticipated.
- For identified barrier and HIC cases, the RP's substantiation considered the withstand for internal combined hazards loads.
- For areas containing exceptions to segregation, the RP's functional analysis contained in the single hazard reports was stated to be equally applicable to the RP's combined hazard analysis.

980. These assumptions limit the assessment to single rooms with no escalation to other rooms. Whilst I noted that (Ref. 227) discussed cliff edge considerations, the narrative provided by the RP was unclear and focused only on fire and flooding as potential spreading hazards.

981. For BSX and BFX, the RP claimed these hazards to be no worse than the single hazard consequences (loss of a single division). For BRX the consequences were claimed to be tolerable. Hence, in my judgement the RP's assumption that the barriers and rooms adjacent to hazards were the same for the combined hazards as for the single hazards needs further verification.

982. Furthermore, the RP's combined hazards report did not consider the validity of these assumptions, or consider the impacts if any of these assumptions were invalid. In my judgement whilst the basis for the assumptions seems reasonable, further evidence and underpinning is required to substantiate and verify them. This places potential risk on the design if, during detailed design, major changes are needed to underpin the assumptions or to deal with the consequences of invalid assumptions.

983. As I have previously discussed above, I have confidence from the RP's response to RO-UKHPR1000-054 (Ref. 58) (and associated RQs) that the licensee can make a suitable safety case for the consideration of combined hazards impacts to the non-barrier elements, and my civil engineering colleagues have also considered the impacts to the building structure and raised an Assessment Finding AF-UKHPR1000-0215 to address this. Hence, although in my judgement the RP's assumptions need to be fully reviewed at detailed design, I have confidence that solutions can be implemented. I have included this concern in the Assessment Finding AF-UKHPR1000-0074 raised below to meet the expectation of ONR SAPs EHA.1, EHA.6 and EHA.7.

984. Through my assessment of the RP's response to RO-UKHPR1000-054 (Ref. 58) and combined hazards report (Ref. 227) I noted the following:

- The RP had identified two locations in the fuel building where horizontal valves were present. This was in my view contrary to the screening assumption presented in the combined hazards analysis report (Ref. 227) which stated that valve missiles could only strike the ceilings of the rooms, hence only vertical valves were anlaysed by the RP. In my view, the omission of horizontal valve missiles may present additional challenges to barriers, civil structures or other SSCs, which the RP does not appear to have considered. The RP provided further information and analysis in response to my queries in RQ-UKHPR1000-1722 (Ref. 232) and RQ-UKHPR1000-1724 (Ref. 233), which indicated that no divisional barriers will be impacted by horizontal missiles. Although no detailed analysis or evidence was provided, I was satisfied that for the missiles sampled there was not a significant risk gap.
- In the response to RO-UKHPR1000-054 (Ref. 58) the RP identified a case where a dropped load may lead to a pipe whip and the combined loads would impact the floor of the room. A load combination of this type had not been considered in the combined hazards report (Ref. 227). In RQ-UKHPR1000-1722 (Ref. 232) I asked how this potential new load case had been fed back to the combined hazards assessment. In response the RP argued that the combined load case did load the divisional barriers, however this response did not address the potential impact to non-barrier structures such as the floor. This is a gap I have already highlighted and is captured as part of AF-UKHPR1000-0074.
- In RQ-UKHPR1000-1722 (Ref. 232) I also queried why the response to RO-UKHPR1000-054 (Ref. 58) did not identify a hydrogen hazard source in one room of the fuel building (room BFX1520ZRM). The RP acknowledged the explosion type hazard scenario, stating that this scenario is bounded by another similar room containing hydrogen pipework. Based on the RP's response I was satisfied that its bounding argument was acceptable, and I have assessed the hydrogen hazards in detail in the explosion section of this report.

985. Taking account of the above findings and the RP's responses to RO-UKHPR1000-053 (Ref. 57), RO-UKHPR1000-54 (Ref. 58), RQ-UKHPR1000-1722 (Ref. 232) and RQ-UKHPR1000-1724 (Ref. 233), I am satisfied, that for the purposes of GDA, the RP has provided an adequate combined hazards case to address the most likely combined hazards. Where queries have been raised, and through the RO work, I have confidence that the shortfalls identified can be addressed. However, further analysis and evidence will be required at detailed design and I do not consider this significant enough to undermine my overview of the adequacy of the combined hazards case for the purposes of GDA. I have identified the following combined hazards Assessment Finding in line with SAPs EDR.2, EHA.6 EHA.7, EHA.18, EKP.5, ELO.4 and FA.7 to address the shortfalls identified.

AF-UKHPR1000-0074: The licensee shall, as part of detailed design, address the gaps identified in GDA concerning combined internal hazards analysis, including but not limited to:

- The potential for event sequences resulting from domino effects.
- The potential for single and combined hazards to spread to adjacent buildings.
- The effects on load bearing structural elements.
- Prevention or mitigation of escalating event sequences.
- Justification of the worst-case scenarios.
- Validation of the assumptions of the containment of hazards in discrete rooms for hazards other than fire and flooding.
- Demonstration that the appropriate safety functional requirements for all relevant structures, systems and components are derived for combined internal hazards.

4.9.3.2 Combined Hazards Initiated by External Hazards

986. The RP’s combined hazards analysis initiated by external hazards (Ref. 228) identified and screened hazard combinations with external hazards as the initiator. A matrix was presented which indicated several combinations requiring further assessment. These were:

External Hazard	Internal Hazard
Earthquake (E1)	Internal Fire
Earthquake (E1)	Internal Explosion
Earthquake (E1)	Internal Flooding
Earthquake (E1)	High Energy Pipe Failures
Earthquake (E1)	Internal Missiles
Earthquake (E1)	Dropped Loads
Extreme Flooding (E2)	Internal Flooding
Extreme Hail, Sleet, Snow, Icing (E8)	Internal Flooding

987. All other potential external to internal hazard combinations were screened out for further assessment at detailed/ site specific design stages when further, more detailed, plant and site layout information will be available.

988. It should be noted that ONR defines Internal Flooding as initiated within the site, for example something over which the licensee has control. Hence ONR does not consider the hazard combinations generated by E2 and E8 to result in internal

hazards, as the 'internal flooding' is caused by the external floodwater entering the building rather than by failures of internal plant. These hazard combinations are therefore assessed in the ONR External Hazard Assessment Report (Ref. 156) which addresses measures for keeping water out of the plant buildings.

989. The only External to Internal hazard combinations considered by the RP in the external combined hazard report (Ref. 228) are therefore the six earthquake (seismic) induced internal hazards listed above.

990. The external combined hazard report (Ref. 228) described the RP's approach, recognising that the analysis of internal hazards resulting from an external hazard initiator depends on details of the plant items and system and building layout. The RP claimed that for the reference design, it had looked at the effects of internal explosion, internal flooding, high energy pipe failures and internal missiles caused by earthquakes. The RP's view was that the risks can be tolerated, and no further action was required in GDA phase. I was satisfied that for the purposes of GDA, this was an acceptable position, as this would need to be revisited at both the detailed and site-specific stages. Therefore I consider this as part of normal business.

991. The RP's report then referenced further work to be undertaken to consider these combinations. Earthquake induced internal fire was specifically addressed by ONR in RO-UKHPR1000-055 (Ref. 112) and hence is reported in the fire section of this report. The RP also addressed earthquake induced dropped loads in response to RO-UKHPR1000-055 (Ref. 182) which concluded that:

> "The main targets impacted by the crane swing loads are pipes related to the lifted items, HVAC items and JPI pipes and valves. If swinging loads impact HVAC items, this may cause a loss of cooling water for one operational train and, as a consequence, the safety related ventilation systems may fail".

992. The RP also stated that; "a commitment can be made in the site-specific stages that if an operating crane can cause more than one train to fail, administrative measures shall be established to control the lifting operation". Furthermore, the RP stated; "the JPI system is a defence in depth fire protection measure and it is not claimed to be functional in the RP's hazards analysis, hence the RP assume that the failure of JPI pipe is considered to be acceptable".

993. The earthquake induced dropped loads report (Ref. 182) also highlighted that design changes will be required but that these could be impacted by site layout changes, hence the RP concluded that:

> "A robust ALARP study would need to analyse the full impact of layout changes on all items, so the relative costs of each option can be understood and compared to the safety benefit. Better informed decisions on the preferred options can be made in the site-specific stage. The analysis of earthquake induced swinging and collapsed loads will need to be considered for all items in all buildings in the site-specific stage".

994. I judge that the RP's position is acceptable for the purposes of GDA, for external hazards induced combined hazards. However, a further in-depth assessment is required during the site-specific stage to ensure all potential external to internal hazard combinations are fully analysed and minimised to reduce risks in line with the ALARP principle. This will be followed up during normal regulatory business.

4.9.4 Summary of Assessment and Affirmation of PCSR Claims

995. For combined hazards the RP has undertaken, for the purposes of GDA, sufficient analysis to provide confidence that there are no significant combined hazard risks that undermine the conclusions drawn from the various individual hazard analysis. I have

sampled specific aspects of the combined hazards case and I have identified various shortfalls, and one Assessment Finding to address the gaps identified.

4.9.4.1 Affirmation of Claims for the Combined Hazards Safety Case

996. This section provides a summary of my assessment of the principal claims associated with the combined hazards case.

- Sub-claim 3.2.1.SC19.1: The individual internal hazards and hazard combinations that can potentially cause initiating faults and thus affect nuclear safety are sufficiently identified.

997. I have been satisfied that the RP has adequately identified the appropriate types of hazard combinations, independent, consequential and correlated. For the consequential and correlated, I was satisfied that the methodology implemented was appropriate and as such I was satisfied that for the purposes of GDA sufficient combinations had been identified to indicate that there are no significant combined hazard risks. I have identified shortfalls in the RP's screening and hazard identification approach that need to be addressed at later design stages once further design information is available.

- Sub-claim 3.2.2.SC19.2.26 (Hazard Combinations): After the safety assessment, the safety measures to mitigate the consequences of hazard combinations are sufficiently identified and properly classified.

998. I have been satisfied that the RP, for the areas screened in for assessment, has identified and characterised the hazard loads, and identified the relevant safety measures, predominantly barriers, to mitigate the escalation of the hazards. I identified a shortfall related to analysis of combined loads on non-barrier load bearing structural elements, which was adequately addressed by the RP as part of its response to RO-UKHPR1000-054.

- Sub-claim 3.2.2.SC19.2.27 (Hazard Combinations): The safety measures to mitigate the consequences of hazard combinations are sufficiently substantiated

999. I identified a number of shortfalls regarding safety measure substantiation; a number of these were addressed through the RP's response to RO-UKHPR1000-054 and UKHPR1000-055. For the remaining shortfalls I have raised Assessment Finding AF-UKHPR1000-0074 for the licensee to address at both the detailed and site-specific stages.

4.9.5 Combined Hazards Safety Case Strengths

1000. Through my assessment recorded above, I have noted the following strengths in the RP's combined hazards case.

- The RP defined a combined hazards methodology that is consistent with relevant good practice.

4.9.6 Outcomes

1001. I have been satisfied that the RP's approach for combined hazards is adequate for the purposes of GDA. However, I recognise that some gaps remain in the RP's analysis that should be addressed at detailed and site-specific design stages. To ensure appropriate regulatory oversight on these gaps I have raised Assessment Finding AF-UKHPR1000-0074.

4.9.7 Conclusions

1002. Based on the outcomes of my assessment of the RP's combined hazards safety case, I have concluded that the methodology and its implementation in the safety case is adequate for the purposes of GDA. I have identified various gaps in the safety case and addressed this through an Assessment Finding. I do not judge that these gaps are significant enough to prevent issue of a DAC, as I am confident that they can be addressed by the licensee at detailed and site-specific stages.

4.10 Other Hazards

1003. This section provides a summary of my assessment for other hazards that fall within the scope of internal hazards but for the purposes of GDA has not been subject to deep sliced sampling.

4.10.1 Turbine Disintegration

1004. The RP presented the principal turbine disintegration safety case evidence for the generic UK HRP1000 design within the 'Turbine Disintegration Safety Assessment Report' (Ref. 234). Supplementary information was provided in the internal missiles methodology (Ref. 192) and in the RP's ALARP Demonstration Report (Ref. 33).

1005. The documents provided by the RP listed above presented consideration of the failure modes for a generic turbine, including ageing mechanisms and overspeed failures. An illustrative layout of the Turbine Hall was included, although this is outside the scope of GDA. The RP's reports also discussed potential missile characteristics such as the size and number of fragments, missile ejection angles, and the velocity of fragments leaving the casing. The assessment presented comprehensive information on a generic missile comprising a 1/3 of the low pressure (LP) rotor disc as well as the potential effects from a 1/4 LP rotor disc.

1006. The RP listed SSCs which could be affected by turbine disintegration and identified the corresponding buildings housing these systems. The RP's evaluation (Ref. 234) was based on the discussion and presentation of:

- Failure modes of the turbine.
- Probability of failure of the turbine.
- Consequences of turbine missile impact.
- Demonstration that the risks form turbine disintegration are reduced ALARP.

1007. The RP presented (Ref. 234) the impact result for turbine missiles on the BSC, BFX and BRX building for 1/4 and 1/3 LP discs considering different impact orientations on the flat roof of the BSC and BFX building. In all cases the RP concluded that the ceiling barriers or outer protective containment was perforated and in most cases the missile was stopped by that initial impact. However, the RP determined that for two cases within the BSC building, missiles may penetrate the ceiling but will be stopped by the floor below, and due to the low residual velocity following the penetration, the impact on the floor would not cause scabbing affecting items in the rooms below.

1008. I discussed the potential impact to the BSC with the ONR Mechanical Engineering Inspector (Ref. 163) who raised RQ-UKHPR1000-1598 (Ref. 107) querying the potential for turbine missiles to impact HVAC systems. In response to RQ-UKHPR1000-1598, the RP stated that although there is a potential for the DVL systems to be impacted, no safety function is lost and that all three trains of the DVL cannot be impacted and simultaneously lost. I am content that the response provided is suitable for GDA and further analysis can be undertaken as part of normal business following the finalisation of the turbine hall design.

1009. In summary, I am satisfied that the RP has provided adequate evidence of hazard identification and screening process for the internal missile hazard from turbine failures.

4.10.2 Vehicle Impact

1010. The RP addressed the potential for vehicle impacts in its ‘Vehicular Transport Impact Safety Assessment Report’ (Ref. 235). The report outlined that the RP’s hazard protection strategy to mitigate against vehicle impacts was to reduce the probability of vehicle impact. The prevention measures credited by the RP included:

- Specified safe routes for all material movements on site.
- Suitable operating restrictions (e.g. speed restriction and access restriction via security controls).
- Use of suitably trained and experienced drivers.
- Periodic inspection of vehicles.
- Vehicle impact barriers mainly located externally.

1011. The RP’s assessment considered the potential for criteria A, B and C scenarios; hence the RP sought to identify potential scenarios in which vehicle impacts could lead to damage to divisional barriers, redundant safety trains or impacts to High Integrity Components.

1012. The RP’s vehicular transport impact safety assessment (Ref. 235) mainly focused on the collision of the vehicles on the divisional barriers or the SSCs important to safety. All vehicles that may move on site during normal operation and maintenance were considered.

1013. The exterior of buildings close to transport routes were claimed as protection barriers limiting the vehicular transport impact external to building. These barriers (building structure) were claimed to reduce impacts and hence protect the SSCs important to safety contained within the buildings.

1014. Where vehicles enter buildings, the boundaries of the rooms in which vehicular movements are allowed were also claimed as barriers to limit the consequence of vehicular impact to one train of the systems delivering the safety functions.

1015. The report (Ref. 235) concluded that, due to plant layout, HIC are located internally away from potential vehicle routes and hence cannot be impacted by vehicles.

1016. I raised RQ -1093 (Ref. 236) to better understand the claims, arguments and evidence presented by the RP. I particularly queried the potential for vehicle impacts to cause radiological releases and to damage firefighting equipment and gas lines. In response (Ref. 236), the RP claimed that sufficient protection existed due to layout distances and barriers, and that these prevented radiological releases. In addition, the RP’s safety case did not claim firefighting equipment to protect SSCs against internal fires, and no external gas lines important to safety are located such that they can be impacted by vehicles. Whilst I am content with this response for GDA, I would expect this to be reviewed at the site-specific phase, when the full detail of the plant layout will be known. In my judgement potential vehicle impacts should be included in decisions on plant layout during the site-specific design phase. This may be followed up during normal regulatory business.

1017. I am content that the RP has presented sufficient claims, arguments and evidence for GDA to indicate that direct vehicle hazards can be prevented or controlled, noting that additional assessment will be required during the site-specific detailed design stage.

4.10.3 Electromagnetic Interference

1018. The scope of assessment for EMI for internal hazards is to determine if the RP has an adequate methodology for the identification of EMI hazards. EMI as a hazard may interrupt, obstruct, degrade, or limit the performance of electrical and control and instrumentation (C&I) circuits performing nuclear safety significant functions and therefore impact nuclear safety.

1019. EMI hazards are principally considered by ONR Electrical and C&I inspectors where they relate to the specification or functionality of electronic equipment. However, the consequences of EMI may impact on claims made in the safety case and hence can be considered as an internal hazard.

1020. The RP's EMI methodology (Ref. 237) clearly defined its scope and highlights EMI hazards that could be fault initiators. It highlights that the system design should incorporate segregation, shielding of equipment and resilience through functional countermeasures. I judge that the RP's methodology approach for the protection of EMI is methodical and meets internal hazards expectations of ONR SAPs EHA.1 and ESS.1. This aspect is addressed further in the C&I report (Ref. 238), where the C&I assessment concurs with my judgements. However, the C&I assessment has raised Assessment Finding, AF-UKHPR1000-0029, to ensure that EMI control measures are adequately implemented during the site-specific stages.

1021. To ensure that the RP had undertaken a joined-up approach in the assessment of EMI, I raised RQ-UKHPR1000-0875 (Ref. 239) to determine the golden thread of evidence. The RP's response confirmed that:

> "…the lifecycle process that the UK HPR1000 shall adopt for assessing, mitigating and managing EMI, culminating in a validated EMC Safety Case at the end of site specific stage…is based on the principles of electromagnetic resilience defined in the IEC functional safety standard (BS EN 61000-1-2, Electromagnetic compatibility (EMC) Part 1-2: General — Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena) and the IET Code of Practice…".

1022. This response detailed above, provided me with confidence that the RP has in place a clear strategy for the assessment of EMI which in my view is consistent with the methodology presented (Ref. 237).

1023. The RP's methodology (Ref. 237) can be summarised as follows:

- Define Area: including a definition of general layout and equipment.
- Identification of SSCs potentially affected.
- Identification of EMI sources and effects.
- Identification of mitigation measures.
- Demonstration that risks are reduced to ALARP.

1024. In addition to consideration of EMI during design and construction, the RP also recognised that changes in technology throughout the design life of the plant could lead to new EMI threats being introduced. Therefore, the RP stated that the assessment and management of EMI hazards will be required for all future changes in service. I consider this to be good practice and is a positive element to the RP's strategy.

1025. The RP identified the following standards that have been used to inform its methodology:

- BS EN 61000 (Ref. 240) and BS IEC 62003:2009 (Ref. 241) for hazard identification of sources.
- BS EN 61000 series of standards to classify EMI environments.
- BS IEC 62003:2009 to inform the severity of the hazard.

