Office for Nuclear Regulation

New Reactors Division

Step 4 Assessment of Internal Hazards for the UK Advanced Boiling Water Reactor

Assessment Report: ONR-NR-AR-17-033-UK ABWR
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EXECUTIVE SUMMARY

Hitachi-GE Nuclear Energy Ltd is the designer and Requesting Party (RP) for the United Kingdom Advanced Boiling Water Reactor (UK ABWR). Hitachi-GE requested ONR to commence a Generic Design Assessment (GDA) in 2013 and completed their submissions in support of Step 4 in 2017.

This assessment report is my Step 4 assessment of the Hitachi-GE UK ABWR reactor design in the area of internal hazards**.**

The scope of the Step 4 assessment is to review the safety, security and environmental aspects of the UK ABWR in greater detail, by examining the evidence, supporting the claims and arguments made in the safety documentation, building on the assessments already carried out for Step 3. In addition, I have provided a judgement on the adequacy of the internal hazards information contained within the Pre-Construction Safety Report (PCSR) and supporting documentation.

My assessment conclusions are:

1. I am satisfied with the claims, arguments and evidence laid down within the PCSR and supporting documentation for internal hazards.

2. I consider that from an internal hazards view point, the Hitachi-GE UK ABWR design is suitable for construction in the UK subject to future permissions and permits being secured.

My judgement is based upon the following:

- The hazard identification process has been systematic;
- Issues arising during Step 4 have been satisfactorily addressed via regular interventions and workshops with the RP.
- During the GDA, I challenged the RP via targeted Regulatory Queries (RQs) and Regulatory Observations (ROs). The RP responded in a positive and proactive manner, leading to additional documentation in response to my concerns and improvements in the safety case submissions for all areas of internal hazards;
- I challenged and influenced the RP to revise its analysis assumptions and design criteria for fire, flooding, pressure part failure, internal blast, conventional and turbine missiles, dropped loads, steam release and combined hazards in line with the relevant good practice established in the UK;
- I challenged the RP on the qualitative and quantitative consequences analysis undertaken for all areas including the computational modelling analysis;
- I achieved convergence on key UK regulatory expectations and consistency between the internal hazards, structural integrity, civil engineering and fault studies technical disciplines in the assessment criteria on pipe whip and jet impact, and combined consequential hazards;
- From my assessment of the Topic Reports and PCSR Chapter 7, I gained confidence that the claims are suitable and sufficient, and that they are supported by robust arguments and evidence;
- A coordinated approach with ONR specialist disciplines of civil engineering, fault studies, structural integrity and probabilistic safety assessment was followed to maintain consistency and clarify interfaces between our assessments.

Several assessment findings have been identified; these are for a future licensee to consider and take forward in their site-specific safety submissions. These matters do not undermine the generic safety submission, require licensee input/decision and do not prevent issuing a Design Acceptance Confirmation (DAC). A number of assessment findings will require significant analysis, but the RP is confident that there is reasonable flexibility in the design to enable full substantiation of the claims without major plant layout modifications.

I consider that from an internal hazards view point, the Hitachi-GE UK ABWR design is suitable for construction in the UK subject to future permissions and permits beings secured.

LIST OF ABBREVIATIONS

3D	Three-Dimensional
ABWR	Advanced Boiling Water Reactor
AC	Alternating Current
ACI	American Concrete Institute
ACOP	Approved Code of Practice
ADS	Automatic Depressurisation System
AF	Assessment Finding
AIRIS	Assumption Issue Register Information System
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
AP	Annulus Pressurisation
ARI	Alternative Rod Insertion
ASD	Adjustable Speed Drive
ASME	American Society of Mechanical Engineers
ATWS	Anticipated Transients Without Scram
B/B	Back-up Building
BBCR	Back-up Building Control Room
BBG	Back-up Building Alternative Generators
BDB	Beyond Design Basis
BDBE	Beyond Design Basis Event
BLEVE	Boiling Liquid Expanding Vapour Explosion
BPVC	Boiler and Pressure Vessel Code
BS	British Standard
BSL	Basic Safety Level
BSO	Basic Safety Objective
BSR	Barrier Substantiation Report
BWR	Boiling Water Reactor
C/B	Control Building
CBEEE/Z	Control Building Emergency Electrical Equipment (Zone)
CE	Civil Engineering
CFAST	Consolidated Fire and Smoke Tool
CFD	Computation Fluid Dynamics
CH	Chugging
C&I	Control and Instrumentation
CMR	Christian Michelsen Research
CO	Condensation Oscillation
COMAH	Control of Major Accident Hazards