1026. These standards are recognised as relevant good practice, however, it is noted that some of the standards quoted by the RP has already been superseded, such as BS IEC 62003 2009 being updated to BS IEC 62003:2020 (Ref. 242). At detailed design, I expect that the licensee will ensure that appropriate up to date standards are used and I consider this normal regulatory business. In summary, I have assessed the methodology presented by the RP for the identification and control of EMI hazards and I deem it appropriate for the purposes of GDA, as it has satisfied the requirement to ensure EMI hazards are captured and assessed.

4.10.4 Toxic and Corrosive Materials and Gases

1027. The RP addressed the potential for hazards from toxic and corrosive materials and gases in its ‘Toxic and Corrosive Materials and Gases Safety Assessment Report’ (Ref. 243). The scope of the RP’s analysis included the following three hazard effects for toxic and corrosive materials and gases:

- Toxic effects, as they could be harmful or fatal and hence disable personnel carrying out actions important to safety.
- Asphyxiation effects, as they could cause a reduction in the amount of oxygen available and hence disable personnel carrying out actions important to safety.
- Corrosion effects, as they could cause corrosion to SSCs important to safety.

1028. The RP’s case considered the impact of the above effects on the nuclear safety functions performed by buildings within the GDA.

1029. Whilst the RP did not undertake detailed evaluations, the report (Ref. 243) included arguments relating to the effects of gas releases causing failure of back-up diesel generators due to reduced oxygen levels, and the toxic and asphyxiant effects of fire products.

1030. The RP selected nitrogen as a bounding case asphyxiant due to the large quantities used and stored. The RP also considered the effects of carbon dioxide. Both substances are located in the general gas storage area. For toxic gases, hydrazine hydrate was selected as the bounding case/ substance. This is located in the Chemical Dosing Room which is in close proximity to the Safeguard Buildings. The RP also considered ammonium hydroxide due to the large quantity and high concentrations used within the design.

1031. A key assumption made in the RP’s case (Ref. 243) was that delivery vehicles would be well-controlled. Therefore, the RP considered that the vehicles would not leave their designated route such that vehicles become closer to the nuclear significant buildings than the bulk storage compound (which was assessed as the bounding case). The RP discussed the potential for delivery vehicles to leave their designated routes and a major release occurring closer to safety significant buildings. The RP identified defence in depth measures to control and mitigate these risks including control of delivery operations and the shutdown of the MCR intakes for long duration releases.

1032. The RP’s analysis used storage capacities and conditions together with conservative assumptions based on the reference design. At the site-specific project phase this analysis will need to be reviewed and assessed to ensure that the appropriate site data is accurately reflected. This may be followed up during normal regulatory business.

1033. The RP’s analysis report (Ref. 243) concluded that:

- The consequences of toxic and corrosive gases and materials do not threaten the fulfilment of safety requirements by SSCs and by personnel in the MCR.
- Confidence has been provided that the site-specific layout for the bulk storage of toxic gases can be located at a safe distance from nuclear significant buildings.
- Provision of safe separation and further defence in depth measures (relating to both toxic gases and corrosive materials) ensures the risk is reduced to ALARP.

1034. I raised RQ-UKHPR1000-1094 (Ref. 244) to query a number of areas, including the potential for the missiles from turbine disintegration to cause toxic gases or corrosive materials releases. The RP's response (Ref. 244) stated that in the unlikely event of missiles induced by turbine disintegration impacting the gas storage and chemical warehouse, the effects of any release can be enveloped by the analysis undertaken (Ref. 243). I am content with the RP's response that the consequences will be bounded by the worst-case scenarios already assessed. However, I would expect this to be reviewed, by the licensee, and fully assessed during detailed design since the plant and layout away from the sampled buildings is outside the scope of the GDA. This should be followed up during normal regulatory business.

1035. In RQ-UKHPR1000-1094 (Ref. 244) I also queried some of the RP's analysis assumptions regarding potential scenarios in which operators may be incapacitated by toxic gases or corrosive materials releases. In response, the RP confirmed that releases of nitrogen and ammonium hydroxide can only reach the exterior of the nearest occupied building (the safeguard building). The nitrogen and ammonium hydroxide releases were considered unlikely to incapacitate personnel carrying out manual operations (due to the modelled concentrations in air) and hence the toxic and corrosive materials and gases release hazard will not impact nuclear safety. I am content that this response is adequate for GDA purposes. However, this will require further assessment and substantiation during detailed design with data relating to the chosen layout of plant in areas away from the sampled buildings. This should be followed up as part of normal regulatory business.

1036. I am content that the RP has presented sufficient claims, arguments, and evidence for GDA to indicate that risks from the release of toxic and corrosive materials and gases can be prevented and or controlled, noting that additional assessment will be required during detailed design.

4.10.5 Assessment of Other Buildings

1037. The RP produced an assessment of internal hazards in buildings other than the principal GDA scope buildings in its 'Safety Assessment Report for Buildings Important to Safety within GDA Scope (other than BSX/BRX/BFX)' (Ref. 245). Internal fire, internal explosion, internal flooding, high energy pipe failure, dropped loads and internal missiles were all addressed in the RP's analysis report (Ref. 245) and identical hazard methodologies were applied by the RP as for the GDA scope buildings. Additional review of the hazard specific methodologies is not necessary as my assessment of these in the specific hazard sections above remains valid.

1038. The buildings assessed within the report (Ref. 245) were screened for Class 1 and Class 2 systems:

- Buildings which contain the radiological inventory:
    - Nuclear Auxiliary Building (BNX).
    - Personnel Access Building (BPX).
    - Radioactive Waste Treatment Building (BWX).

- Buildings which do not contain the radiological inventory:
  - Emergency Diesel Generator Building A (BDA).
  - Emergency Diesel Generator Building B (BDB).
  - Emergency Diesel Generator Building C (BDC).
  - SBO Diesel Generator Building for Train A (BDU).
  - SBO Diesel Generator Building for Train B (BDV).
  - Extra Cooling System and Fire-fighting Water Supply System Building (BEJ).
  - Equipment Access Building (BEX).

1039. The RP’s assessment was based on the same three criteria used throughout the GDA internal hazards assessments. The assessment was effectively reduced to just criterion A (hazard scenarios which have the maximum hazard loadings to potentially cause damage to the claimed barriers) as criteria B and C were discounted on the basis that the exception to segregation areas and the location of HIC are not relevant to these other buildings. In my judgement this approach is appropriate for GDA.

1040. I raised a number of queries related to the safety assessment of the emergency diesel generator buildings in RQ-UKHPR1000-1472 (Ref. 246). I specifically queried the consequences of fire addressed in IH-IF-BDX-01 which can cause the loss of two redundant emergency diesel generators (EDG). In response (Ref. 246) the RP noted that for GDA the bounding case selection criteria for internal hazards assessment focused on the impact on claimed safety measures, rather than defence in depth measures.

1041. I also questioned the identification of safety functional requirements of barriers between diverse safety relevant systems. In response (Ref. 246) the RP stated that the

- Three emergency diesel generators in BDA/BDB/BDC provide backup for each other.
- Since BDB is segregated with BDA and BDC by distance, a fire cannot impact the three emergency diesel generators at the same time.
- Defence-in-depth measures (such as fire detectors and fixed firefighting systems) control the fire spread (these are not claimed as safety measures).

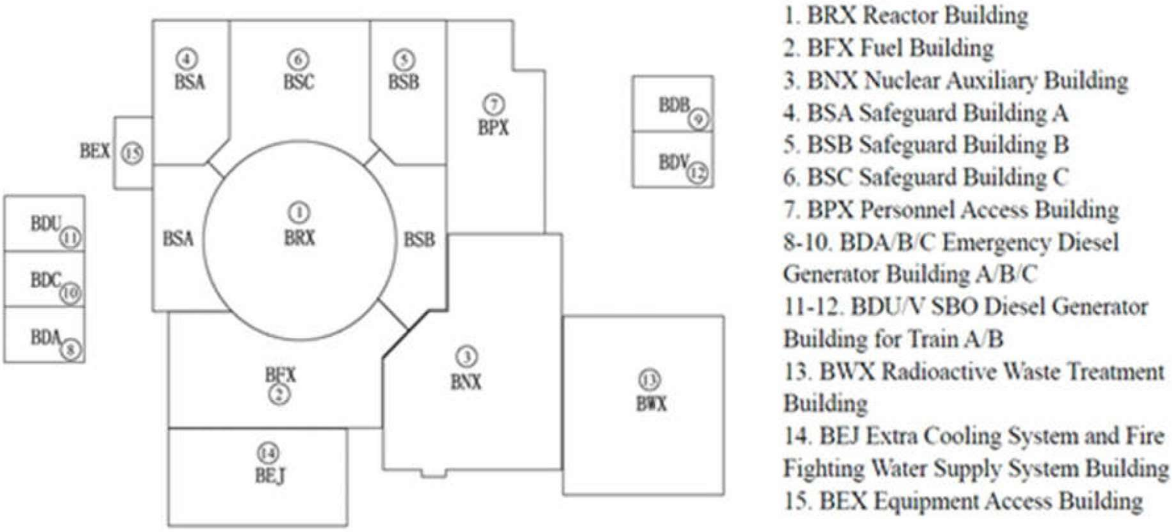

Figure 11: Generic UK HPR1000 GDA Building Layout

1042. In order to clearly understand the RP's response, I reviewed the generic GDA building layout provided in the generic plant description report (Ref. 125) and presented in figure 11 above. This figure clearly shows that building BDA and BDC are located next to each other on the left-hand side of the reactor building, with BDB being located in a completely separate place, on the other side of the reactor building. I have reviewed the RP's response (Ref. 246) together with the generic building layout and in my judgement this RQ response is acceptable for GDA, however further analysis and consideration of other potential internal hazards, such as flood and turbine disintegration as well as defence in depth measures will be required during detailed design. This analysis should address the potential for EDGs to be unavailable due to maintenance or following other failures. In addition, the design and location of the EDGs is subject to the licensee's choice. I have therefore raised the following Assessment Finding, to meet the expectations of ONR SAPs ESS.2 and ELO.4, to be addressed at detailed design when the licensee is finalising the building layout and the detailed design safety case.

> AF-UKHPR1000-0075**:** The licensee shall, as part of detailed design, demonstrate that the risks to the emergency diesel generators, from all internal hazards, are reduced to as low as reasonably practicable, and that the generators are adequately segregated.

1043. Overall, the RP has provided sufficient evidence of adequate hazard identification and of a screening process for the internal hazards in buildings other than the principal GDA scope buildings. The scenarios identified for further analysis or bounding are deemed adequate and provide confidence that the principal risks to these buildings from internal hazards have been captured.

1044. Hence in my judgement the internal hazards safety assessment report in combination with additional information provided in response to RQs provides an adequate GDA assessment of the internal hazard safety case for these buildings.

4.10.6 Other Hazards Safety Case Strengths

1045. Through my assessment recorded above, I have noted the following strengths in the RP's other hazard cases.

- The RP has applied relevant good practice for the assessment of turbine disintegration, vehicle impact, electromagnetic interference and toxic and corrosive materials and gases.
- The RP has considered the impact on internal hazards for other buildings across the generic UK HPR1000 site. The RP applied a consistent approach in the hazard identification and screening of internal hazards in line with its assessment criteria and I judge this adequate for the purposes of GDA.

4.10.7 Outcomes

1046. I have been satisfied that the RP's approach for the hazards and areas detailed above is adequate for the purposes of GDA. I have identified one shortfall where I have raised an Assessment Finding related to the siting of the backup diesel generator buildings to be addressed at the site-specific stage.

4.10.8 Conclusions

1047. Based on the outcomes of my assessment detailed above, I have concluded that the RP has presented an adequate case for the purposes of GDA. I have identified one Assessment Finding, but I do not judge that this is significant enough to prevent issue of a DAC, as I am confident that it can be addressed by the licensee at the site-specific stage.

4.11 Regulatory Observations

4.11.1 Overview

1048. Throughout the ONR GDA assessment, the RP provided a number of submissions to describe the generic UK HPR1000 safety case, which were related to the generic UK HPR1000 plant and building layouts. As I carried out my assessment, I raised a number of queries for additional information to underpin various aspects of the RP's internal hazards safety case. Where I identified potential regulatory shortfalls which required action and new work by the RP to be resolved, I raised Regulatory Observations.

1049. In the earlier sub-sections of section 4 of this assessment report I have referred to information provided by the RP in response to these ROs. The ROs were based on my sampling assessment approach and were designed to obtain confidence in specific aspects of the internal hazards safety case.

1050. The ROs I raised cover the fundamental aspects of the internal hazards case particularly where I judged significant shortfalls had been identified, covering:

- The provision of evidence to support bounding case justifications – RO-UKHPR1000-053 (Ref. 174).
- The validation of internal hazard loadings used for civil engineering of non-barrier elements – RO-UKPR1000-054 (Ref. 98).
- The consequential internal hazards resulting from seismic events – RO-UKHPR1000-055 (Ref. 110).
- A demonstration that the Risks to HIC Components from Internal Hazards are Reduced to ALARP Identification of safety measures – RO-UKHPR1000-046 (Ref. 88).

1051. This section of my report covers the key findings from these ROs.

4.11.2 RO-UKHPR1000-053 – Provision of Evidence to Support Bounding Case Justifications

4.11.2.1 Background

1052. This section summarises my assessment of submissions provided by the RP in response to Regulatory Observation RO-UKHPR1000-053 – Provision of evidence to support bounding case justifications (Ref. 174).

1053. ONR's expectation of any safety case is that it shows that risks have been reduced to ALARP, and this includes those nuclear safety risks associated with internal hazards. This should be underpinned with robust evidence providing a clear description of the plant and layout of SSCs within the safety case.

1054. The RP's safety case included internal hazard reports presenting representative bounding cases of the internal hazards in the safeguard buildings, fuel building and the reactor building. During my initial assessment of these safety case reports I found it difficult to assess the identification of hazards and the selection of bounding cases without data on the rooms, their interconnectivity and the SSC's included within them. To address these shortfalls, I raised RQ-UKHPR1000-1031 (Ref. 196) to understand how the 3D model links to the analysis and RQ-UKHPR1000-1532 (Ref. 247) to get clarity on how the data taken from the 3D model underpins the analysis.

1055. In response to these RQs the RP stated that the safety case analyses had relied upon access to the 3D model (Ref. 196), but the generic UK HPR1000 model would not be submitted as evidence to underpin the ONR GDA assessment (Ref. 247). Based on the RPs responses I raised RO-UKHPR1000-053 to ensure that the RP provided adequate information, for sample areas, to enable me to understand and assess the internal hazards aspects of the safety case.

1056. My sampling approach for RO-UKHPR1000-053 focused on the building with the greatest radiological risk, the BRX.

1057. The RP's response to RO-UKHPR1000-053 comprised the following documents:

- The RP's resolution plan for RO-UKHPR1000-053 (Ref. 248).
- Justification of internal hazards for the sampled areas (Ref. 57).
- Room data sheets for the sampled areas (Ref. 77).
- Detailed room drawings (Ref. 78).

4.11.2.2 Delivery of RO Tasks

1058. I have detailed my assessment of the RO-UKHPR1000-053 submissions in an assessment note (Ref. 249) and in the corresponding hazard sections of this report, where applicable. Sample hazard areas assessed were fire, flooding, dropped loads, missiles, and high energy pipe failure.

1059. Following my challenge, the RP provided relevant 2D drawings from the 3D model (Ref. 78) to provide the source data for the room data sheets. This provided evidence to demonstrate that the RP's 3D model has the required level of detail to ensure that the RP's analysis was representative of the generic UK HPR1000 design.

4.11.2.3 Conclusions from the Assessment

1060. In my judgement the RP has demonstrated that a suitable and sufficient evidence basis exists to provide confidence in the data and plant descriptions described within the IH safety case and therefore the purpose and intent of the RO has been addressed. I therefore formally closed RO-UKHPR1000-053, the rationale for which is captured in the RO assessment note (Ref. 249), and confirmed in a formal letter to the RP (Ref. 250).

1061. In summary I am satisfied that the RP's approach and overall suite of submissions in the delivery of this RO provides a narrative and evidential basis in line with relevant good practice. I consider that the RP's approach, with this level of detailed evidence, should be adopted for the IH assessment at detailed design when the 3D model is updated to reflect the latest plant state in order to satisfy SAPs SC.2, SC.4, EHA.2 and AV.5. As this work needs to be progressed at the later design stages, I consider this can be addressed as part of normal business.

4.11.3 RO-UKHPR1000-054 - Validation of Internal Hazard Loadings Used for Civil Engineering of Non-barrier Elements

4.11.3.1 Background

1062. This section summarises my assessment of submissions provided by the RP in response to Regulatory Observation RO-UKHPR1000-0054 – Validation of internal hazard loadings used for civil engineering of non-barrier elements (Ref. 98).

1063. Analysis of internal hazards provides a key input into the civil engineering design, as hazard loadings (for example fire, explosion etc.) need to be clearly defined such that structural barriers and other civil structures may be substantiated to withstand these loads. Through my assessment of the RPs safety case, I noted that only divisional barriers had been assessed against the bounding loads, however it was unclear if the other load bearing walls within the compartment (or others), had been assessed; to get clarity on this I raised RQ-UKHPR1000-0943 (Ref. 251). In response to the RQ (Ref. 251) the RP confirmed that it had not assessed load bearing elements other than the claimed divisional barriers. Based on the RPs response I raised RO-UKHPR1000-054 to ensure, for a sample area, that this gap does not impact the safety case.

1064. Following consultation with the ONR civil engineering inspector, I elected to sample the fuel building which contains the spent fuel pond. Within the RO I requested that the RP should provide hazard loads on civil structures for the sample areas of the rooms below the spent fuel pool (fuel building). I asked that the RP's response covered the following aspects:

- Demonstration that the loads applied were appropriately bounding. I requested evidence to support the approach/process of identification and the characterisation of internal hazard loads on the non-barrier civil structures in the sample areas.
- Information on the plant and layout in the sampled area documented in the form of room datasheets for each room using the format generated in response to Regulatory Observation 053.
- Calculation of the hazards loads on the non-barrier structures in the sampled areas and justification that the loads could be bounded by the decoupled load used in civil engineering analysis.

1065. In response the RP provided the following documents:

- The RP's resolution plan for RO-UKHPR1000-054 (Ref. 252).
- Validation report of internal hazard loadings used for design of non-barrier elements (Ref. 58).
- Detailed rooms drawings (Ref. 78).

4.11.3.2 Delivery of RO Tasks

1066. I assessed the submissions to address RO-UKHPR1000-054 and I have reported my detailed assessment in the corresponding hazard sections of this report and the corresponding assessment note (Ref. 253).

1067. Based on the evidence reviewed, I am satisfied that the RP had delivered sufficient evidence to underpin the bounding hazard loads for the identified hazards within the sample areas (Ref. 58). This satisfies SAPs EHA. 2, 6, 14 and 19.

1068. I am satisfied that the RP has provided adequate evidence to demonstrate that its hazard identification and characterisation has been comprehensive and systematic and, based on the evidence provided in detailed drawings (Ref. 78), has satisfied SAP EHA.1.

1069. Whilst I am satisfied that the RP has provided enough evidence to support closure of RO-UKHPR1000-054, I identified several shortfalls regarding safety measures claimed to manage the hydrogen explosion hazard and the adequacy of the analysis to underpin the fire analysis. I raised Assessment Findings to capture these in the fire section (sub-section 4.3) and explosion section (sub-section 4.4) of this report. The hazard loading analysis for civil purposes is out of the IH scope and has been assessed separately by the ONR civil engineering team (Ref. 49).