CPS	Condensate Purification System
CRD	Control Rod Drive System
CST	Condensate Storage Tank
CUW	Clean-up Water System
DAC	Design Acceptance Confirmation
DB	Design Basis
DBA	Design Basis Analysis
DC	Direct Current
DEPSS	Drywell Equipment and Pipe Support Structures
DID	Defence in depth
DNV	Det Norske Veritas
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
DSP	Dryer Separator Pool
D/W	Dry Well
DWC	Drywell Cooling
EA	Environment Agency
ECCS	Emergency Core Cooling System
EC&I	Electrical, Control & Instrumentation
EDG	Emergency Diesel Generator
EDG/B	Emergency Diesel Generator Building
EECW	Emergency Equipment Cooling Water System
EHC	Electro-Hydraulic Control
EMI	Electromagnetic Interference
EMIT	Examination, Maintenance, Inspection and Testing
ES	Extraction Steam System
FCVS	Filtered Containment Venting System
FDT	Fire Dynamic Tools
FDW	Feed Water System
FEA	Finite Element Analysis
FLSS	Flooder System of Specific Safety Facility
FMCRD	Fine Motion Control Rod Drive
FNC	Frazer Nash Consultancy
FPC	Fuel Pool Cooling and Clean-up System
FSF	Fundamental Safety Function
Fv/B	Filter Vent Building
FZK	Forschungszentrum Karlsruhe (Karlsruhe Research Center)
GDA	Generic Design Assessment
HELB	High Energy Line Break
HCU	Hydraulic Control Unit

HD	Feedwater Heater Drain system
HEAF	High Energy Arcing Fault
HECW	HVAC Emergency Cooling Water System
HELB	High Energy Line Break
HMI	Human Machine Interface
HP	High Pressure
HPCF	High Pressure Core Flooder
HRR	Heat Release Rate
HRRUA	Heat Release Rate Per Unit Area
HS	Heating Steam
HSCR	Heating Steam Condensate Water Return
HSE	Health and Safety Executive
HV	High Voltage
HVAC	Heating Ventilation and Air Conditioning
HWBP	Hard Wired Backup Panel
HWBS	Hard Wired Backup System
HWC	Hydrogen Water Chemistry
Hx/B	Heat Exchanger Building
IAEA	International Atomic Energy Agency
I&C	Instrumentation & Control
ID	Identification
iDAC	interim Design Acceptance Confirmation
IEEE	Institute of Electrical and Electronics Engineers
IH	Internal Hazards
J-ABWR	Japanese Advanced Boiling Water Reactor
JANTI	Japan Nuclear Technology Institute
LCW	Low Conductivity Waste System
L/D	Length divided by diameter
LDS	Leak Detection System
LEL	Lower Explosive Limit
LFL	Lower Flammability Limit
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LP	Low Pressure
LPFL	Low Pressure Core Flooder
LS	Livermore Software Technology Corporation
LT	Low Trajectory
MADA	Multi-Attribute Decision Analysis
MCC	Main Control Console

MCR	Main Control Room
MDEP	Multi-national Design Evaluation Programme
MEM	Multi Energy Method
MG	Motor Generator
MS	Main Steam
MSIV	Main Steam Isolation Valve(s)
MSL	Main Steam Line
MSLBA	Main Steam Line Break Accident
MSR	Moisture Separator Reheater
MSTR	Main Steam Tunnel Room
MUWP	Makeup Water Purified System
MVP	Mechanical Vacuum Pump
NMCA	Noble Metal Chemistry Addition
NI	Nuclear Island
NIST	Nation Institute of Science and Technology
NRC	Nuclear Regulatory Commission
NRW	Natural Resources Wales
NSC	Nuclear Special Crane
NUREG	(United States) Nuclear Regulatory Commission Regulation
OECD-NEA	Organisation for Economic Co-operation and Development Nuclear Energy Agency
OG	Off-gas
ONR	Office for Nuclear Regulation
OPEX	Operational Experience
PCIS	Primary Containment Isolation System
PCSR	Pre-Construction Safety Report
PCV	Primary Containment Vessel
P&ID	Piping & Instrumentation Diagram
Pre-AMP	Pre-Amplifier
PS	Power Supply System
PSA	Probabilistic Safety Assessment
PSR	Preliminary Safety Report
PWR	Pressurised Water Reactor
R/B	Reactor Building
RBEEZ	Reactor Building Electrical Equipment (Zone)
RC	Reinforced Concrete
RCA	Radiation Controlled Area
RCCV	Reinforced Concrete Containment Vessel
RCIC	Reactor Core Isolation Cooling System
RCW	Reactor Building Cooling Water System