4.11.3.3 Conclusions from the Assessment

1070. In my judgement the RP has now demonstrated sufficient rigour on this aspect of the IH safety case and therefore I conclude that the purpose and intent of the RO has been addressed. I therefore formally closed RO-UKHPR1000-054 the rationale for which is captured in the RO assessment note (Ref. 253), and confirmed in a formal letter to the RP (Ref. 254).

4.11.4 RO-UKHPR1000-055–Consequential Internal Hazards Resulting from Seismic Events

1071. This section summarises my assessment of submissions provided by the RP in response to Regulatory Observation RO-UKHPR1000-0055 –Consequential internal hazards resulting from seismic events (Ref. 110).

1072. The Requesting Party had undertaken a generic analysis of seismic initiators for a range of consequential internal hazards. These were reported in a series of earthquake analysis reports, (Ref. 255), (Ref. 256) and (Ref. 108). I assessed these reports and I identified that the methodology applied (Ref. 256), and associated analysis, did not consider all potential consequential hazards including dropped loads and internal fire. The exclusion of these hazards is not in line with relevant good practice as both hazards could impact multiple systems and components. Initially I raised my specific queries in RQ-UKHPR1000-832 (Ref. 109), but I judged that the response did not adequately address the analysis gaps.

1073. I therefore raised RO-UKHPR1000-055 to obtain demonstration, based on key examples, that the generic UK HPR1000 design is robust against consequential internal hazards initiated by an earthquake, and that the results reported in the earthquake safety evaluation reports are underpinned by a robust evidential basis. In RO-UKHPR1000-55 I asked the RP to provide:

- Documentation demonstrating that a detailed, comprehensive, and systematic identification had been undertaken, and the consequential internal hazard loads to targets as a result of a design basis seismic event had been characterised.
- Documentation to demonstrate that either the consequences from the identified loads on targets are bounded where appropriate by the existing hazard analysis, or, where this is not the case, to provide justification why the risks are tolerable.

1074. I raised RO-UKHPR1000-055 to ensure that the RP provided information to address the most significant gaps in the seismic induced hazards assessment, namely consequential dropped loads and fire. The RO sought to obtain confidence that seismically induced fire and dropped load hazards do not present a significant challenge to nuclear safety following a seismic event.

1075. I selected BSC as a sample building for seismic fire, to provide confidence that the MCR and RSS remain after the seismic event. For dropped loads, I selected BFX to determine if non-seismically qualified equipment could result in dropped loads that could adversely affect the integrity of the spent fuel pond. I also included BSB for consideration as it contains key exception to segregation areas.

1076. In response the RP provided the following documents

- The RP’s resolution plan for RO-UKHPR1000-055 (Ref. 110).
- Earthquake Induced Internal Fire Safety Evaluation Report (Ref. 59), (Ref. 112).
- Earthquake Induced Dropped Loads Effects Safety Evaluation Report (Ref. 182).
- Detailed rooms drawings (Ref. 78).

4.11.4.1 Delivery of RO Tasks

1077. I have assessed the RP's submissions to address RO-UKHPR1000-055 and I have reported my detailed assessment in an assessment note (Ref. 257) and the corresponding hazard sections of this report.

1078. Based upon my assessment, I am satisfied that the RP has delivered sufficient evidence to underpin its overall claims and arguments for the sample areas detailed. I am also satisfied that the RP has provided adequate evidence to demonstrate that the hazard identification and characterisation has been comprehensive and systematic, and based on the generic UK HPR1000 design and this is now captured within the suite of documentation provided.

1079. The RP provided information and data for the screening of the fire and dropped load hazard sources and the assessment of their impact to SSE1 systems. The RP has also provided sufficient safety case narrative and analysis and has adequately addressed the shortfalls identified. This satisfies SAPs EHA. 2, 6, 14 and 19.

1080. Although the RP has provided enough evidence to support closure of RO-UKHPR1000-055, several shortfalls have been identified regarding the categorisation of safety measures. These shortfalls are addressed by Assessment Findings and shortfalls raised earlier in this assessment report, and are summarised in the table in Annex 2.

4.11.4.2 Conclusions from the Assessment

1081. Based on the outcome of my assessment of the RP submissions, I judge that the RP has provided adequate evidence, for the purposes of GDA, to give me confidence in the data and plant descriptions described within the IH safety case for consequential internal hazards resulting from seismic events. I judge that the intent of the RO has been adequately addressed. I therefore formally closed RO-UKHPR1000-055, the rationale for which is captured in the RO assessment note (Ref. 257), and confirmed in a formal letter to the RP (Ref. 258).

4.11.5 RO-UKHPR1000-046 – Demonstration that the Risks to HIC Components from Internal Hazards are Reduced to ALARP

1082. This section summarises my assessment of submissions provided by the RP in response to Regulatory Observation 'RO-UKHPR1000-0046 – Demonstration that the Risks to HIC Components from Internal Hazards are Reduced to ALARP' (Ref. 88). In this section I refer to sections of this assessment report in which hazard effects on HIC have been covered, but this section is provided to summarise the RP's response to RO-UKHPR1000-046, and to consolidate discussion and findings relating to my assessment of the impact on HIC from internal hazards, as detailed within my RO assessment note (Ref. 259) that documents my rationale for closure of this RO.

1083. I raised RO-UKHPR1000-046 (Ref. 88) to obtain sufficient evidence from the RP to demonstrate that the risks from internal hazards to HIC have been reduced to ALARP. This is because based on my initial sampling of the various safety analysis reports there was insufficient detail to provide assurance that the risks to HIC had been adequately assessed. Therefore, to resolve this shortfall the RP was required to provide additional evidence to:

- Demonstrate that the layout of the generic UK HPR1000 design has been optimised to reduce the risks to HIC from internal hazards so far as is reasonably practicable.
- Demonstrate that those hazards that can impact HIC are adequately identified.

- Demonstrate that the hazard loads and consequences are adequately analysed.
- Demonstrate that, where hazards have not been eliminated, that the integrity of the HIC can be demonstrated.

1084. The RP's submission in response to RO-UKHPR1000-046 is comprised of the following documents:

- RO-UKHPR1000-046 Resolution plan (Ref. 260).
- HIC Substantiation Methodology Report (Ref. 143).
- Substantiation of Reactor Pressure Vessel (RPV) against IH (Ref. 261).
- Substantiation of Main Steam Lines (MSL) against IH (Ref. 89).
- Substantiation of Steam Generators (SG) against IH (Ref. 129).
- Substantiation of Pressuriser (PZR) against IH (Ref. 262).
- Substantiation of Main Coolant Lines (MCL) against IH (Ref. 263).
- Substantiation of Reactor Coolant Pump Casing and Flywheel (RCP) against IH (Ref. 118).
- ALARP Demonstration on Plant Layout in Respect to HIC (Ref. 155).

4.11.5.1 Delivery of RO Tasks

RO-UKHPR1000-046 HIC Substantiation Methodology

1085. The RP's HIC substantiation methodology report (Ref. 143) details the methodologies adopted by the RP to determine the impact of internal hazard loadings on to HIC. The report applies the same methodologies to derive the individual hazard loads as described in the relevant sections of this report and therefore these are not repeated here. However, the approach used by the RP to demonstrate the integrity of the HIC are discussed here.

1086. For fire hazards, the RP's methodology for deriving the severity of the fire load is described and assessed in sub-section 4.3.2 of this report. The RP's HIC integrity substantiation is dependent on demonstrating that the HIC temperature has not been raised above design temperature. The RP's methodology stated that the HIC are generally surrounded by thermal insulation which will act to prevent direct flame impingement and reduce heat transfer to the HIC. The RP stated that no formal credit is taken in the substantiation for the thermal insulation. Although I consider that as additional defence in depth, the approach defined by the RP, with respect to comparison to operational temperature, presents limited assurance. It is my view that the HIC withstand should be assessed against its relevant design codes. This is a shortfall against SAP ECS.3, which I have highlighted already in the fire section of this report and is captured in Assessment Finding AF-UKHPR1000-0057.

1087. For internal explosion the RP's analysis is based on RCC-M B3200 and B3600 (Ref. 80) which are the design code rules for the HIC mechanical pressure-retaining components. The methodology involves deriving the pressure loading and evaluating against the design code using either hand calculations or finite element methods. The method assumed that the blast precedes any other hazard load, and therefore is not treated in combination with other hazards.

1088. It is my view that the assumption that blast can be treated as an individual hazard is reasonable, as the shock wave will travel faster than the missiles generated. However, for substantiating HIC or SSC survival, it should be confirmed that the blast wave does not cause any permanent deformation of the HIC or SSC. Damage to the SSC could weaken it prior to impact by other forces such as jet impact, pipe whip or missile loads. This is identified as a shortfall against SAPs FA.3, FA.1, EMC.1, EMC.2 and EMC.3 in the RP's analysis. This shortfall is captured as part of Assessment Finding AF-UKHPR1000-0076 for the licensee to address as part of the detailed design.

1089. The RP's analysis of flooding loads focuses principally on immersion of HIC, with little consideration of other effects such as spray or dynamic / hydraulic forces acting on components. I have assessed the RP's approach and I judge this to be acceptable for GDA and I consider the omissions are a minor issue due to the HIC protective insulation. However, the effects of spray to other components should be considered and appropriate requirements set for qualification to ensure functions are not lost when SSCs are exposed to flooding effects, which is a shortfall against SAP ECS.1. I consider this as normal business to ensure appropriate safety functional requirements are established for all equipment supporting HIC at the detailed design stage.

1090. The RP's HIC analysis methodology for missile hazards utilised the R3 impact assessment procedure (Ref. 44), appendix G of which specifically deals with missile impacts on steel plates. R3 provides correlation formulae to test if real situations equate to empirically derived failure results. The formulae have specific applicability and I note that target deformation is not considered by the method.

1091. I am satisfied that the methods described in R3 appendix G are adequate to determine the severity of an impact. In my view the simplification of the impact cases to the level required in those methods provides a level of conservatism. However, R3 appendix G does not account for deformation to the target, which for a HIC may impact its integrity claims. This means that in cases where the impact energy is close to the calculated perforation energy, the R3 appendix G method alone does not provide adequate reassurance that the HIC, subject to operating conditions, will continue to retain integrity. The RP's approach for determining HIC withstand against Pipe whip is also based on the R3 impact assessment procedure appendix G for equipment targets (e.g. vessels) and Appendix I for pipe targets. My comments above relating to appendix G apply also for pipe whip impacts. However, the methods in Appendix I in my view are robust and I consider these adequate for this analysis.

1092. To address the absence of any deformation analysis, the RP extended its methodology to include deformation. For the impact cases relying on substantiation of HIC withstand, the RP applied an indentation/deformation calculation (Ref. 264) based on the R3 procedure appendix D plastic hinge methodology, that had been adapted by the RP for determining the consequences of the missiles impacting plates. This new approach was defined as R3 appendix K. I have assessed the revised methodology presented by the RP; I am satisfied that the additional method is sound in logic and provides additional assurance that the RP had taken account of deformation in non-perforation cases to provide further confidence in the integrity claims of the HIC. This satisfies SAPs EMC.1, EMC.2 and EMC.3.

1093. Jet impact loads are calculated by the RP based on the R3 impact assessment procedure volume 1 and assessed against requirements of B3238 of RCC-M code (Ref. 80). I am satisfied in this case that the combination of the R3 loading and substantiation against the relevant RCC-M code for the HIC provides a robust methodology and satisfies SAPs ECS.3 and EMC.1, EMC.2 and EMC.3.

1094. The RP's dropped load analysis adopted the R3 impact assessment procedure volume 3 which provides dropped load impact energy calculations to determine the resistance of reinforced concrete structures as well as metal plate target resistance (as discussed above for Missiles). In the case of the RPV head drop, the RP has extended its approach to include LS-DYNA finite element modelling to verify the RPV integrity. I am satisfied this provides an adequate basis for assessing the impact to the HIC and judge the methods appropriate, thereby satisfying SAP EHA.6.

1095. The RP’s combined hazards analysis approach for impacts on HIC had been limited to only two possibilities: fire causing High Energy Pipe Failure (HEPF), and HEPF induced by another HEPF. It is my view that given the complexity of the layout, there is a possibility that other hazard combinations could exist but have not been assessed as the layout has not been fully finalised. I have addressed shortfalls in the identification of combined hazards in sub-section 4.9 of this report.

1096. In conclusion, it is my view that the HIC substantiation methodologies involve adequate simplifications which add conservatism and provide an adequate basis for analysis of the damage to HIC for the purposes of GDA. Where shortfalls have been identified these have been assessed for each of the HIC components to determine the risk gaps and are detailed in my assessment below.

RO-UKHPR1000-046 Assessment of the Reactor Pressure Vessel

1097. The RP’s substantiation of the reactor pressure vessel against IH report (Ref. 261), presented a summary of the identified internal hazards that could challenge the RPV and contains analysis and evidence to substantiate the HIC integrity.

1098. The RPV HIC components covered by this assessment are the vessel, closure head and closure bolts. The Reactor internals are not considered. The RPV vessel is composed of several ferritic steel forgings (the core shell, nozzle /flange shell, lower head transition ring and lower head dome and nozzles). The nozzles and nozzle safe ends and welds are also included within the HIC classification. The vessel and closure head are clad internally with stainless steel. The RPV closure head includes the control rod drive mechanism adapter nozzles which are welded to the closure head. The CRDMs are not part of the HIC classification.

1099. The substantiation report (Ref. 261) highlighted from the RP’s hazard screening that the RPV is subject to fire, flooding and dropped load hazards. The scenarios related to fire (IH-IF-BRX-15) and flooding (IH-FL-BRX-09) are detailed in the relevant sections of this report. In both instances sufficient evidence was provided by the RP that no fundamental issues existed with the analysis, and that HIC integrity was demonstrated. However further evidence was required on the assurance of the functions of the watertight doors. This is captured in Assessment Finding AF-UKHPR1000-0066.

1100. For the RPV, the most challenging hazard identified by the RP was from dropped loads. During normal operation the RP stated that a protection slab is installed above the RPV to protect it from dropped loads and to protect other components from CRDM missile hazards, but this protection slab is removed during shutdown to enable access to the RPV for refuelling (Ref. 261). During refuelling outage, the RP stated that there are many lifts carried out which could result in dropped load impacts on the RPV.

1101. I acknowledge that these lifts are carried out only during shutdown, but it is my view that it needs to be demonstrated that the RPV maintains its ability, in hazard conditions, to maintain leak tightness and keep the fuel assemblies in a coolable geometry to enable continued cooling of the fuel. The RP’s analysis identified that the bounding load drop on the RPV was drop of the RPV head assembly onto the vessel itself (IH-DL-BRX-01). The RPV head assembly is the largest mass lifted over the vessel by a large margin, and therefore has the greatest potential to damage the RPV HIC.

1102. The RP’s analysis of the dropped RPV head on the RPV is detailed here, the impact of the head on to the reactor cavity is assessed separately in the dropped loads section of this report.

1103. The dropped load energy from the RPV head was calculated by the RP using the R3 impact procedure (Ref. 44) and used LS-DYNA finite element (FE) model to define a strain for the RPV vessel. The strain was then compared to the allowable strain according to the RPV design code RCC-M. As described above I consider this an adequate approach and the comparison of strains within the RPV design code provides confidence that the RPV integrity can be substantiated. This satisfies SAPs EMC.3, EHA.5 and EHA.6.

1104. The RP's results demonstrated that drop from the maximum lift height based on the reference plant lift path caused a strain beyond the RCC-M design limit and therefore was unacceptable to the RP's safety case. The RP then undertook an optioneering study and presented two alternative lift paths involving staged lifting of the RPV head assembly to partial heights and then moving it horizontally, so it is no longer directly above the RPV before raising it to the full height required to move it to its storage position (Ref. 261).

1105. From the options, the RP selected a complex seven-stage lift where the RPV head assembly is lifted above the RPV to clear the guide rods. At this drop height, the RP calculated that the dropped load was within the acceptable limits of the RCC-M design code and therefore the lift path was chosen on that basis. Once over the guide rods the head is moved horizontally within the reactor well until it is no longer above the RPV, then it is lifted to operating deck level and then moved in a radial (curved) path.

1106. From my sampling of this new lift path, I noted that the RPV head would be partially over the reactor well and partially over the operating deck before it is moved horizontally outwards, and then finally up and horizontally to its storage location. I therefore raised RQ-UKHPR1000-1507 (Ref. 265) to obtain further clarification on the proposed lifting path, analysis assumptions, and identified lifting controls.

1107. The RP's response to RQ-UKHPR1000-1507 (Ref. 265), implied that the lift would be controlled through electronic interlocks, but the details of these safety measures had not been provided, which I judge to be acceptable as this can be addressed by the licensee at detailed design. In response to my queries relating to potential consequences, I was satisfied the RP provided sufficient evidence to confirm that no unacceptable damage would occur to the various SSCs that could be impacted by RPV head assembly in the new lifting paths, thereby satisfying EHA.1 and EHA.6.

1108. From my sample, I am satisfied that the combination of the RP's RQ response (Ref. 265) and substantiation report (Ref. 261) has provided sufficient evidence that the RPVs integrity against a dropped load is substantiated for the purposes of GDA. It is my opinion that some uncertainty remains regarding the extent of manual and electronic controls in the selected lifting sequences and the nature of the safety interlocks. However, I judge that these controls can be resolved by the licensee at the detailed design stage as part of normal business.

RO-UKHPR1000-046 Assessment of Main Steam Lines

1109. The RP's substantiation of main steam lines against the internal hazards report (Ref. 89), presented a summary of the identified hazards affecting the main steam lines and the RP's analysis to substantiate the HIC integrity. The MSL HIC covered by the report included the 3 sets of piping which connect the Steam Generators to the main steam lines taking steam to the turbine hall. The extent classified as HIC includes; all piping from the SG nozzle to the point where the MSL leaves each safeguard building, including BRX Containment penetration; BSX penetration, and; the Main Steam Isolation Valves (MSIV) located in the BSX.

1110. The substantiation report highlighted that the MSL is subject to fire, flooding, explosion, missiles and dropped loads hazards. In response to the initial report I sought clarification on the extent of components designated as HIC and analysis methods and assumptions adopted for missile impact in RQ-UKHPR1000-1505 (Ref. 266). The RP's response to RQ-UKHPR1000-1505 (Ref. 266), provided adequate clarification and I was satisfied that the additional information was included in the updated ALARP analysis report (Ref. 155).

1111. For fire, the RP initially reported that the MSLs were not subject to fire loads. However, following detailed sampling in RO-UKHPR1000-053 (Ref. 57) and queries raised in RQ-UKHPR1000-1723 (Ref. 85) I identified that the MSL was subject to fire loads. This scenario is assessed in detail in the fire sub-section (4.3) of this report. My assessment concluded, based on the evidence provided, that HIC withstand was demonstrated. However, I noted that the principal claim was on the HIC withstand rather than the RP implementing measures to reduce the risks further. I judged this to be a shortfall against SAPs EHA.5 and EHA.6 and captured it in Assessment Finding AF-UKHPR1000-0057 (fire substantiation of SSCs).

1112. Flooding is argued by the RP not to affect the MSLs in BRX and BSX because they are located at elevated levels within the buildings. I have assessed these claims in detail in the flooding section of this report and I am satisfied that this is an adequate argument.