RDCF	Reactor Depressurisation Control Facility
RGP	Relevant Good Practice
RHR	Residual Heat Removal System
RI	Regulatory Issue
RIP	Reactor Internal Pump
RFI	Radio Frequency Interference
RO	Regulatory Observation
RP	Requesting Party
RPS	Reactor Protection System
RPT	Recirculation Pump Trip
RPV	Reactor Pressure Vessel
RPVHS	Reactor Pressure Vessel Head Spray
RQ	Regulatory Query
RSP	Reactor Shutdown Panel
RSS	Remote Shutdown System
RSW	Reactor Building Service Water System
RVI	Reactor Vessel Instrumentation System
RW	Reactor Well
Rw/B	Radwaste Building
RWSP	Reactor Well Shield Plug
SA	Severe Accident
SAP(s)	Safety Assessment Principle(s)
SAuxP	Safety Auxiliary Panel
S/B	Service Building
S/C	Suppression Chamber
SCDM	Safety Case Development Manual
SDC	Shutdown Cooling Mode
SFAIRP	So Far As Is Reasonably Practicable
SFP	Spent Fuel Storage Pool
SFS	Spent Fuel Storage Facility
SJAE	Steam Jet Air Ejector
SLC	Standby Liquid Control System
SoDA	Statement of Design Acceptability
SP	Suppression Pool
SPC	Safety Property Claims
SPCU	Suppression Pool Clean-up System
SRNM	Startup Range Neutron Monitoring System
SRV	Safety Relief Valve

SSC	System, Structure (and) Component
SSLC	Safety System Logic and Control
SSER	Safety, Security and Environmental Report
ST	Service Tunnels
TAF	Top of active fuel
TAG	Technical Assessment Guide
T/B	Turbine Building
TNT	Trinitrotoluene
TR	Topic Report
TSC	Technical Support Contractor
TSW	Turbine Building Service Water System
VCE	Vapour Cloud Explosion
VHI	Very High Integrity
UPS	Uninterruptible Power Supply
US	United States of America
US NRC	United States (of America) Nuclear Regulatory Commission
UK	United Kingdom
WDP	Wide Display Panel
WENRA	Western European Nuclear Regulators' Association
XLPE/SLPE	Cross linked polyethylene

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1 INTRODUCTION

1. This assessment report details my Step 4 Generic Design Assessment (GDA) of Hitachi-GE's UK ABWR reactor design in the area of internal hazards.

1.1 GDA Background

2. Information on the GDA process is provided in a series of documents published on our website **http://www.onr.org.uk/new-reactors/index.htm**. There could be three potential outcomes at the end of Step 4:

- Provision of a Design Acceptance Confirmation (DAC), marking the end of GDA for that generic design.
- Provision of an interim DAC (iDAC) identifying outstanding GDA Issues.
- No DAC being provided.

3. If ONR are fully content with the generic safety and security aspects a DAC will be the outcome for ONR at the end of Step 4. Similarly, a Statement of Design Acceptability (SoDA) for the Environment Agency (EA) and Natural Resources Wales (NRW) will be the outcome.

4. The GDA of the UK ABWR has followed a step-wise approach in a claims-arguments-evidence hierarchy which commenced in 2013. Major technical interactions started in Step 2 with an examination of the main claims made by Hitachi-GE for the UK ABWR. In Step 3, the arguments which underpin those claims were examined. The reports in individual technical areas and accompanying summary reports are also published in ONR's website.

5. The objective of the Step 4 assessments is to undertake an in-depth assessment of the safety, security and environmental evidence. Through the review of information provided to ONR, the Step 4 process should confirm that Hitachi-GE:

- Has properly justified the higher-level claims and arguments;
- Has progressed the resolution of issues identified during Step 3; and
- Has provided sufficient detailed analysis to allow ONR to come to a judgment of whether a DAC can be issued.

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

- Consideration of issues identified in Step 3.
- Judging the design against the Safety Assessment Principles (SAPs) and whether the proposed design reduces risks to as low as is reasonably practicable (ALARP).
- Reviewing details of the Hitachi-GE design controls, procurement and quality control arrangements to secure compliance with the design intent.
- Establishing whether the system performance, safety classification, and reliability requirements are substantiated by the detailed engineering design.
- Assessing arrangements for ensuring and assuring that safety claims and assumptions are realised in the final as-built design.
- Resolution of identified nuclear safety and security issues, or identifying paths for resolution.

7. All regulatory observations (ROs) issued to Hitachi-GE as part of my assessment are also published on ONR's website, together with the corresponding Hitachi-GE resolution plan and confirmation of adequate closure.

1.2 Scope

8. The intended assessment strategy for GDA Step 4 in the internal hazards area was set out in an assessment plan (Ref. 2).

9. The objective of this GDA Step 4 internal hazards assessment has been to assess the safety case submitted by the RP for all applicable internal hazards including combined and consequential events.

10. The scope of this assessment focused on the internal hazards Design Basis Analysis (DBA) undertaken by the RP. It includes an assessment of plant specific internal hazards, development and application of consequences analysis methodologies, identification of safety measures and substantiation of them. It focuses primarily on Class 1 buildings such as the Reactor Building (R/B), Control Building (C/B) and Heat Exchanger Building (Hx/B), which contain most of the Systems, Structures and Components (SSCs) delivering the Fundamental Safety Functions (FSF), and to a lesser extent other buildings such as the Turbine Building (T/B) where an internal hazard originating in them could threaten Class 1 buildings.

11. The internal hazards GDA review has followed a step-wise approach in a claims-argument-evidence hierarchy, as set out in ONR's guidance. In the earlier Steps 2 and 3, the underpinning safety claims and arguments were assessed (Refs. 3 and 4). As a result of my interactions with the RP, during Steps 2 and 3, the safety claims and arguments identified in the internal hazards safety case have been reviewed and updated during Step 4. The Step 4 assessment, therefore, focuses on the completeness of the internal hazards related claims and arguments and looking in greater detail at the evidence that supports the claims and arguments made by the RP. This has involved the review of documentation:

- Summarising the safety case claims, arguments and evidence for each internal hazard including combined internal hazards;
- Detailing the methodologies and analysis undertaken for each internal hazard;
- Summarising the substantiation of the barriers;
- Summarising the safety case for specific plant areas where divisional segregation by barriers is unavailable;
- Demonstrating that claims and arguments identified in internal hazards are being cascaded and linked to other technical areas and safety case documentation; and
- In response to Regulatory Queries (RQs) and ROs.

12. In addition to the technical information contained within submissions, this assessment has also considered the adequacy with which the multiple documents provided in the internal hazards area are linked together to form a coherent safety case, and how they interface with and support the safety case documentation in other technical areas. The RP's top-level report which summaries the totality of its safety case for the UK ABWR, and ties all the different topic areas together is the generic pre-construction safety report (PCSR).

1.3 Method

13. My assessment complies with ONR guidance on the mechanics of assessment described in NS-PER-GD-014, 'Purpose and Scope of Permissioning' (Ref. 5).

2 ASSESSMENT STRATEGY

2.1 Standards and Criteria

14. The Safety Assessment Principles (SAPs, Ref. 6) constitute the regulatory principles against which dutyholders' safety cases are judged, and therefore are the basis for ONR's nuclear safety assessments, including the assessment detailed in this report. The SAPs are supplemented by Technical Assessment Guides (TAGs, Refs. 7 and 8) which provide additional advice to ONR inspectors on assessing safety case submissions.

15. International guidance documents are also available which capture long-established Relevant Good Practices (RGP) for reactor design basis analysis.

2.1.1 Safety Assessment Principles

16. The key SAPs applied within the assessment are listed in Annex 1.

2.1.2 Technical Assessment Guides (TAGs)

17. The TAGs that have been used as part of this assessment are listed in Annex 2.

2.1.3 National and International Standards and Guidance

18. The national, international standards and guidance that have been used as part of this assessment are listed in Annex 3.