1113. The RP's analysis of explosion hazards stated that there are no internal explosion hazards within the BRX which can affect the MSLs (Ref. 89). However, an explosion source was identified within the safeguards building, related to the VDA pipework (IH-EX-BSX-05). This scenario has been assessed in the explosion section of this report. For this scenario the RP demonstrated withstand of the HIC in accordance with the relevant RCC-M design codes and stated that margins existed. Although I was content with the substantiation approach for the MSL, I noted that the RP's analysis for the MSIV was limited, and is captured in Assessment Finding AF-UKHPR1000-0064.

1114. Internal missiles impacting MSL within the BRX are characterised by the RP in two scenarios; IH-IM-BRX-09 (relating to valve missiles) and IH-IM-BRX-18 (relating to rotating plant). The valves identified by the RP are stated to be all relatively small valves within piping systems, having a diameter less than DN25 (Ref. 89).

1115. To address the number of valves that could impact the HIC as a result of the RO-UKHPR1000-046 work, the RP had made the commitment to alter the orientation of the valves to avoid possibility of impact on MSLs. These valves are located in all the buildings. In the BRX annular area (BSB area) the RP stated that rotating the valves by 90° will mean impacts are with barriers or other components instead of MSLs.

1116. I have assessed the proposed modifications and I am satisfied that in principle these are feasible but their justification remains a gap within the safety case. Detailed analysis of the associated hazards will need to be undertaken at the detailed design stage to demonstrate that the changes in direction do not lead to other hazard consequences. I consider this as work for the licensee to undertake, and the outstanding analysis is captured as Assessment Finding AF-UKHPR1000-0077 to maintain regulatory oversight in line with SAPs EHA.7, EHA.18 and ESS.1. The RP's rotating plant missile analysis was related to the RPE system (vacuum pump). The RP stated that the RPE pump design specification will require the pump casing to be qualified to retain missiles. I judge this as an acceptable approach, as this is a design specification that will be based on licensee choices which is also captured in Assessment Finding AF-UKHPR1000-0077 below.

AF-UKHPR1000-0077: The licensee shall, as part of detailed design, address gaps identified in GDA to demonstrate that the risks to high integrity components from internal missile hazards are reduced to as low as reasonably practicable. This should include, but not be limited to:

- Demonstration that the implications of changing valve orientation to avoid high integrity component impacts does not result in other hazards.

- Demonstration that options other than changing valve orientation, have been considered.
- Substantiation that the design of rotating equipment minimises the risks of generating missiles.
- Justification of the selection of 10° as the maximum angle for valve missile ejection.
- Demonstration that for those missile impacts that cannot be eliminated, the withstand capability of associated high integrity components is substantiated.

1117. The principal internal missiles identified by the RP impacting MSLs in the BSX related to valve missile impacts from the main steam line small bore pipework (less than DN25). Like the BRX the RP proposed to rotate valve orientations at the detailed design stage to eliminate the valve missiles to the MSL. The RP's analysis also identified potential rotating plant missile impacts to MSL. Again, the RP proposed to qualify the fan casings to retain missiles. In both instances I am satisfied that the RP has applied a consistent approach. However, the shortfalls I highlighted above relating to the valve orientation and case retention claims discussed above also apply here.

1118. From my sampling of the BSX missile assessment (Ref. 195), I noted that the RP had not considered two significant safety valves in its analysis. These valves were the main steam safety valve (MSSV) and the main steam safety relief valve (MSSRV). These valves are mounted on top of the MSL and will eject upwards if they were to fail, but would also fall back down onto the MSL or MSIV. I raised RQ-UKHPR1000-1727 (Ref. 267) to obtain further analysis from the RP in this regard.

1119. I was satisfied that the RP's response to RQ-UKHPR1000-1727 (Ref. 267) provided me with sufficient evidence to have confidence that the impact from MSSV or MSSRV falling back onto the MSL would not threaten the integrity of the MSL. The RP also confirmed that the MSIV actuator is not HIC, and failure of the MSIV to operate would not cause unacceptable consequences as the integrity of the pressure boundary would not be lost. I consider this satisfies SAP EHA.6.

1120. For high energy pipe failures, the RP stated that no HEP were identified that could impact MSLs in the BRX (Ref. 155). Within the BSX, however, I challenged the RP on the potential of the feedwater (ARE) lines impacting the MSLs; this is discussed in detail in the HEPF section of the report. The conclusion of my assessment has been the RP implementing a layout modification (Ref. 268) to separate the lines by installing a concrete barrier preventing the pipe whip and jet impact effects. Blast and steam release overpressure hazards remain but the MSL line had been substantiated against these effects. Therefore, I am satisfied that the modification proposed is appropriate and satisfies SAPs ELO.4 and EKP.3.

1121. The RP stated in the analysis report (Ref. 89) that the MSLs are protected from load drops from the polar crane in BRX by the SG and RCP compartment roofs. Large load drops, such as the RPV head assembly (which is stored on top of one of the RCP compartments roofs) have the potential to damage MSL Loop 3 if the floor fails, but this lift is only carried out when plant is shut down and MSLs are depressurised. The RP stated that all lifting operations which occur in the BRX and which could damage the MSLs are carried out during outage. The only lifting beams in BSX above the MSLs are those associated with maintaining the MSIV or safety valves which are not in use during operation. I am content that, for the purposes of GDA, the RP's screening and analysis is adequate.

1122. In summary, I am satisfied that the RP has adequately addressed my queries associated with the substantiation of the MSL, within responses to my RQs and through the evidence contained in the ALARP Layout Report (Ref. 155) and revised HIC Substantiation Report (Ref. 89). I am content that the RP has provided sufficient evidence to demonstrate that hazards to MSLs in the BRX and BSX have been eliminated where possible, and where existing hazards remain the RP has provided confidence that their integrity will be assured.

1123. The RP has positively made commitments to eliminate some remaining hazards (such as those from small bore pipework and valves). These changes may introduce additional hazards and hazard combinations, but their intent is positive, and I have raised an Assessment Finding to ensure the gaps I identified are adequately addressed at the detailed design stage.

RO-UKHPR1000-046 Assessment of Steam Generators

1124. The RP sated that the SG HIC is composed of primary and secondary pressure retaining parts. The inlet and outlet nozzles in the primary head, tubesheet, and primary U-tube bundles together make up the primary coolant circuit components, which operate at reactor temperature and pressure, and form part of the reactor coolant pressure boundary. The secondary side which operates at lower pressure comprises the outer shells around the tube bundle, an expansion section, steam drum shells, steam generator head and steam outlet, feedwater and auxiliary feedwater nozzles. The internal parts (feedwater downcomer shell, primary and secondary steam separators, tube bundle supports) are not listed as HIC components.

1125. The RP's substantiation of the steam generators against the internal hazards report (Ref. 129) highlighted that the SG is subject to fire, flooding, explosion, HEPF and missiles hazards.

1126. For fire, the RP initially reported that the steam generators were not subject to fire loads. However, following detailed sampling of the areas defined in RO-UKHPR1000-053 (Ref. 57) and my associated queries raised in RQ-UKHPR1000-1503 (Ref. 269) and RQ-UKHPR1000-1036 (Ref. 81), I clarified that there were locations where the SGs are subject to fire loads. This fire load was a direct result of the reactor coolant pump motor lubrication oil fire located in adjacent compartments. My assessment of the RCP fire loads and RP's analysis is reported in detail in the fire section of this report.

1127. The RP's analysis of the SGs withstand for this scenario was addressed as part of RO-UKHPR1000-046 (Ref. 129). The RP's analysis credited the proposed modification to the oil bunding (Ref. 155). On the basis that the modification is effective the RP calculated the radiative heat flux to the SG in the adjacent compartment. The RP's calculation demonstrated that the heat flux was low and that the maximum temperature at the outside of the SG metallic insulation is estimated to be 53°C. The analysis does not detail the actual temperature rise expected, as the SG surface temperature is likely to be close to 300°C, and temperature at the insulation surface is likely to be greater than 53°C in normal operation. Although I judge this to be an unlikely issue this needs to be adequately justified at detail design, this is therefore captured as part of Assessment Finding AF-UKHPR1000-0058.

1128. For flooding, the RP's report (Ref. 129) stated that the internal flooding paths to drain flood water to the IRWST are located within the SG compartments. The RP stated the SGs are supported above the floor level on support structures. From my sampling of the flood hazards I am satisfied that the RP has demonstrated that flooding would not affect the SG integrity. I am satisfied that significant margin has been demonstrated by the RP with respect to flood heights (Ref. 57); my assessment related to these findings are documented in the flooding section of this report.

1129. For explosion, I noted that the RP's screening had not identified any explosion sources impacting the SG's. I challenged the basis of the RP's screening through RQ-UKHPR1000-1030 (Ref. 123), in response (Ref. 123) the RP accepted that the ARE feedwater lines connected to the SG could present a BLEVE explosion source. My assessment of this scenario is discussed in the explosion section of this report. The RP analysis of the HIC withstand against this explosion load is detailed in its RO-UKHPR1000-046 response (Ref. 129). The RP calculated the stress of the upper shell based on a minimal affected area to provide a conservative estimate of the force (Ref. 129). The stress calculated by the RP was then compared to the allowable stress intensity according to RCC-M B3238 (Ref. 80). The RP concluded that the stress intensity was around 1% of that allowable within the RCC-M code. The blast load component on the nozzles was also calculated by the RP and found to be within acceptable limits. From my sampling, I am satisfied that the RP has applied appropriate analysis and codes and sufficient evidence to justify the survival of the SG's against blast loads, thereby satisfying SAPs ECS.3, EMC.1 and EMC.3.

1130. For internal missiles the RP's substantiation report (Ref. 129) identified approximately 62 valve impacts on the SGs for the three loops. This number takes account of all valves identified by the RP as being installed vertically with a potential missile ejection angle 10° off vertical.

1131. It is my view that the RP's rationale for assuming that valve missiles are only ejected along the axis of the valve stem is acceptable as long as the valve design is demonstrated to preclude the ejection of the valve bonnet / stem / actuator in any other direction. I recognise that a purely vertical ejection will result in a worst-case missile velocity. However, it is my view that not all valve designs are the same and surrounding equipment may result in the valve missile being deflected, albeit at a lower energy. The RP stated that the 10° deviation allows for 'cliff-edge' effects and ensures consideration of all potential missile / target combinations. Although I accept that the approach adopted by the RP will provide the most significant missile impacts, it is my opinion that by limiting to the 10° deviation, the RP may have screened out other potential missile hazards. I judge this to be a gap within the safety case as it does not fully meet ONR expectations as stated in TAG-014 (Ref. 7) which states that a missile should be considered to go in any direction, and I judge this a shortfall against SAPs EHA.1, EHA.19, EHA.3 and EHA.6. At detailed design I expect that this gap is addressed to justify the placement, locations, and design of the valves to demonstrate that the risks to HIC are reduced to ALARP. This expectation is captured in Assessment Finding AF-UKHPR1000-0077.

1132. While most of the valves identified by the RP had a relatively low impact energy (less than 100kJ), the RP identified 22 valves that had energy impacts of 500kJ and above, with most of these having an impact energy of around 1500kJ (Ref. 129). Of these potential valve impacts for all SGs, the missile from the Safety Injection Valve RIS2560VP in Loop 2 bounded them all. The RP stated that this had the largest impact energy level of over 3300kJ. The RP stated that this valve is situated in SG compartment BRA2102ZRM, below the primary head of the SG along with other Safety Injection System valves, including RIS2510VP which has a lower impact energy of around 650kJ.

1133. For the bounding valve (RIS2560VP) impact on the SG of Loop 2, the substantiation report (Ref. 129) presented the RP's analysis that demonstrated that the impact energy was 47% of the perforation energy. The RP's analysis was done in line with the R3 impact methods (Ref. 44). From my assessment of the RP's analysis I noted that while the missile velocity, target thickness and span relative to the missile equivalent diameter were within the R3 formulae range, the missile equivalent length to equivalent diameter ratio (L/d) was substantially outside the lower limit of the range for all the formulae. I therefore raised RQ-UKHPR1000-1506 (Ref. 270) to obtain clarity on the RP's approach.

1134. The RP's response to RQ-UKHPR1000-1506 (Ref. 270), highlighted that the RP adopted the R3 appendix G approach that recommends the use of determining the 'worst-case' of all the correlations when non-dimensional parameters are outside of the validated ranges. Although this proposed approach is likely to result in a conservative answer, the analysis is out of the valid ranges and therefore does not satisfy SAP AV.2. I also noted that this approach ignores the fact that although the actual missile impact is unlikely to perforate the target, it is very likely to cause damage and deformation of the target which the R3 approach adopted did not consider. I raised RQ-UKHPR1000-1767 (Ref. 271) to address the lack of clarity in this regard.

1135. In its response to RQ-UKHPR1000-1767 (Ref. 271) the RP clarified that its initial analysis had not credited a wall (BRE2119VB-/001) that sits above the RIS2560VP valve. The RP stated that it had assessed the wall against the valve impact, including the 10° deviation from the vertical direction. The RP stated the wall has adequate withstand against the valves impact (Ref. 101), and therefore the wall protects the SG from the valve impact. On this basis the RP screened out the valve as a missile source to the SG.

1136. My assessment of the RP's response to RQ-UKHPR1000-1767 (Ref. 271), has provided me with confidence that an adequate barrier is in place to protect the SG from the RIS valves, but I note that this is only substantiated for a 10° deviation. I do not consider this a major issue as the RP had undertaken analysis for the maximum loading, which has provided me with confidence that the SG integrity would be maintained, thus for any wider angles where the impact velocity would be lower the margins would be greater. However, the RP should assess this, as the impact location for any wider impacts could differ. I consider this as a shortfall that I expect a license to address during detailed design and is captured in Assessment Finding AF-UKHPR1000-0077.

1137. For all the other valves with energies greater than 1000kJ, the RP stated in the ALARP report (Ref. 155) that all these valves can be re-aligned to avoid impacts with the SGs. These are valves listed by the RP as RISi570VP-, RISi571VP-, RISi572VP; i=1,2,3. As stated above, I expect the licensee to justify the orientations to demonstrate that they do not result in additional hazards. This is already captured in Assessment Finding AF-UKHPR1000-0077.

1138. The RP's analysis of valve impact to the SG highlighted that the feedwater valve AREi440VL cannot be realigned as it is a check valve. To address the risks the RP proposed to install a baffle above to prevent the missile impact on the SG (Ref. 155). I judge this to be an adequate solution, but its substantiation needs to be provided at detailed design (see Assessment Finding AF-UKHPR1000-0077). The RP's substantiation report (Ref. 129) also presents the RP's analysis on the one remaining valve (RISi510VP-, i=1,2,3) which has impact energy around 700kJ and cannot be realigned or moved. Unlike the previous case in this instance, the RP stated that there is no space to install protective measures such as barriers.

1139. In this instance the valve would impact the SG. To demonstrate that the SG's integrity would be maintained, the RP calculated the potential for perforation and provided an assessment of deformation following the impact of these valves. The RP concluded that the missile would not penetrate the SG and extended its analysis to include its method to assess the components deformation (Ref. 264), where it demonstrated that the SG would not be significantly damaged.

1140. From my assessment of the RP's approach, I am satisfied that the updated analysis had demonstrated that very little deformation will occur. Given that perforation has been discounted I am satisfied that the HIC will not be compromised by these missiles. Furthermore, the RP has proposed to fit these valves with secondary containment measures to prevent missiles. This approach could be utilised for other valves and should be considered at the detailed design stage as an alternative to re-alignment, because the latter approach does not eliminate the missile. This is captured in Assessment Finding AF-UKHPR1000-0077.

1141. I also note following my sampling, that the valves RCP1113VP-/RCP2113VP-/RCP3113VP with impact energies just over 500kJ have not been addressed in the ALARP report (Ref. 155) or the HIC substantiation Report (Ref. 129). I judge it unlikely that the impact energy of these valves could threaten the integrity of the HIC on the basis that higher energies have already been assessed. However, the safety case should be completed and the risks from missiles should be demonstrated to not result in unacceptable damage due to the impact location. I judged this a shortfall in line with SAPs EHA.2, EHA.3 and EHA.6. At detailed design I expect the licensee to provide evidence that the SG has been substantiated against impacts from valves RCPi113VP-(i=1,2,3), as these valve impacts have not been eliminated and therefore a gap remains. This is captured in Assessment Finding AF-UKHPR1000-0077.

1142. For HEPF the RP analysis identified a total of 8 pipes that could whip on the SGs and a total of 33 pipes that could result in jet loads on the SGs (Ref. 155). The RP highlighted that the most significant pipe whip resulted from the main feedwater pipe ARE1440TY impacting SG Loop 1; this impact was calculated by the RP to result in 90% of the calculated perforation energy. Following further review, the RP identified additional measures to modify the pipe layout and add restraints to eliminate the impact of feedwater pipes AREi440TY- (i=1,2,3) to prevent the worst-case impacts (Ref. 155). This is captured as part of the updated design reference modification M91 (Ref. 268) for incorporation in the latest generic UK HPR1000 design reference (DR3). From my sampling I am satisfied that the RP has identified the hazard and undertaken adequate optioneering and adopted an appropriate approach to eliminate the whip hazard. This therefore satisfies SAP EKP.3.

1143. The RP analysed the impacts of the steam generator blowdown pipes' APG [SGBS] pipe whip on the SG, as well as the jet impact loads from the ARE feedwater HEPF (as the pipe is now restrained so pipe whip is eliminated) (Ref. 129). Jet impact loads were demonstrated to be significantly smaller and bounded by pipe whip loads. I therefore sampled the analysis related to pipe whip loads from the APG pipe. The pipe whip loads were evaluated by the RP using R3 appendix G methods and with the RP demonstrating that the impact energy is approximately 35% of the calculated perforation energy. This result was also verified by additional FE analysis undertaken by the RP which provided a stress intensity result of 24MPa. The RP then conservatively added this stress to the internal pressure induced stress. The combined stress was then compared against the allowable stress intensity under ASME Boiler and Pressure Vessel Code Section III, against which the SGs are designed. The RP concluded that the SG's had appropriate withstand from the stress loads (Ref. 129). Through my assessment of the RP's pipe whip analysis, I am satisfied the RP has provided sufficient evidence to demonstrate for the purposes of GDA that the SGs have withstand from the hazard loads.

1144. From my assessment of the analysis of the internal hazards to the SG I am satisfied that the RP has provided adequate substantiation of the SG integrity. The most significant hazards identified originated from the HEP connections. In my view the RP has adequately addressed these and provided confidence in the design, based on the RP's proposed modifications to ARE feedwater pipework which removes the most challenging HEPF hazard load. I am also satisfied that the SG substantiation report (Ref. 129) has provided sufficient evidence that most identified hazards to the SGs have been eliminated where possible, and that the SGs have been adequately substantiated against the remaining hazards.

RO-UKHPR1000-046 Assessment of the Pressuriser

1145. The PZR HIC is composed of cylindrical shells and hemispherical upper and lower heads which are welded together. The PZR is connected via the surge line (not HIC) to the Hot Leg on one of the Main Coolant Line loops. All nozzles forming part of the pressure boundary are classified as HIC. The internal heater elements, internal nozzle elements (filters /flow straighteners) and manway cover are not classified as HIC.

1146. The RP's substantiation report (Ref. 262) highlighted that the pressuriser is subject to fire, explosion, dropped load and HEPF hazards.

1147. The report (Ref. 262) highlighted that the fire hazards to the PZR are from the heater cable trays which run around the compartment beneath the PZR bottom head. The PZR substantiation report calculated a radiative heat flux of around 8.6kW/m^2 which was stated as being tolerable by the RP, based on the distance that flame impingement can be discounted. I have reviewed the RP's analysis and based on the evidence I am satisfied that the scenario is acceptable for GDA. I also note that the PZR is clad with insulation material which was not credited in the analysis, and in my view is likely to reduce the impact of any fire further. My detailed assessment of this scenario is detailed in the fire section of this report.

1148. A single dropped load scenario was identified by the RP relating to the lifting beam installed to remove the manway door. The RP stated that when this lift is required the PZR will be out of service and depressurised, as this lift is only required during an outage, the RP concluded that any dropped load would not impact nuclear safety. The layout and location of the PZR is such that it is contained within a compartment that isolates it from any other dropped loads that could occur during operation. Therefore, based on the RP's hazard analysis and for the purposes of GDA, I am content that from a dropped loads perspective the RP has demonstrated that the risks are acceptable, satisfying SAP. EHA.4 and EHA.6.

1149. For explosion hazards and HEPF hazards the RP identified that the principal sources were from the surge line, spray line, and severe accident injection line (Ref. 262). The RP stated that failure of the surge line could generate overpressures of around 200kPa. This loading was analysed by the RP using RCC-M B3200 code. The RP's results demonstrated a safety margin of >99%, and therefore stated that the PZR withstand was assured within its design code with significant margin. The RP applied the same methods and concluded that the safety margin against failure of the PZR support structure was assessed as around 70%. The RP also highlighted that other HEPF consequences could impact the PZR. The failure of the surge line (RCP6110TY) could create a jet impact load on the bottom head of the PZR, the failure of the spray line (RCP6135TY) can result in both a pipe-whip and jet impact load on the head of the PZR, and finally the failure of the severe accident injection line (RCP6310TY), could result in a jet impact load on the head of the PZR.

1150. Due to the number of potential impacts, I raised in RQ-UKHPR1000-1502 (Ref. 272) clarification of the RP's analysis of pipe-whip effects and the potential for combination of HEPF effects, as I noted variation in the input data. The RP's response (Ref. 272) clarified that the thickness of the target (PZR vessel) had to be reduced to bring the non-dimensional parameters to within the applicable validated ranges to allow use of the correlation formula in the R3 codes. The RP stated that with the thinner wall, the calculated perforation energy is likely much lower (more conservative) than it would be. The report (Ref. 262) calculated that the impact energy from the bounding pipe whip case (RCP6135TY) was 95% of that required to perforate (a 5% safety margin). The

RP's analysis of jet impact loads from the surge line and spray line / severe accident injection lines have been demonstrated by the RP to be insufficient to threaten HIC integrity alone. The RP's response to RQ-UKHPR1000-1502 (Ref. 272) also addressed the possibility of coincident pipe-whip / jet impact loads and dismissed them as not credible due to the layout of the pipes. The RP also stated that because blast loads act before pipe-whip / jet impact loads, they are claimed not to be coincident. I judged this to be a reasonable assumption, however this approach does not consider the potential for blast loads to cause damage to the HIC leaving it vulnerable to damage from other HEPF effects. I have raised this issue already and captured it in Assessment Finding AF-UKHPR1000-0076.

1151. However, to satisfy the intent of RO-UKHPR1000-046 (Ref. 88) to demonstrate a position that reduces risks to ALARP, the RP conducted further analysis of these hazards in particular the pipe whip from the spray line. The RP detailed its optioneering in the ALARP review (Ref. 155), and identified an option to amend the layout of the spray line (RCP6135TY). The RP stated that it is its intent to modify the pressuriser pipe work to reduce the overall length of straight pipes to eliminate the pipe whip hazard; the lengths would be reduced by introducing additional elbows in the pipework. I note that the proposal is subject to further detailed design, but I am satisfied that the modification appears to be credible to reduce or eliminate the pipe whip load. This has been captured by the RP in the M91 modification which is included in the generic UK HPR1000 design reference report (Ref. 268).

1152. Following the ALARP optioneering (Ref. 155), the RP stated that pipe whip and jet impact loads relating to the spray line have been removed, and the jet impact load on the vessel head is bounded by the larger jet impact load from the severe accident injection line, which the RP had indicated would not threaten the PZR integrity. I am satisfied that the RP has presented a feasible approach to modifying the spray line pipe layout. However, detailed analysis has not been undertaken to substantiate this. This is therefore a gap in the current evidence, and I raise this as an Assessment Finding in line with SAPs FA.1, FA.4, EHA.5 and EHA.6. It is down to the licensee to determine the layout of the pipes and finalise the measures in place to eliminate the pipe whip hazard. I am satisfied that options are available but these need to be finalised through licensee choices.

AF-UKHPR1000-0078: The licensee shall, at as part of detailed design, demonstrate that the risks to the pressuriser from the pressuriser spray line pipe whip have been reduced to as low as reasonably practicable.

1153. The RP has not identified any hazard combinations which could affect the PZR. As the other loads (blast wave and jet impact) are very low compared to the damage threshold values (safety margins of over 90%), I am satisfied that the RP's conclusions are appropriate, and that the RP has provided an adequate safety case, for the purposes of GDA, on the internal hazard impacts on the PZR, thereby satisfying SAP's EHA.2, EHA.6 and EMC.3.

RO-UKHPR1000-046 Assessment of the Main Coolant Lines

1154. The generic UK HPR1000 design has three cooling loops each consisting of a Steam Generator, a Reactor Coolant Pump, and the Main Coolant Lines (MCL) which connect these components to the Reactor Pressure Vessel. The MCL HIC are composed principally of large bore (760mm internal diameter) forged pipework with integral nozzles for connection of smaller bore pipework.

1155. Each loop of the MCLs consists of a Hot Leg (made of a single forging) connecting the RPV outlet nozzle to the SG inlet nozzle, a Cross-over Leg (made of 3 forgings) connecting the SG outlet nozzle to the RCP suction, and a Cold Leg (made of a single forging) connecting the RCP pump discharge to the RPV Inlet nozzle.

1156. The HIC boundary goes up to and includes the welds to the nozzles on the RPV, SG, and RCP, but excludes the nozzles themselves which are part of their respective component HIC designation. This includes the 'safe-ends' for the SG and RPV nozzles. The Hot Leg of Loop 3 connects via the Surge Line (Non-HIC) to the PZR. The MCLs are arranged within the same compartments as the components to which they connect and are therefore divisionally segregated by barriers. The Hot and Cross-over Leg MCLs are just below the SG level and the Cold Leg is at the same elevation as the RCP. All MCLs pass through the reactor well wall to connect to the RPV.

1157. The RP's substantiation report (Ref. 263) identified that the MCLs are subject to fire, explosion, missile and HEPF hazards.

1158. For fire the principal hazard was identified following the RP's response to RO-UKHPR1000-053 (Ref. 57), where the RP found that an RCP oil fire could impact the MCL. The fire scenario from the RCP motor oil fire is argued by the RP to be contained by the proposed modifications and qualification of the motor casing to retain the oil fire, as discussed earlier in this report. For the purposes of GDA, I am satisfied that the RP has a reasonable basis for its claims. This claim will, however, need substantiation during the detailed design of the equipment. I consider that this has already been captured in Assessment Finding AF-UKHPR1000-0058 in the fire section of this report.

1159. The RP's analysis identified that internal explosion / blast effects are possible due to high energy pipes connected to the MCLs and therefore cannot be eliminated (Ref. 263). From the various sources, the RP identified that the most onerous was the failure of the Surge Line connecting to Hot Leg of Loop 3 (RCP6110TY). The RP analysed the blast impact severity according to RCC-M B3600 code (Ref. 80). The RP calculated that the blast load had a maximum value of approximately 34MPa, which was then compared to the withstand limit of the component, which was calculated by the RP as being 171MPa (Ref. 263). Based on its analysis the RP concluded that the component had a large safety factor. From my assessment of the RP's analysis, I am satisfied that the RP had applied a conservative analysis due to the simplifications and assumptions inherent in the assessment method, such as using the maximum overpressure value rather than actual incident overpressure over the surface of the target. I am content that the claimed safety margin is justified and therefore provides an adequate demonstration of withstand. This satisfies SAP's EHA.2, EHA.6 and EMC.3.

1160. Internal missiles hazards have been identified by the RP resulting from valve failure that can affect the MCLs. The RP identified a single case that it stated could bound the 14 cases identified (Ref. 263). Of these 14 cases, 4 cases have valves with impact energies over 100kJ and the bounding case was selected based on impact energy. No rotating plant or vessel missiles were identified by the RP that could affect the MCLs.

1161. The internal missile bounding case was calculated by the RP using the R3 impact assessment procedure vol 3 appendix G to determine a target perforation energy as discussed earlier in this report. I am satisfied that this is an adequate method for this scenario, thereby satisfying SAP. AV.2. I noted that for this scenario, the non-dimensional parameters used by the RP to characterise the impact had not been within the validated ranges for the correlation formulae. The RP calculated the impact energy to be 784kJ, around 12% of the calculated perforation energy (6741kJ). I have assessed the RP's analysis and I am satisfied that, given the conservatism built into the assessment process, for the purposes of GDA, the RP has provided an adequate case for the assessment of missile hazards on the MCL.

1162. Further ALARP assessment (Ref. 155) by the RP concluded that all internal valve missile cases could be eliminated through reorientation of the valve bodies to direct missile trajectory away from the MCLs. The majority of the valves are in small bore (DN50) pipework which will be subject to detailed design post-GDA. I consider that reassessment of impacts against barriers and other SSCs, and the potential for cascade failure, will need to be evaluated at this point. This is addressed in Assessment Finding AF-UKHPR1000-0077 above.

1163. For HEPF pipe whip impacts to the MCL the RP had stated that they had been eliminated through layout design changes as detailed in the ALARP report (Ref. 155). This includes installing pipe whip restraints on safety injection system line RISi510TY and on lines RISi561TY- (i=1,2,3). Other options considered (such as re-routing of pipework) were deemed unacceptable due to space constraints, an approach which I judge to be reasonable. I am satisfied that the RP has adopted appropriate measures to eliminate pipe whip hazards to the MCLs, and these modifications are captured as part of modification M91 as detailed in the generic UK HPR1000 design reference report (Ref. 268).

1164. From my sampling of the RP's analysis for HEPF hazards, I was satisfied that the RP had adequately substantiated the MCLs against the remaining HEPF impacts (Jet impact and blast), which could not be reasonably eliminated due to pipework connections to the MCLs. I raised RQ-UKHPR1000-1504 (Ref. 273) to obtain additional evidence to underpin the RP's analysis of pipe whip and jet impact coincidence. The RP's response (Ref. 273) clarified the use of pipe whip restraints and stated that the whip hazard was removed and therefore can be excluded. For jet impact loads, the RP calculated that the Surge Line failure resulted in the largest jet load with an average shear stress of approximately 18MPa compared to the RP's calculated allowable stress of 68MPa for the MCL, thus indicating around 25% utilisation (a safety margin of 75%). Based on the RP's analysis (Ref. 263) and RQ response (Ref. 273) I am satisfied that the RP has undertaken sufficient analysis to provide me with confidence that the integrity of the MCL can be assured following a jet load, satisfying SAP's EHA.2, EHA.6 and EMC.3.

1165. The RP identified one combined hazard case (Ref. 263) which could affect the MCL Loop 2. The sequence described by the RP is initiated following the failure of the Safety Injection System line RIS2510TY, the resulting blast wave can then impact the Cross-over leg MCL of Loop 2 (RCP2112TY). This could lead to a consequential failure of reactor coolant clean-up and volume control system pipework (RCV7312TY) in the same compartment. The pipework failure of RCV7312TY was identified by the RP to result in a jet impact on the MCL Loop2 Cross-over leg. This then results in a combined HEPF hazard on the MCL leg RCP2112TY.

1166. The analysis conducted by the RP resulted in an estimated blast wave stress loading of 32% of the allowable component stress which is deemed acceptable under the RCC-M code (Ref. 80). For the jet load the RP calculated that the average shear stress was approximately 6% of that allowable under the RCC-M code. The RP concluded this is acceptable as the two loads were applied sequentially and not combined, as the RP assumed that no significant damage would occur to the MCL following the blast impact.

1167. I have assessed the RP's analysis (Ref. 263) and I am satisfied that its approach is adequate for GDA. I am content that the RP has assessed the blast and jet loads independently, as I agree with the view that the blast wave would precede the jet. The RP has provided me with confidence that the blast load is unlikely to result in significant damage, and therefore the assumed withstand for the jet loading is judged to be appropriate. It is my view that a more detailed examination by the licensee is warranted at detailed design, as it is not clear why similar blast / jet impact combinations are not possible against the Hot Leg MCL or in other locations.

Therefore, I have raised the following Assessment Finding in line with SAPs EHA.7, EHA.18 and ESS.1, to ensure that appropriate analysis is undertaken.

AF-UKHPR1000-0076**:** The licensee shall, as part of detailed design, demonstrate that the risks to high integrity components from combined internal hazard sequences are reduced to as low as reasonably practicable. This demonstration should include, but not be limited to:

- Blast wave preceding further hazard impacts.
- Demonstration that the combined blast / high energy pipe failure impact on the main coolant line loop 2 crossover leg is bounding.

1168. From my assessment of the internal hazards to the MCLs I am satisfied that the RP has provided adequate substantiation of the MCLs integrity. I have also been satisfied that the RP has eliminated hazards where possible and therefore for the purposes of GDA, has provided an adequate case for the MCL.

RO-UKHPR1000-046 Assessment of Reactor Coolant Pump Casing and Flywheel

1169. The RP's HIC categorisation only applies to specific parts of the RCP, namely the pump casing up to the welds connecting to the Main Coolant Lines, and the flywheel which is mounted on the RCP motor shaft within the RCP motor housing. The generic UK HPR1000 design contains 3 cooling loops within the Reactor Coolant System and each cooling loop includes a RCP located between the SG and the RPV. The RCP is a single stage vertical axis mixed flow pump with suction inlet nozzle at the bottom of the RCP casing beneath the shaft-line of the pump / motor, which is connected to the SG outlet via the MCL crossover leg.

1170. The RP's substantiation report (Ref. 118) highlighted that the RCP and Flywheel are subject to fire, flooding, missile, dropped load and HEPF hazards.

1171. Through my assessment as part of RO-UKHPR1000-053 (Ref. 57) it was identified that the RCP motor lubrication oil system could affect the RCP casing and flywheel. I have assessed this in detail in the fire section of this report. The outputs from my assessment were that the RP stated the RCP motor casing will be re-designed to ensure any leaking oil is appropriately retained and mitigate the fire affecting the RCP. However, from my assessment of the RO-UKHPR1000-046 response (Ref. 118), I am of the opinion that a minor gap remains in the evidence with respect to the flywheel. This is because the flywheel is located within the RCP motor casing and could still be affected by increased temperatures. From my understanding of the scenario and design, I am of the opinion it is highly unlikely that this fire scenario would prevent the delivery of the flywheel safety function. However, this is not clearly presented in the safety case and should be addressed by the licensee at detailed design and is captured as part of AF-UKHPR1000-0058.

1172. For flooding, the RP stated that the RCP would not be immersed by flooding and therefore their safety functions would be assured. I have been satisfied that through the RP's response to RO-UKHPR1000-053 (Ref. 57) the RP has provided adequate evidence to demonstrate that the components would not be submerged. To ensure that the RP had also addressed the impacts from other flood effects, I raised RQ-UKHPR1000-1503 (Ref. 269) to query the impacts of spray. In response, the RP stated (Ref. 269) that water spray would not affect the RCP casing because it is clad with insulation, and the flywheel is contained within the sealed motor casing. Based on the RP's response, I accept that any potential effect of spray water is likely to be small. I am satisfied that the risks from flooding are low and SAPs EMC.1 and EMC.3 have been met.

1173. For missiles, the RP's substantiation report (Ref. 118) identified a total of 14 valves which could impact the RCP casing. The RP stated that all these valves are part of small-bore pipework systems which will be designed at the detailed design stage, and therefore out of scope for GDA. However, the RP has committed to install these valves in non-vertical orientation to avoid impacts with the RCP casing, which is captured in the ALARP report (Ref. 155) and is captured as part of the M91 modifications described in the generic UK HPR1000 design reference document (Ref. 268). I am satisfied that this is a reasonable strategy, but care needs to be taken in the change in valve orientation. I have already discussed this in the sections above and Assessment Finding AF-UKHPR1000-0077 is also applicable here.

1174. The RP identified three HEPF cases which could result in jet impacts against the RCP casing (Ref. 118). The RP stated that these jet impacts cannot be avoided by pipework redesign or routing. The RP calculated the thrust force against the RCP to be approximately 50kN, and compared this to the allowable stresses using the RCC-M code (Ref. 80). The RP's analysis concluded that the jet impact load represented only 1.7% of the load required to fail the RCP casing. Based on the analysis undertaken by the RP, I am satisfied that an adequate approach was presented, and I am satisfied that the components integrity has been adequately demonstrated with appropriate design codes with good margin. This satisfies SAP's EHA.2, EHA.6 and EMC.3.

1175. Dropped loads have not been evaluated in detail by the RP for the RCP. This is because the only lifting operations which can affect the RCP are only carried out when the component is out of service and not performing a safety function. I judged this to be an acceptable position at this stage.

1176. Blast and combined hazards are claimed not to affect the RCP casing and flywheel HIC. I have assessed the evidence presented in the submissions and I consider that these conclusions are reasonable. However, it is also my view that the combined hazards assessment needs to be revisited during the site-specific phase as the large number of valves which are proposed to be rotated in this and other linked compartments means individual hazard events may propagate to other SSCs, thus creating potential for additional hazard scenarios currently not evaluated. This remains a safety case gap, and the shortfall is captured as part of Assessment Finding AF-UKHPR1000-0077.

1177. From my assessment of the internal hazards to the RCP I am satisfied that the RP has provided adequate substantiation of the RCP integrity. I have also been satisfied that the RP has eliminated hazards where possible and therefore for the purposes of GDA, has provided an adequate case for the RCP.

4.11.5.2 Conclusions from the Assessment

1178. My assessment of the RP's response to RO-UKHPR1000-046 (Ref. 88) has included all the submissions made to provide confidence that risks to highest integrity components (HIC) from internal hazards have been identified and reduced to a level which is ALARP.

1179. I am satisfied that the RP has applied adequate methodologies and analysis and has applied appropriate acceptance criteria from the relevant design codes, thus satisfying SAP's ECS.3 and EMC.3. The RP used R3 impact assessment methods for a number of areas, and I am satisfied that these are applied appropriately. The RP also extended its analysis to determine deformation and damage from a pipe whip impact, and this was applied to a sample case. Overall, I am satisfied that for GDA the RP has provided confidence that there are no fundamental shortfalls and satisfies SAP's EHA.1, EHA.6 and AV.2 with respect to analysis.

1180. Where hazards had been identified, the RP provided ALARP reviews (Ref. 155). I am satisfied that the RP updated the ALARP report (Rev B) (Ref. 155) to address the issues identified in almost all cases by opting to eliminate the hazard. I am satisfied that the RP has undertaken a robust hazard analysis and identified various modifications to plant and layout to eliminate hazards, satisfying SAP's EKP.3 and ELO.4. I have therefore formally closed RO-UKHPR1000-046, the rationale for which is captured in the RO assessment note (Ref. 259). The residual matters identified in the AN have been addressed by the RP, as detailed in my assessment above. I confirmed the closure of this RO in a formal letter to the RP (Ref. 274).