2.2 Use of Technical Support Contractors (TSCs)

19. It is usual in GDA for ONR to use technical support, for example to provide additional capacity to optimise the assessment process, enable access to independent advice and experience, analysis techniques and models, and to enable ONR's inspectors to focus on regulatory decision making.

20. To supplement ONR's internal capability, for a limited period, a TSC (Frazer Nash Consultancy) was contracted to work as an integral part of the GDA Step 4 assessment team under my supervision. The TSC work focused on an assessment of the early Step 4 revisions of Topic Reports and support information for the safety cases on internal flooding, conventional missiles, internal fire, inside the Primary Containment Vessel (PCV) and inside Main Control Room (MCR). The use of a TSC allowed ONR's internal hazards resources to focus on significant issues such as analysis methodologies and overall convergence between UK and Japanese regulatory expectations. The outcome of the TSC assessment was captured in a number of RQs.

21. It is important to note that the overall judgements and conclusions reached in this assessment report are my own.

2.3 Integration with Other Assessment Topics

22. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment cannot therefore be carried out in isolation as there are often safety issues of a multi-topic or cross-cutting nature. The nature of internal hazards is such that it requires interface with many topics with the following areas particularly notable:

- **Civil Engineering: Substantiation of Class 1 barriers against internal hazards**. Segregation of Class 1 SSCs by Class 1 barriers is one of the key claims in the internal hazards area. Substantiation of barriers including penetrations was the subject of Regulatory Observation RO-ABWR-0082 (Ref. 9) which its resolution required collaboration with civil engineering. In addition throughout the Step 4 stage, collaboration with civil engineering on various other topics took place including; Emergency Diesel Generators (EDGs) site relocation optioneering studies, doors on Class 1 barriers, design of the tunnels and spent fuel export optioneering studies.

- **Control and Instrumentation (C&I): Doors on Class 1 barriers**. Regulatory Observation RO-ABWR-0012 (Ref. 10) was raised in order to understand the role and claims made for the doors on Class 1 barriers. Interactions centred on minimising doors on Class 1 barriers, incorporation of door alarms and classification of the alarm system. Interactions were held to ensure that the C&I expectations were reflected in the design of the door alarm system.
- **Control and Instrumentation: Electromagnetic interference (EMI) hazard**. Interactions took place to ensure the C&I expectations on design of C&I systems against Electromagnetic Interference (EMI) hazards was reflected in the design and in the Topic Report submitted.
- **Control and Instrumentation / Electrical / Mechanical Engineering/ Fault Studies: Exceptions to Segregation**. The UK ABWR design includes a number of plant areas where the fundamental principles of segregation, redundancy and diversity could not be applied. Interactions were required to ensure a systematic analysis of all relevant internal hazards consequences, identification of safety measures to deliver the fundamental safety functions, cohesive claims, arguments and evidence and a demonstration that the risks had been reduced to ALARP.
- **Control and Instrumentation / Fault Studies / Mechanical Engineering / Structural Integrity / Civil Engineering / Nuclear Liabilities: Spent Fuel Route**. Regulatory Observation RO-ABWR-0056 (Ref. 11) was raised on the optioneering studies undertaken on the spent fuel export covering the removal of spent fuel from the Spent Fuel Pool (SFP), loading the spent fuel into the transfer container and its export from the Reactor Building (R/B). Dropped load consequences analysis of the spent fuel cask required interactions with these disciplines to ensure that the risk from the proposed design is reduced to As Low As Reasonably Practicable (ALARP).
- **External hazards: Combined and consequential events**. Interactions were held on the derivation of consequential internal hazards induced by external hazards.
- **Fault Studies: Fault schedule and links to the hazard schedules**. Internal hazards are potential initiators of design basis and beyond design basis events. Interactions were held to ensure alignment between fault studies and internal hazards; and that suitable information was reflected in hazard schedule.
- **Fire Safety: Regulatory Observation RO-ABWR-0012**. Some limited interactions were held with conventional fire safety.
- **Probabilistic Safety Analysis (PSA): PSA prioritisation**. The internal hazards deterministic analysis provided input information for the PSA analysis. This ensured that the PSA assumptions were aligned with the design and operational procedures in this area.
- **Reactor Chemistry: Radiolytic hydrogen**. Interactions were held to ensure that the consequences analysis from any radiolysis gases generated in normal operating conditions from the process were addressed in the internal hazards safety case as per Regulatory Observation RO-ABWR-0044 (Ref.12).
- **Structural integrity: Analysis methodology of pipe whip and jet impact**. The analysis methodology used in the consequences analysis in the internal hazards area also fed into the categorisation and classification of structural integrity components. Break locations, consequential analysis and pipe to pipe interactions inside and outside containment were key aspects of our interactions.