4.11.6 Internal Hazard Input to Other Regulatory Observations

1181. This section presents a short summary of the key internal hazard inputs supporting the assessment of other ROs raised by other specialisms:

- **RO-UKHPR1000-004** - Development of a Suitable and Sufficient Safety Case (Ref. 275).

1182. As an input to RO-UKHPR1000-004, I was requested to review the RP's hazard schedule structure. The RP provided its final hazard schedule (Ref. 92) to summarise the principal hazard scenarios identified in relation to its 3 assessment criteria. I assessed the hazard schedule structure and was content with it. I note that the schedules primarily focused on the safety systems to deliver their principal safety functions. In most instances these are the claimed class 1 divisional barriers.

1183. From my sampling and assessment, I identified that in addition to engineered safety systems the RP had made claims on human actions. To understand how the RP determined the need for relevant human based safety claims I raised RQ-UKHPR1000-1435 (Ref. 138). The RP's response (Ref. 138) provided clarity in the approach, and confirmed that the hazard analysis process had claimed human based safety claims that were necessary for the safety case (such as isolation of the JAC pump to minimise flooding in the BSX and stopping of battery charging to mitigate hydrogen release). I noted that human actions that could be claimed as defence in depth (like ensuring water-tight doors are closed) have not been fully captured. I do not consider this a significant issue as I expect this to be addressed by the licensee during detailed design as it develops the operational requirements.

1184. Overall, I am satisfied that the hazard schedule provided adequate details on the hazard protection requirements. I have sampled the claims on the barriers within my assessment and followed these to the safety functional requirements within the basis of design documents (Ref. 46), which demonstrated an auditable trail of evidence. The RP has now implemented a referencing system to enable improved tracking of hazard sequences and barrier substantiations. Based on my review of the hazard schedule (Ref. 92) I am satisfied that the hazard schedule is adequate for the purposes of GDA, thereby satisfying SAP SC.4. I expect these schedules to be developed further as the hazard analysis work is undertaken by the licensee at detailed design.

- **RO-UKHPR1000-008 -** Justification of the Structural Integrity Classification of the Main Coolant Loop (Ref. 276). **RO-UKHPR1000-058 -** Justification of the Structural Integrity Classification of the UK HPR1000 Main Steam Line and Associated Major Valves in the Safeguards Buildings (Ref. 166).

1185. I have provided support to the ONR structural integrity team in assessment of the consequential effects of the candidate HIC. I have assessed several reports and provided advice on the adequacy of the analysis to the SI team for their consideration. The most significant of which related to my assessment of the MSL classification within the BRX and BSX. Following assessment of this report (Ref. 223), I raised RQ-UKHPR1000-0925 (Ref. 141) to challenge the RP's understanding and analysis of the hazard consequences. As a result of this engagement, the RP reclassified the MSL in the BSX as a HIC. My assessment of the MSL is detailed in the HEPF and RO-UKHPR1000-046 sections of this report.

- **RO-UKHPR1000-014 -** Spent Fuel Building – Design of Nuclear Lifting Operations to Demonstrate Relevant Risks are Reduced to ALARP (Ref. 189).

1186. RO-UKHPR1000-014 was led by the ONR mechanical engineering team. The purpose of the RO was to review the design of nuclear lifting operations to determine relevant risks are reduced ALARP in the fuel building. In response to the RO the RP provided a review of the various lifting operations and associated consequences (Ref. 277). The RP's report identified that the most significant dropped load consequences related to the movement of fuel assemblies.

1187. The outputs of the RP's report were taken account of in my assessment of the dropped loads in the BFX (Ref. 168). My assessment of the dropped load report (Ref. 168) identified a number of gaps in the RP's safety case, principally relating to the lack of demonstration of controls to manage/eliminate the risks from the lifts. A number of RQs were issued to understand the gaps, and these are detailed in the dropped load section of this assessment report (sub-section 4.7). The shortfalls I identified principally related to the management of lifting operations to minimise the risks from lifting of fuel assemblies, and associated controls. In response and as part of RO-UKHPR1000-014, the RP undertook further review of the controls which was reported in the classification of the typical cranes report (Ref. 278). This report had also been used to inform my assessment on the adequacy of controls.

1188. Some of the RP's identified improvements as a result of RO-UKHPR1000-014 (Ref. 279) have resulted in changes in the BFX civil structure as well as to some SSCs which have not yet been fully incorporated in the generic UK HPR1000 design model. As detailed in sub-section 2.1 of this report, the scope of my IH assessment has been based on design information associated with design reference DR2.1 (Ref. 6).

1189. Although I have sampled these modifications, detailed assessment is out of my assessment scope, principally because the associated detailed design information is not expected for GDA. From my sample I found that the information in the report (Ref. 279) with respect to hazards was limited. It is my view that because there were no fundamental changes in SSC's I judge that it is unlikely that any significant risks have been introduced. Therefore it is my opinion the hazards identified in the relevant hazard reports for the BFX remain valid. I am also satisfied that the increase in building size is unlikely to result in significant cliff edge effects, although I expect some increase in hazard loads, such as combustible inventories from cables.

1190. A redesign of the building, such as that introduced by this RO, requires detailed assessment on a room-by-room basis. This can only be achieved once the detailed information is available at the detailed design following licensee design choices to ensure that the new layout, associated hazards, and consequences are clearly understood. This gap is captured in Assessment Finding AF-UKHPR1000-0071 (dropped loads).

- **RO-UKHPR1000-056 -** Fuel Route Safety Case (Ref. 190).

1191. RO-UKHPR1000-056 was principally led by the ONR fault studies team. Support was requested from internal hazards to review the proposed impact arrestor/ limiter design proposed by the RP (Ref. 187) to address identified shortfalls within the fuel route safety case.

1192. I sampled the RP's proposed design as presented in its response to RO-UKHPR1000-056 (Ref. 187). In the report (Ref. 187) the RP highlighted that the purpose of the arrestor is to reduce the impact load on the spent fuel cask falling from the design basis heights. The RP identified that the Cask has a withstand of 60G. Therefore, the safety functional requirement of the impact arrestor for any cask drop scenario is to maintain the deceleration of the cask below the 60G withstand criteria.

1193. For the purposes of GDA my sample focused on the RP’s case to demonstrate proof of concept. From my assessment I found that insufficient evidence had been provided to enable a judgment to be made on the adequacy of the design. This is based on the following:

- The surface selected to mitigate the fuel container impact is a thick reinforced concrete slab. I was not satisfied that the RP adequately demonstrated that the layout was optimised for impact absorption. I was unclear on the function of the aerated concrete directly underneath the thick concrete slab, as from the analysis the slab appears to act as the main absorber.
- The material properties were not defined by the RP and it was unclear how they had been used in modelling to represent the behaviour of the concrete and aerated concrete under the dynamic loads.
- The RP’s modelling assumed a perfect face down landing. This in my view may not necessarily represent the worst case drop load orientation.
- The RP’s analysis results demonstrate that there is little margin from the highest drop. Any uncertainty in the modelling approach, orientation of impact, variation in material dynamic properties, and lack of sensitivity analysis, places doubt in the claimed margin.
- The graphs from the simulations indicate that the cask sees the highest loading at the point of impact. This underlines my observation made above regarding the concrete slab thickness. The impact profile is representative of an object impacting a hard unyielding surface. To this end the evidence implies that the arrestor provides little or no deceleration of the falling mass. Therefore, the principal claim appears to be on the withstand of the container rather than the arrestor.
- It is unclear if this scenario is fully bounding. It is likely that the transporter would be in position during the lift and therefore justification is required by the RP to clarify how this impacts the conclusions made.

1194. Overall, I am not satisfied that the RP has demonstrated that the current arrestor/ impact limiter design is adequate to fulfil its safety function at this stage. I consider that the proposed design should be progressed alongside the BFX building modifications at detailed design. Once the licensee has developed the design further, a detailed analysis is required to substantiate the arrestor function. Due to this shortfall being important to the dropped loads case I have captured this in Assessment Finding AF-UKHPR1000-0071.

4.11.6.1 Regulatory Observations Safety Case Strengths

1195. Through my assessment recorded above, I have noted the following strengths in the RP’s response to regulatory observations raised.

- In all instances the RP has responded positively to all ONR challenges.
- For RO-UKHPR1000-0046 I have been satisfied that the RP has applied RGP and provided adequate assurance of HIC integrity against relevant design codes.
- For RO-UKHPR1000-053 the RP has demonstrated that a robust audit trail of evidence can be generated in line with relevant good practice.
- For RO-UKHPR1000-054 the RP has applied a systematic approach to its detailed hazard identification process to determine hazard loads in line with relevant good practice.

- For RO-UKHPR1000-055 the RP has provided a comprehensive and systematic hazard analysis in line with relevant good practice.

4.11.6.2 Outcomes

1196. In response to RO-UKHPR1000-046 assessment the RP has committed to implementing the following modifications within its HIC ALARP report (Ref. 155):

- Modification to pipe RCP6135TY to reduce the straight pipe length of the nozzle outlet to minimise pipe whip impact.
- Modification of valve orientations for valves RISi570VP, RISi571VP and RISi572VP (i=1,2,3).
- To add protective structure or baffle above the feedwater valves AREi440VL (i=1,2,3).
- To modify the orientation of all valves that can impact the SGs.
- To add pipe restraint on the horizontal section of AREi440TY (i=1,2,3).
- To add pipe restraints between pipe RISi561TY (i=1,2,3) and MCLs.
- To modify the orientation of all valves that can impact the MCLs.
- To add anti-whip restraints between RISi510TY (i=1,2,3) and MCLs.
- To modify the orientation of all valves that can impact the MSLs within the BRX and the BSX.
- Installation of wall and anti-whip restraint between AREi510TY (i=1,2,3) and MSLs.

1197. The above design modifications have been adequately consolidated by the RP. The modifications have been subject to the generic UK HPR1000 design modification process as design modification M86 (Ref. 280) and M91 (Ref. 281). These modifications are now incorporated in the latest generic UK HPR1000 design reference DR3.0, and documented in the updated design reference report (Ref. 268). I am satisfied that all the modifications are feasible, but further analysis and substantiation will be expected at detailed design.

1198. For all other ROs I have been satisfied for the purposes of GDA that the RP has provided sufficient evidence to satisfy my queries and close the ROs.

4.11.6.3 Conclusions

1199. Overall, I conclude that, following my assessment of the RP’s RO responses detailed above, I have confidence that the shortfalls identified in the safety case resulting in the raising of these ROs have been adequately addressed by the RP. I have identified several minor issues and Assessment Findings relating to the substantiation of safety measures, analysis methods and specific evidence gaps, but I do not judge these significant enough to prevent the issue of a DAC. I am satisfied that all assessment findings can be addressed at the detail design stage.

4.12 Demonstration that Relevant Risks Have Been Reduced to ALARP

4.12.1 Assessment

1200. For internal hazards the demonstration that risks have been reduced to ALARP is predicated on the application of RGP for the analysis and design process under design basis conditions and consideration of cliff edge effects. This is expected to inform whether adding further targeted engineered safety systems is grossly disproportionate to the risk reduction potentially achieved.

1201. With respect to the application of RGP, from my assessment I have noted areas where improvement is needed and/or future work is required to optimise or more fully articulate site-specific aspects of the internal hazards methodology and substantiation of associated safety measures. Nonetheless, for the purposes of GDA, I am satisfied the RP has adequately demonstrated the application of RGP and I highlight the following:

- The RP has identified the principal internal hazards within the scope of the GDA assessment.
- For criterion A, the RP has provided sufficient evidence to demonstrate that the claimed divisional barriers to maintain nuclear safety are acceptable.
- For criterion B, internal hazards that have the potential to affect more than one train of SSCs have been identified and have been shown to be acceptable through adequate hazard and functional analysis.
- For criterion C, internal hazards that have the potential to damage HIC, the RP's case provides reassurance that the risks to HIC from internal hazards have been adequately assessed and reduced to a level which is ALARP through layout or protection measures.
- The declared suite of standards and design codes are in line with relevant good practice, are relevant to their application and have been applied appropriately.
- Where I have found shortfalls, the RP has presented a case to demonstrate that the fundamental nuclear safety claims are not challenged, and where appropriate have addressed them through plant modifications.

1202. The RP has submitted several documents that explicitly present its arguments that risks have been reduced ALARP.

- ALARP demonstration report for internal hazards (Ref. 33).
- ALARP demonstration on plant layout in respect to HIC (Ref. 155).
- Holistic ALARP report (Ref. 282).
- PCSR Chapter 33 ALARP evaluation (Ref. 283).
- Draft PCSR Chapter 33 ALARP evaluation (Ref. 284).
- Post-GDA Commitment list (Ref. 285).

1203. From assessing these documents, I am satisfied that the documents listed provide an adequate demonstration that, for GDA, internal hazards risks are reduced to as low as reasonably practicable.

4.12.2 Strengths

- The RP has applied RGP and incorporated this within its methodologies.
- The RP has achieved demonstration that its three assessment criteria have been satisfied for the purposes of GDA.
- The RP has adequately captured the various shortfalls identified and where appropriate implemented modifications.

4.12.3 Outcomes

1204. I am satisfied that the RP has applied appropriate methodologies in its assessment of internal hazards. A number of shortfalls have been identified and Assessment Findings raised, however, I have judged these not to fundamentally challenge the overall generic UK HPR1000 design and can be addressed at detailed design.

1205. For internal hazards, the next stage of hazards safety case will be significantly influenced by the finalisation of the plant layout and site-specific design choices. These site-specific aspects should be considered as part of normal business post-GDA.

1206. As noted in Sub-section 2.1 the internal hazards safety case has been fixed on the design information associated with design reference (DR) 2.1 (Ref. 6). Further evolution of the design occurred during step 4 and I have sampled relevant modifications when appropriate, noting that in some instances the detailed design information was not fully available. On this basis the GDA assessment for internal hazards is predicated on de-risking the main design layout and methodologies via sample demonstrations of their application. Therefore, at GDA it is my opinion that it is not realistic for the RP to demonstrate fully that risks are reduced ALARP for internal hazards. Rather, the RP is expected to demonstrate that no significant issues remain that would preclude a full demonstration being made in the site-specific phase and that the overall design concept is viable.

1207. From my assessment recorded in the sections above, I judge that the RP has achieved this aim and adequately de-risked the layout of the generic UK HPR1000 design for hazard analysis. Therefore, I judge that the risks associated with this internal hazard assessment, at this stage of design development, have been reduced to ALARP.

4.12.4 Conclusion

1208. In conclusion, based on my assessment recorded in the sections above, I judge that for the purposes of GDA, the RP has demonstrated, at this stage of the design, that the risks from internal hazards are reduced to ALARP.

4.13 Consolidated Safety Case

4.13.1 Assessment

1209. As part of the requirements for GDA it is ONRs expectation (Ref. 1) that design changes, including modifications and any information provided in response to ONR technical questions within the scope of GDA, are consolidated into the relevant design reference documents.

1210. To address this requirement the RP provided its safety case consolidation strategy (Ref. 286) which is presented within the internal hazards production strategy (Ref. 287). The production strategy summarises the RP’s internal hazards safety case and its consolidation work for the internal hazards subject area.

1211. The RP stated that all the identified modifications will be fully incorporated in the final internal hazards PCSR version. I have reviewed the latest draft PCSR (Ref. 288) submitted by the RP to evidence its consolidation work. I sampled the following areas to determine the adequacy of the consolidation:

- That the MSL and MSIV are identified as HIC within the BSX.
- Inclusion of the barrier and restraints between the main feedwater pipes and main steam lines within the safeguard buildings related to IH-HEPF-BSX-10.
- The increase in the barrier thickness between the two main feed water pipes in safeguard building B related to IH-HEPF-BSX-07.
- The design improvements to reduce the potential drop height of the RPV head.
- The classification of the hydrogen isolation valves within the BFX in room BFX2020ZRM.
- All the proposed modifications on valve orientations to minimise risks to HIC.

1212. From my assessment I am satisfied that the RP has acknowledged these improvements in its draft PCSR update (Ref. 288). However, the current safety case, and associated references, in my view does not wholly present a complete consolidated case. Updates have not yet been applied for the lower-tier safety case documents, such as the hazard schedule and the main safety analysis reports. These will require updating at detailed design.

1213. For the consolidation of RQ responses and RO responses, I am satisfied that adequate documentation has been provided through the ALARP demonstration report for internal hazards (Ref. 33), the ALARP demonstration on plant layout in respect to HIC (Ref.

155), and Post-GDA Commitment list (Ref. 285), that capture the various IH modifications. These documents need to be used to update the main safety case documentation to ensure they reflect the current plant status going in to detailed design, and appropriate methodologies have been applied for all relevant analysis.

4.13.2 Strengths

- The RP has captured the improvements at a high level following the GDA process within the Draft PCSR report.

4.13.3 Outcomes

1214. From my assessment of the consolidation of the internal hazard safety case, I am satisfied that the RP has generally demonstrated that the outcomes from the step 4 assessment has been captured in its PCSR update. I recognise that further consolidation of the technical material throughout the lower safety case tiered documents is required, however for the purposes of GDA, I am content that the RP's consolidation is adequate.

4.13.4 Conclusion

1215. In conclusion, I have been satisfied that all the significant shortfalls that require specific design modifications as a result of ONR RQs and ROs have been captured within the PCSR. For the consolidation of the ROs responses and RQs, in the lower tier safety case documents, the RP has not fully achieved this within GDA. It is my view that this is a minor shortfall that can be addressed at detailed design when the internal hazards assessment must be revisited. Thus, for the purposes of GDA I am content that the RP has adequately consolidated the internal hazards case.

4.14 Comparison with Standards, Guidance and Relevant Good Practice

1216. I have assessed the RP's submissions with respect to their compliance with standards, guidance and relevant good practice. I have highlighted these areas within the appropriate sections of my report and highlighted areas where this has not been achieved. I have been satisfied that the RP has generally based its internal hazards assessment on RGP which has been incorporated within its methodologies. I have assessed the adequacy of the application of these methodologies. Overall, for the purposes of GDA, I am satisfied that the RP has followed and implemented RGP as detailed in the body of my report.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1217. This report presents the findings of my internal hazard assessment of the generic UK HPR1000 design as part of the GDA process.

1218. Based on my assessment, undertaken on a sampling basis, I have concluded the following:

- For the sample areas assessed, the RP has provided sufficient evidence to substantiate the claims and arguments detailed in the PCSR. This conclusion has been based on my assessment of the generic UK HPR1000 safety case and responses through various RQs and ROs.
- Detailed assessment of the methodologies applied for the various internal hazards has been undertaken. I have concluded that the methodologies are consistent with relevant good practice. Where shortfalls have been identified these have been raised and addressed by the RP for the highest risk areas. Although some shortfalls remain, these are judged not to undermine the conclusions of this report.
- The RP has provided adequate details of its hazard identification and screening processes to demonstrate that the key hazard areas have been identified and analysed.
- The generic UK HPR1000 design provides adequate segregation between the principal nuclear safety related divisions. This segregation is provided through claimed divisional barriers, the majority of which have been sufficiently substantiated through the assessment process. Where this has not been the case, I am satisfied that the RP has undertaken sufficient analysis to demonstrate that this does not have a significant impact to nuclear safety, and that further work has been identified to address this at the detailed design stage.
- The generic UK HPR1000 design has adequately identified areas where exceptions to segregation exist. In these situations, I have been satisfied that the RP demonstrated the design to be largely tolerant of loss of the systems in these areas. Where this is not the case, I am content the RP has adequately justified no significant impact to nuclear safety, and further work has been identified to address these at the detailed design stage.
- I am satisfied that the RP has adequately reviewed the risks from internal hazards to High Integrity Components (HIC) within the generic UK HPR1000 design. HIC are essential in maintaining nuclear safety and the impact on them from hazards must be eliminated as far as is reasonably practicable. A detailed review was undertaken to assess the risks of internal hazards to these components through my regulatory observation RO-UKHPR1000-046. As a result, the RP has proposed reorientation of approximately 300 valves across the three trains; modifications to various components, and installation of pipe whip restraints. Where hazards could not be avoided due to the limitations of the design, I am satisfied that the RP provided adequate analysis in line with relevant good practice to demonstrate that the components' integrity would not be compromised.
- Based on the segregation of plant and adequacy of the analysis undertaken by the RP I am satisfied that for the purposes of GDA the RP has provided sufficient evidence to demonstrate that the layout of the plant and the divisional barriers are adequate.
- The licensee needs to undertake further work to identify and fully substantiate all safety measures particularly for defence in depth and consolidate these within the hazard schedule.

1219. Based on my sample assessment of the safety case for the generic UK HPR1000 design undertaken in accordance with ONR’s procedures, I am satisfied that the case presented within the PCSR and supporting documentation is adequate. On this basis, I am content that a DAC should be granted for the generic UK HPR1000 design from an Internal Hazards perspective.

5.2 Recommendations

1220. Based upon my assessment detailed in this report, I recommend that:

- **Recommendation 1:** From an Internal Hazards perspective, ONR should grant a DAC for the generic UK HPR1000 design.
- **Recommendation 2**: The 23 Assessment Findings identified in this report should be resolved by the licensee for a site-specific application of the generic UK HPR1000 design.

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Annex 1

Relevant Safety Assessment Principles Considered During the Assessment

SAP No	SAP Title	Description
The Regulatory Assessment of Safety Cases		
SC.2	Safety case process outputs	The safety case process should produce safety cases that facilitate safe operation.
SC.3	Lifecycle aspects	For each lifecycle stage, control of the hazard should be demonstrated by a valid safety case that takes into account the implications from previous stages and for future stages.
SC.4	Safety case characteristics	A safety case should be accurate, objective and demonstrably complete for its intended purpose.
SC.5	Optimism, uncertainty and conservatism	Safety cases should identify areas of optimism and uncertainty, together with their significance, in addition to strengths and any claimed conservatism.
Engineering principles: Key principles		
EKP.1	Inherent safety	The underpinning safety aim for any nuclear facility should be an inherently safe design, consistent with the operational purposes of the facility.
EKP.2	Fault tolerance	The sensitivity of the facility to potential faults should be minimised.
EKP.3	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.
EKP.4	Safety function	The safety function(s) to be delivered within the facility should be identified by a structured analysis.
EKP.5	Safety measures	Safety measures should be identified to deliver the required safety function(s).
Internal Hazards		
EHA.1	Identification and characterisation	An effective process should be applied to identify and characterise all external and internal hazards that could affect the safety of the facility.
EHA.19	Screening	Hazards whose associated faults make no significant contribution to overall risks from the facility should be excluded from the fault analysis.

SAP No	SAP Title	Description
EHA.2	Data sources	For each type of external hazard either site-specific or, if this is not appropriate, best available relevant data should be used to determine the relationship between event magnitudes and their frequencies.
EHA.3	Design basis events	For each internal or external hazard which cannot be excluded on the basis of either low frequency or insignificant consequence (see Principle EHA.19), a design basis event should be derived.
EHA.4	Frequency of initiating event	For natural external hazards, characterised by frequency of exceedance hazard curves and internal hazards, the design basis event for an internal or external hazard should be derived to have a predicted frequency of exceedance that accords with Fault Analysis Principle FA.5. The thresholds set in Principle FA.5 for design basis events are 1 in 10 000 years for external hazards and 1 in 100 000 years for man-made external hazards and all internal hazards (see also paragraph 629).
EHA.5	Design basis event operating states	Analysis of design basis events should assume the event occurs simultaneously with the facility's most adverse permitted operating state - See SAPs para 631 c and d
EHA.6	Analysis	The effects of internal and external hazards that could affect the safety of the facility should be analysed. The analysis should take into account hazard combinations, simultaneous effects, common cause failures, defence in depth and consequential effects.
EHA.7	'Cliff-edge' effects	A small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences.
EHA.18	Beyond design basis events	Fault sequences initiated by internal and external hazards beyond the design basis should be analysed applying an appropriate combination of engineering, deterministic and probabilistic assessments.
EHA.13	Use, storage and generation of hazardous materials	The on-site use, storage or generation of hazardous materials should be minimised, controlled and located, taking due account of potential faults.
EHA.14	Fire, explosion, missiles, toxic gases etc – sources of harm	Sources that could give rise to fire, explosion, missiles, toxic gas release, collapsing or falling loads, pipe failure effects, or internal and external flooding should be identified, quantified and analysed within the safety case.
EHA.15	Hazards due to water	The design of the facility should prevent water from adversely affecting structures, systems and components.
EHA.16	Fire detection and fighting	Fire detection and fire-fighting systems of a capacity and capability commensurate with the worst-case design basis scenarios should be provided.
EHA.17	Appropriate materials in case of fires	Non-combustible or fire-retardant and heat-resistant materials should be used throughout the facility (see Principle EKP.1).
Safety Classification and Standards		
ECS.1	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 identified and then categorised based on their significance with regard to safety.

SAP No	SAP Title	Description
ECS.2	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 to safety.
ECS.3	Codes and 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 codes and standards.
Equipment Qualification		
EQU.1	Qualification procedures	Qualification procedures should be applied to confirm that structures, systems and components will perform their allocated safety function(s) in all normal operational, fault and accident conditions identified in the safety case and for the duration of their operational lives.
Design for reliability		
EDR.2	Redundancy, diversity and segregation	Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components.
EDR.4	Single failure criterion	During any normally permissible state of plant availability, no single random failure, assumed to occur anywhere within the systems provided to secure a safety function, should prevent the performance of that safety function.
Layout		
ELO.4	Minimisation of the effects of incidents	The design and layout of the site, its facilities (including enclosed plant), support facilities and services should be such that the effects of faults and accidents are minimised.
Safety Systems		
ESS.1	Provision of safety systems	All nuclear facilities should be provided with safety systems that reduce the frequency or limit the consequences of fault sequences, and that achieve and maintain a defined stable, safe state.
ESS.2	Safety system specification	The extent of safety system provisions, their functions, levels of protection necessary to achieve defence in depth and reliability requirements should be specified.
Fault Analysis		
FA.1	Design basis analysis, PSA and severe accident analysis	Fault analysis should be carried out comprising suitable and sufficient design basis analysis, PSA and severe accident analysis to demonstrate that risks are ALARP.
FA.2	Identification of initiating faults	Fault analysis should identify all initiating faults having the potential to lead to any person receiving a significant dose of radiation, or to a significant quantity of radioactive material escaping from its designated place of residence or confinement.

SAP No	SAP Title	Description
FA.3	Fault sequences	Fault sequences should be developed from the initiating faults and their potential consequences analysed.
FA.4	Fault tolerance	DBA should be carried out to provide a robust demonstration of the fault tolerance of the engineering design and the effectiveness of the safety measures.
FA.5	Initiating faults	The safety case should list all initiating faults that are included within the design basis analysis of the facility.
FA.7	Consequences	Analysis of design basis fault sequences should use appropriate tools and techniques, and be performed on a conservative basis to demonstrate that consequences are ALARP.
FA.8	Linking of initiating faults, fault sequences and safety measures	DBA should provide a clear and auditable linking of initiating faults, fault sequences and safety measures.
Assurance and validity of data and models		
AV.2	Calculation methods	Calculation methods used for the analyses should adequately represent the physical and chemical processes taking place.
AV.3	Use of data	The data used in the analysis of aspects of plant performance with safety significance should be shown to be valid for the circumstances by reference to established physical data, experiment or other appropriate means.
AV.4	Computer models	Computer models and datasets used in support of the safety analysis should be developed, maintained and applied in accordance with quality management procedures.
AV.5	Documentation	Documentation should be provided to facilitate review of the adequacy of the analytical models and data.
AV.6	Sensitivity studies	Studies should be carried out to determine the sensitivity of the analysis (and the conclusions drawn from it) to the assumptions made, the data used and the methods of calculation.

Annex 2

Assessment Findings

Note: These Assessment Findings must be read in the context of the sections of the report listed in this table, where further detail is provided regarding the matters that led to the findings being raised

Number	Assessment Finding/Shortfall	Report Section
AF-UKHPR1000-0056	The licensee shall, as part of detailed design, demonstrate that the risks from barrier failure through scabbing are reduced to as low as reasonably practicable.	4.2 4.8.5.1
AF-UKHPR1000-0057	The licensee shall, as part of the detailed design, refine and implement the internal fire hazards analysis methodology demonstrating that the shortfalls identified in GDA have been addressed. This should include, but not be limited to: ■ Full compartment burnout. ■ Conservative combinations of fire load density, heat release rates and vulnerable structures, systems, and components. ■ Conservative ventilation conditions including but not limited to open access doors and hatches. ■ Sensitivity analysis is conducted to identify and address potential cliff edge effects. ■ Models used for fire analysis are within their valid ranges. ■ Justification of the spatial separation and management of fire loads. ■ Optioneering is undertaken to demonstrate that all reasonably practicable measures to reduce risks have been analysed. ■ The identification and capture of safety requirements for structures, systems, and components. ■ Justification of the structures, systems, and components classification. ■ Justification of the codes and standards used to substantiate the structures, systems, and components.	4.3.2 4.3.4.2 4.3.4.3 4.3.4.4 4.3.4.5 4.3.5.1 4.3.5.2 4.3.6.1 4.3.6.2 4.3.6.3 4.3.7.1 4.11.5.1

Number	Assessment Finding/Shortfall	Report Section
AF-UKHPR1000-0058	The licensee shall, as part of detailed design, demonstrate that risks to SSCs from internal oil fires have been reduced to as low as reasonably practicable. This should include but not be limited to the reactor coolant pumps, the steam generators and the main coolant lines.	4.3.4.2 4.3.7.1 4.11.5.1
AF-UKHPR1000-0059	The licensee shall, as part of detailed design, demonstrate that risks from internal fire hazards to the pressuriser sensors have been reduced to as low as reasonably practicable.	4.3.4.4 4.3.7.1
AF-UKHPR1000-0060	The licensee shall, as part of site-specific design, demonstrate that seismic category 1 structures, systems and components are substantiated against the direct and indirect consequences of seismically induced fires.	4.3.6.2
AF-UKHPR1000-0061	The licensee shall, as part of detailed design, demonstrate that the risks from internal explosion hazard are reduced to as low as reasonably practicable. This should include but not be limited to: ■ The application of relevant blast reflection and correction factors ■ The justification of the screening criteria used for boiling liquid expanding vapour explosions.	4.4.2 4.4.3.2 4.4.3.3 4.4.5.1 4.4.5.2 4.8.2 4.8.4.1 4.8.6
AF-UKHPR1000-0062	The licensee shall, as part of detailed design, demonstrate that all reasonably practicable measures are adopted to prevent and mitigate the risks from blasts following an accumulator failure.	4.4.3.1 4.4.6

Number	Assessment Finding/Shortfall	Report Section
AF-UKHPR1000-0063	The licensee shall, as part of detailed design, demonstrate that the risks from blast following failures in the hydrogen pipe network within the fuel building are reduced to as low as reasonably practicable. This should include but not be limited to: ■ Demonstration that the layout of the hydrogen pipe network in the fuel building is optimised for hazard elimination. ■ Demonstration that the reliability of safety systems for the detection and isolation of hydrogen gas, can deliver the safety case requirements arising from the consequences of an unmitigated hydrogen release.	4.4.4.1 4.4.6
AF-UKHPR1000-0064	The licensee shall, as part of detailed design, substantiate the main steam isolation valves against blast loads.	4.4.5.3 4.11.5.1
AF-UKHPR1000-0065	The licensee shall, as part of detailed design, undertake sensitivity analysis of internal flooding hazards to demonstrate that cliff edge effects are understood and prevented so far as is reasonably practicable.	4.5.2 4.5.4.1 4.5.4.2 4.8.2
AF-UKHPR1000-0066	The licensee shall, as part of detailed design, demonstrate that all safety functions required to bring and maintain the plant in a safe state within the reactor building can be delivered in the event of internal flooding hazards. This should include but not be limited to those structures, systems and components located below the +1.20m level and the barrier door BRA1708VVD.	4.5.3.1 4.5.3.2 4.5.3.3 4.11.5.1
AF-UKHPR1000-0067	The licensee shall demonstrate that the detailed design of divisional barrier penetrations reduces risks to as low as reasonably practicable in the event of internal flooding hazards in the fuel building. This should include demonstration of the application of the hierarchy of safety measures.	4.5.4

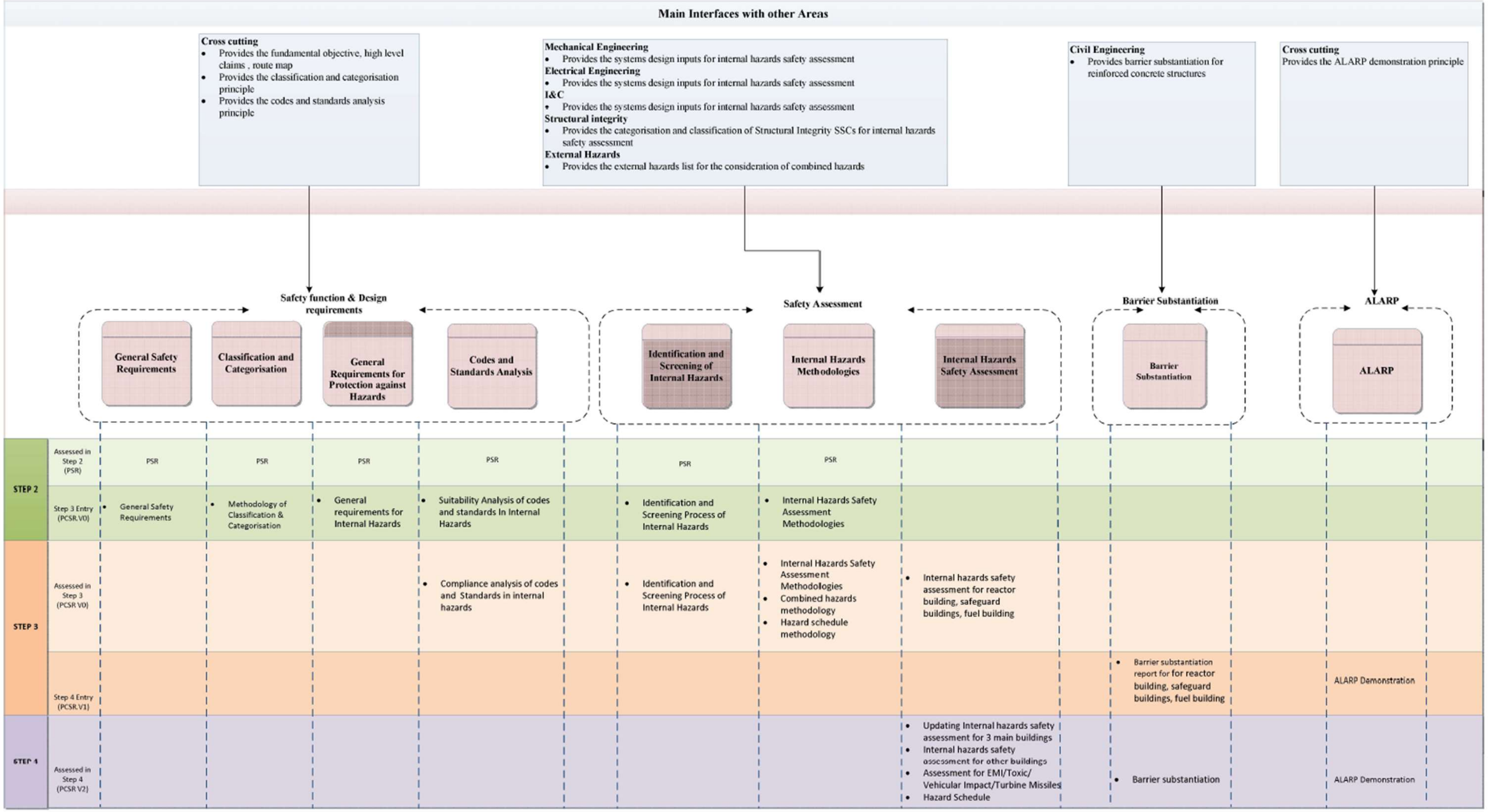
Number	Assessment Finding/Shortfall	Report Section
AF-UKHPR1000-0068	The licensee shall, as part of detailed design, demonstrate that the internal flooding risks from failures within the secondary passive heat removal system have been reduced to as low as reasonably practicable. This should include but not be limited to valves, joints and welds.	4.5.5.1
AF-UKHPR1000-0069	The licensee shall in the analysis of dropped loads for the detailed design, utilise criteria associated with design basis events for compressive strain and tensile strain in reinforced concrete structures.	4.3.6.1 4.6.4.1
AF-UKHPR1000-0070	The licensee shall, as part of detailed design, demonstrate that the risks from consequential flooding in the event of drop of the reactor pressure vessel head on the reactor pool structure have been reduced to as low as reasonably practicable.	4.3.6.1
AF-UKHPR1000-0071	The licensee shall, as part of detailed design, demonstrate that the internal hazards arising from the fuel cask handling operations are reduced to as low as reasonably practicable. This should include but not be limited to substantiation of the impact limiter design.	4.6.4.1 4.6.4.4 4.11.6
AF-UKHPR1000-0072	The licensee shall, as part of detailed design, demonstrate that the risks from internal missile hazards screened out based on restraints are reduced to as low as reasonably practicable. This should include, but not be limited to, substantiation of the restraint systems.	4.7.2
AF-UKHPR1000-0073	The licensee shall, as part of detailed design, demonstrate that the risks from consequential internal missile hazards are reduced to as low as reasonably practicable.	4.7.3.1

Number	Assessment Finding/Shortfall	Report Section
AF-UKHPR1000-0074	The licensee shall, as part of detailed design, address the gaps identified in GDA concerning combined internal hazards analysis, including but not limited to: ■ The potential for event sequences resulting from domino effects. ■ The potential for single and combined hazards to spread to adjacent buildings. ■ The effects on load bearing structural elements. ■ Prevention or mitigation of escalating event sequences. ■ Justification of the worst-case scenarios. ■ Validation of the assumptions of the containment of hazards in discrete rooms for hazards other than fire and flooding. ■ Demonstration that the appropriate safety functional requirements for all relevant structures, systems and components are derived for combined internal hazards.	4.9.3.1 4.9.4.1 4.9.6
AF-UKHPR1000-0075	The licensee shall, as part of detailed design, demonstrate that the risks to the emergency diesel generators, from all internal hazards, are reduced to as low as reasonably practicable, and that the generators are adequately segregated.	4.10.5
AF-UKHPR1000-0076	The licensee shall, as part of detailed design, demonstrate that the risks to high integrity components from combined internal hazard sequences are reduced to as low as reasonably practicable. This demonstration should include, but not be limited to: ■ Blast wave preceding further hazard impacts. ■ Demonstration that the combined blast / high energy pipe failure impact on the main coolant line loop 2 crossover leg is bounding.	4.4.3.3 4.11.5.1

Number	Assessment Finding/Shortfall	Report Section
AF-UKHPR1000-0077	The licensee shall, as part of detailed design, address gaps identified in GDA to demonstrate that the risks to high integrity components from internal missile hazards are reduced to as low as reasonably practicable. This should include, but not be limited to: ■ Demonstration that the implications of changing valve orientation to avoid high integrity component impacts does not result in other hazards. ■ Demonstration that options other than changing valve orientation, have been considered. ■ Substantiation that the design of rotating equipment minimises the risks of generating missiles. ■ Justification of the selection of 10° as the maximum angle for valve missile ejection. ■ Demonstration that for those missile impacts that cannot be eliminated, the withstand capability of associated high integrity components is substantiated.	4.7.5.2 4.11.5.1
AF-UKHPR1000-0078	The licensee shall, at as part of detailed design, demonstrate that the risks to the pressuriser from the pressuriser spray line pipe whip have been reduced to as low as reasonably practicable.	4.11.5.1

Annex 3

Illustrative Summary of the Generic UK HPR1000 IH Safety Case



Cross cutting
- Provides the fundamental objective, high level claims , route map
- Provides the classification and categorisation principle
- Provides the codes and standards analysis principle

Mechanical Engineering
- Provides the systems design inputs for internal hazards safety assessment

Electrical Engineering
- Provides the systems design inputs for internal hazards safety assessment

I&C
- Provides the systems design inputs for internal hazards safety assessment

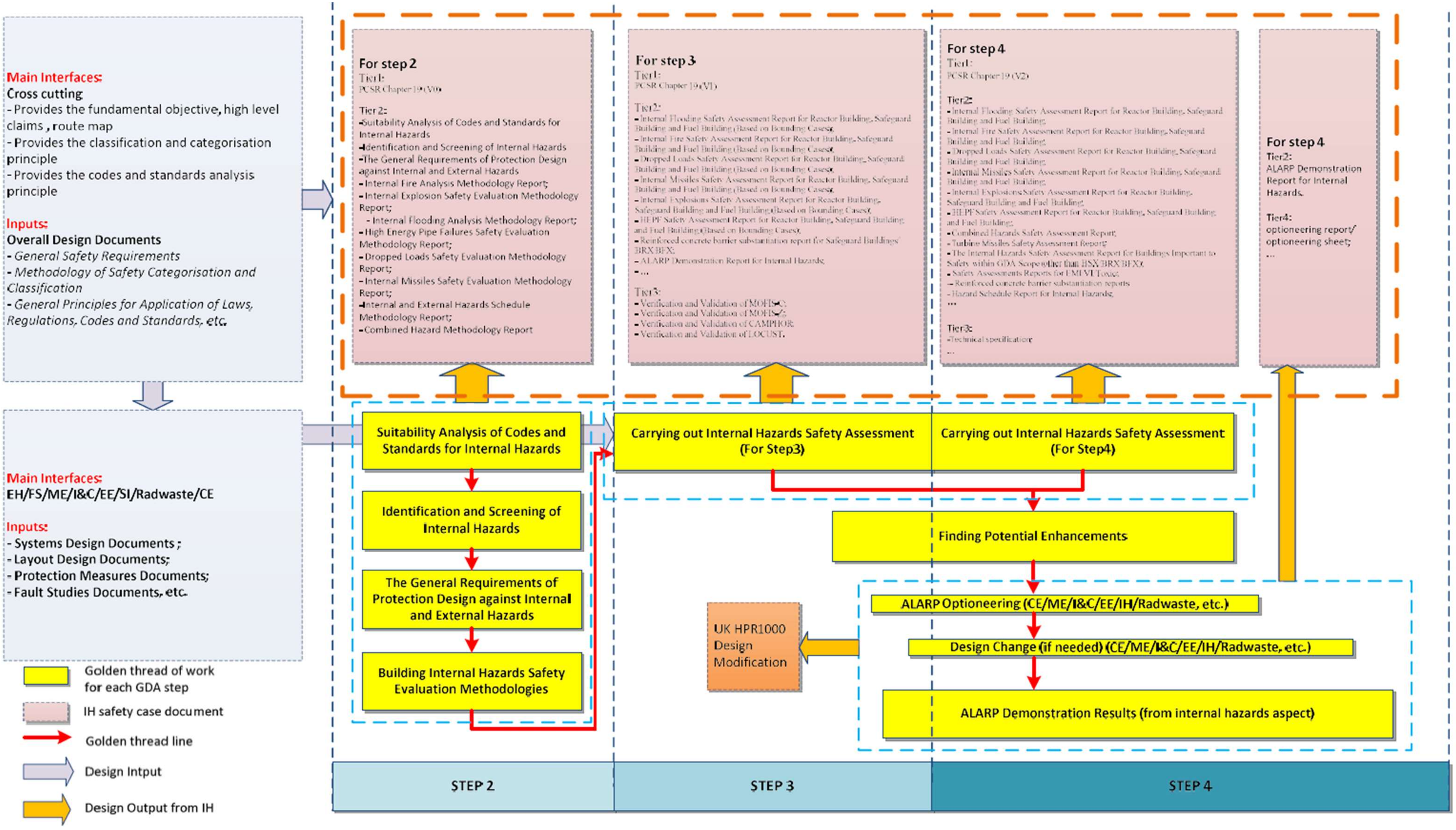
Structural integrity
- Provides the categorisation and classification of Structural Integrity SSCs for internal hazards safety assessment

External Hazards
- Provides the external hazards list for the consideration of combined hazards

Civil Engineering
- Provides barrier substantiation for reinforced concrete structures

Cross cutting
Provides the ALARP demonstration principle

		General Safety Requirements	Classification and Categorisation	General Requirements for Protection against Hazards	Codes and Standards Analysis	Identification and Screening of Internal Hazards	Internal Hazards Methodologies	Internal Hazards Safety Assessment	Barrier Substantiation	ALARP
STEP 2	Assessed in Step 2 (PSR)	PSR	PSR	PSR	PSR	PSR	PSR			
	Step 3 Entry (PCSR.V0)	• General Safety Requirements	• Methodology of Classification & Categorisation	• General requirements for Internal Hazards	• Suitability Analysis of codes and standards In Internal Hazards	• Identification and Screening Process of Internal Hazards	• Internal Hazards Safety Assessment Methodologies			
STEP 3	Assessed in Step 3 (PCSR V0)				• Compliance analysis of codes and Standards in internal hazards	• Identification and Screening Process of Internal Hazards	• Internal Hazards Safety Assessment Methodologies • Combined hazards methodology • Hazard schedule methodology	• Internal hazards safety assessment for reactor building, safeguard buildings, fuel building		
	Step 4 Entry (PCSR.V1)								• Barrier substantiation report for for reactor building, safeguard buildings, fuel building	ALARP Demonstration
STEP 4	Assessed in Step 4 (PCSR V2)							• Updating Internal hazards safety assessment for 3 main buildings • Internal hazards safety assessment for other buildings • Assessment for EMI/Toxic/ Vehicular Impact/Turbine Missiles • Hazard Schedule	• Barrier substantiation	ALARP Demonstration


Main Interfaces:
Cross cutting
- Provides the fundamental objective, high level claims, route map
- Provides the classification and categorisation principle
- Provides the codes and standards analysis principle
Inputs:
Overall Design Documents
- General Safety Requirements
- Methodology of Safety Categorisation and Classification
- General Principles for Application of Laws, Regulations, Codes and Standards, etc.
Main Interfaces:
EH/FS/ME/I&C/EE/SI/Radwaste/CE
Inputs:
- Systems Design Documents;
- Layout Design Documents;
- Protection Measures Documents;
- Fault Studies Documents, etc.
For step 2
Tier1:
PCSR Chapter 19 (V0)
Tier 2:
-Suitability Analysis of Codes and Standards for Internal Hazards
-Identification and Screening of Internal Hazards
-The General Requirements of Protection Design against Internal and External Hazards
- Internal Fire Analysis Methodology Report;
- Internal Explosion Safety Evaluation Methodology Report;
- Internal Flooding Analysis Methodology Report;
- High Energy Pipe Failures Safety Evaluation Methodology Report;
- Dropped Loads Safety Evaluation Methodology Report;
- Internal Missiles Safety Evaluation Methodology Report;
-Internal and External Hazards Schedule Methodology Report;
-Combined Hazard Methodology Report
For step 3
Tier1:
PCSR Chapter 19 (V1)
Tier2:
- Internal Flooding Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building (Based on Bounding Cases);
- Internal Fire Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building (Based on Bounding Cases);
- Dropped Loads Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building (Based on Bounding Cases);
- Internal Missiles Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building (Based on Bounding Cases);
- Internal Explosions Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building (Based on Bounding Cases);
- HEPF Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building (Based on Bounding Cases);
- Reinforced concrete barrier substantiation report for Safeguard Buildings/ BRX/BFX;
- ALARP Demonstration Report for Internal Hazards;
- ...
Tier3:
- Verification and Validation of MOFIS-C;
- Verification and Validation of MOFIS-Z;
- Verification and Validation of CAMPHOR;
- Verification and Validation of LOCUST.
For step 4
Tier1:
PCSR Chapter 19 (V2)
Tier2:
- Internal Flooding Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building;
- Internal Fire Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building;
- Dropped Loads Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building;
- Internal Missiles Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building;
- Internal Explosions Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building;
- HEPF Safety Assessment Report for Reactor Building, Safeguard Building and Fuel Building;
- Combined Hazards Safety Assessment Report;
- Turbine Missiles Safety Assessment Report;
- The Internal Hazards Safety Assessment Report for Buildings Important to Safety within GDA Scope (other than BSX/BRX/BFX);
- Safety Assessments Reports for EMI/VI/Toxic;
- Reinforced concrete barrier substantiation reports
- Hazard Schedule Report for Internal Hazards;
...
Tier3:
-Technical specification
...
For step 4
Tier2:
ALARP Demonstration Report for Internal Hazards.
Tier4:
optioneering report/ optioneering sheet;
...
Suitability Analysis of Codes and Standards for Internal Hazards
Identification and Screening of Internal Hazards
The General Requirements of Protection Design against Internal and External Hazards
Building Internal Hazards Safety Evaluation Methodologies
Carrying out Internal Hazards Safety Assessment (For Step3)
Carrying out Internal Hazards Safety Assessment (For Step4)
Finding Potential Enhancements
ALARP Optioneering (CE/ME/I&C/EE/IH/Radwaste, etc.)
Design Change (if needed) (CE/ME/I&C/EE/IH/Radwaste, etc.)
ALARP Demonstration Results (from internal hazards aspect)
UK HPR1000 Design Modification
STEP 2
STEP 3
STEP 4
Golden thread of work for each GDA step
IH safety case document
Golden thread line
Design Intput
Design Output from IH

Annex 4

Step 4 Assessment Plan & Report Compliance Summary

The table below presents the descriptions of the detailed areas of focus against the step 4 assessment plan activities.

Activity No	Description
Assessment Activities	
1	Assess that the links from the claims in the PCSR are appropriately supported by robust arguments and evidence for the areas sampled, the claims will be checked against the hazard schedule to ensure all relevant claims and arguments are captured.
Completed	Assessment of the evidence to substantiate the PCSR claims have been undertaken for each specific internal hazard and are detailed in the corresponding sections of this report. Overall, I have been satisfied that the PCSR claims have been adequately substantiated for the sample areas assessed, for the purposes of GDA, however several shortfalls have been identified with respect to substantiation of safety measures.
2	Ensure that a robust audit trail is present to justify the selection and application of the bounding cases for all individual internal hazards. Where bounding scenarios are to be applied to other areas to demonstrate hazard robustness, these should be appropriately justified with all relevant Structures, Systems and Components (SSCs) being identified and substantiated. Additionally, application of defence in depth will be sought.
Completed	I identified that the RP had not provided adequate evidence to fully justify all its bounding cases as the source data relating to detailed design was not readily provided. The main data sources for the internal hazards' assessment originate from the RP's 3D model of the generic UK HPR1000, this model is fixed on the design reference DR2.1, and therefore has been identified as the basis of the IH design. To obtain confidence that the RP had the ability to provide the evidence and justify their bounding cases RO-053 was raised to address the shortfall.
3	Assess that adequate methodologies are presented for outstanding internal hazards documents from Step 3 (Electro Magnetic Interference (EMI)/vehicle impact/toxic & corrosive gases and combined hazards (including domino effects)). Furthermore, the assessment will seek to ensure the methodologies (and any update) in all instances have been adequately applied for all internal hazards and RQ responses have been incorporated in the updated versions of all relevant safety assessment reports and methodologies reports.
Completed	All methodologies have been assessed and reported in the specific methodology section for each hazard area.
4	Assess that the updates to the thermal response and internal explosion methodologies are adequately captured.
Completed	Assessment of the CAMPHOR code has been undertaken and the explosion methodologies have also been assessed and reported.
5	Assess that the RP has undertaken a robust hazard analysis (Including unmitigated) for all internal hazards across the site that could impact nuclear safety. Have identified all relevant SSCs (including High Integrity Components) and demonstrated that the risks from internal hazards are ALARP.
Completed	As highlighted in the previous sections, I identified shortfalls in the quality and quantity of available evidence to demonstrate the hazard

Activity No	Description
	identification undertaken and support the narrative for the bounding cases, this extends to the explicit identification of safety systems and associated safety measures. This has been addressed through RO-053 I sampled the hazard impacts to HIC and I identified shortfalls in the narrative and evidence to demonstrate HIC withstand. To address this, I raised RO-046 that targeted this area specifically.
6	Determine the adequacy of the plant layout for internal hazards. This will focus on ensuring that SSCs delivering the fundamental safety functions are appropriately identified, substantiated and positioned such that internal hazards effects are minimised or eliminated, and that adequate defence in depth is demonstrated particularly for exceptions to segregation areas and areas where High Integrity components are located.
Completed	For safety significant highest integrity components (HIC) RO-046 was issued to determine the adequacy of plant layout. For all the other hazards the layout of plant and the associated SSCs and demonstration of withstand for claimed barriers have been assessed for each individual hazard.
7	Ensure that appropriate assessment of credible combined hazards (including Domino effects) has been undertaken. This will include assessment of the adequacy of the identification and analysis of the combined hazards. The assessment will also link in with the external hazards assessment, to ensure seismic events have inducing consequential internal hazards such as internal fire; internal explosions and internal flooding have been adequately captured.
Completed	I have reviewed both the methodology for the assessment and identification of combined hazards and its application. My findings are detailed within the combined hazards section of my report.
8	Work with the structural integrity and mechanical engineering leads in the resolution of the associated regulatory observations. And work with any disciplines as necessary.
Completed	I have supported several regulatory observations owned by different specialisms; the internal hazard inputs are detailed in the regulatory observation section of my report.
9	Ensure that a complete hazard schedule is developed by the RP. The schedule should capture all potential internal hazard sources, associated safety measures and identify defence in depth.
Completed	An example schedule was developed as part of the work linked to RO-4, my review of this is reported in the RO-04 section of my report.
10	Ensure that a conservative assessment and analysis has been undertaken, through the assessment of the application of the models used for steam release, fire and explosion analysis against relevant good practice.
Completed	Assessment of the fire codes (MOFIS) and steam release codes (CAMPHOR) has been undertaken.
11	Ensure that all barriers claimed for internal hazards are appropriately identified and substantiated. For all barrier penetrations appropriate design specifications are defined. The assessment will link with the Civils specialist to ensure that appropriate RGP has been applied in the

Activity No	Description
	analysis of the structural aspects to ensure any barrier failure would not lead to cliff edge effects.
Completed	The RP's GDA safety assessment for internal hazards has principally focused on three key aspects of the design, divisional barriers providing segregation, areas of exception to segregation where multiple trains are located and impacts to HICs. For the assessment of divisional barriers each assessment lists all the barriers and defines a bounding case. I have assessed each of the claims for all the sample buildings for all hazards. My findings are reported in the corresponding sections. I have also reviewed the RP's barrier substantiation methodologies, and this is reported in its specific section. One key shortfall area was the fact that in the assessment of the bounding cases the RP did not account for loads to non-barrier structural elements that provide a load path function for the global civil structure. This was considered a shortfall and therefore RO-054 was raised to address this.
12	Assess the appropriateness of categorisation and classification for safety measures identified. This will also be linked to the assessment of internal hazards across the site and through the development of the hazard schedule.
Completed	I have assessed the appropriateness of the cat and class of safety measures where appropriate within the relevant sections of my report.
13	Assess the RP's justification that the risks from internal hazards are ALARP. This will comprise of assessing the adequacy of identified safety measures, residual risk, identification of shortfalls and optioneering undertaken to address them. The ALARP assessment should be reflective of all modifications made and reflective of the plant as assessed in the internal hazard assessment. Where modifications have been proposed that would impact an internal hazard assessment, evidence will be sought to ensure that adequate change control measures are in place to determine any impact to the IH safety case.
Completed	For each hazard assessment I have reviewed the merits of the case to determine if the RP has provided sufficient evidence to demonstrate the risks are ALARP. This is summarised in the ALARP section.
Shortfalls from Step 3 to follow up	
14	The requisite narrative including transparency, evidence and justification of the bounding scenarios selected. All other initiating faults bounded by the bounding scenarios, identified in Step 3, should be explicitly stated and justified.
Completed	See Comments to 2 & 5
15	The application of the analysis methodologies including the requisite narrative, evidence and transparency of all key assumptions and factors, input data and analytical techniques used in the analysis including sensitivity analysis in demonstrating that the consequences analysis results are bounding and conservative.
Completed	See comments to 5, 6 & 7
16	The consequence analysis for all initiating faults (including vehicle impact, EMI, toxic and corrosive materials and gases and combined hazards), as necessary/ appropriate, for all internal hazards and all relevant buildings (Including all other buildings (within GDA) that

Activity No	Description
	present sources of internal hazards within the site). These should be presented in a coherent manner in the safety assessment reports and in the hazard schedules.
Completed	See comments to 3
17	The demonstration of the adequacy of all safety measures for internal hazards, including all individual safety measures e.g. all barriers, delivering the claims and arguments and their classification and categorisation.
Completed	See Comments 9,11 &12
18	Full application of all methodologies including for those internal hazards not submitted in Step 3, combined hazards (including domino effects) and barriers substantiation and any associated design modification.
Completed	See Comments 3,7 & 11
19	Demonstration that the design layout is robust against internal hazards especially in exception to segregation areas.
Completed	See Comment 6
20	The withstand capability of HIC and other SSC should be supported by the requisite evidence.
Completed	See Comments 5,6 & 8
21	Substantiation of all safety measures to the extent expected for GDA.
Completed	The principal safety measures identified in the generic UK HPR1000 design are the class 1 barriers, these have been assessed as part of the barrier assessment. All other SSCs have been assessed and their justification and adequacy have also been reviewed. It is recognised that at GDA not all SSCs would be fully substantiated.
22	The design specification for barriers penetrations
Completed	The RP provided a detailed example of the mechanical penetrations for high energy pipes that transit through barriers. This has been assessed as part of the High energy pipe failure assessment.
23	The consequences analysis in support of RO-UKHPR1000-0008 and RO-UKHPR1000-0014 (Ref. 14).
Completed	See Comment 8
24	The RP's incorporation of the RQ responses in the updated versions of all relevant safety assessment reports and methodologies reports.
Completed	This has been undertaken via sampling in the consolidation section of this report.
25	The validation and verification of model used in steam release.
Completed	See comment 10
26	The adequacy of the models used in fire and explosions consequences analysis.
Completed	See comment 10
27	The progress made with all the design gaps identified including the optioneering studies.
28	The ALARP demonstration.
Completed	See comment 13