2.4 Sampling Strategy

23. It is seldom possible, or necessary, to assess a safety case in its entirety, therefore sampling is used to limit the areas scrutinised, and to improve the overall efficiency of the assessment process. Sampling is done in a focused, targeted and structured manner with a view to revealing any topic-specific, or generic, weaknesses in the safety case.

24. The sampling strategy for this assessment was to ensure that all relevant areas of the safety case were covered by the RP, and that the nuclear safety significance of each submission was understood and clearly articulated. My assessment focused primarily on the R/B, C/B and Hx/B, which contain the vast majority of SSCs important to the delivery of the FSFs, and on the following aspects:

- The suitability and sufficiency of the claims, arguments and evidence, as captured in the Topic Reports and summarised in Chapter 7 of the PCSR.
- The adequacy of internal hazards characterisation which entailed internal hazard identification, development and application of analysis methodologies, consequences analysis, and substantiation of the claims made.
- Overall consistency in the safety case submissions for each Topic Report and between various reports (e.g. Topic Reports, Barrier Substantiation Report, Boundary Map) and demonstrating that the internal hazards aspects have been cascaded to other technical areas and reflected in the overall design.
- Outstanding issues requiring addressing post GDA.

25. I also focused my assessment to power operation mode which in most cases bounded the consequences of all other operational modes (start up, hot stand by, cold shutdown and refuelling outage). The limited cases where other plant operations presented more challenging scenarios than the power operation mode were also reflected in my assessment.

26. I also undertook some limited sampling on the following:

- Class 2 systems delivery Category B safety functions or making significant contribution to Category A safety functions, e.g. the Flooder System of Specific Safety Facility (FLSS).
- The postulated events and consequences analysis for the Turbine Building focusing on fire and turbine disintegration. Such an event may compromise delivery of Category A safety functions.
- The finalised version of the RP's PCSR was not available until late on in the assessment period (31 August 2017), and therefore I only carried out a limited sample of the final PCSR (Ref. 15). It should be also stated here that early draft versions of the PCSR were available for information and high level comments from ONR (Refs. 13-14), but these did not form part of my formal assessment as captured in this assessment report.).
- Service tunnels: which are in concept design stage. My assessment was limited to provide some guidance on ONR's expectations on the control of internal hazards in this area via RQs. The detail design of service tunnels will be completed post GDA.

27. My sampling strategy specific to each internal hazard topic area is given in section 4 below, which described ONR's assessment in detail.

2.5 Out of Scope Items

28. The following items have been agreed with the RP as being outside the scope of this GDA and remain outside the scope of this assessment:

- Suitable closure of AFs (assessment findings) shall be the responsibility of a licensee and assessment of these will be undertaken post GDA in site-specific activities by ONR.
- Site-specific elements of the UK ABWR design. These will be assessed by ONR as part of any future site-specific activities.
- Postulated internal hazards resulting in non-nuclear safety consequences impacting on persons either within the site or outside of the site boundary. These shall be the responsibility of a licensee and assessment of these may be undertaken post GDA in site-specific activities by ONR.

3 REQUESTING PARTY'S SAFETY CASE

3.1 Safety Case Structure and Documentation

29. The RP submitted its generic PCSR which is the key documentation that outlines the reasons supporting its top level claim that the "UK ABWR constructed on a generic site within the United Kingdom, can be operated safely under all operating and fault conditions." (Ref.16, p.1.1-1).

30. The PCSR includes 32 chapters. Chapter 7 of the PCSR (Ref. 15) is on internal hazards. This chapter presents the summary of the lower level safety case documents covering internal hazards, such as Topic Reports and other reports. It is these references (and supporting references from these reports) which have been the main areas for assessment during GDA Step 4 and provide the technical basis for most of the regulatory judgements included in this report.

31. The RP's safety case for internal hazards is documented in the following key documents:

- Pre-Construction Safety Report (PCSR) Chapter 7 (Refs. 15 and 16);
- Topic Report on Electromagnetic Interference (Refs. 17, 18, 19, 20 and 21);
- Topic Report on Exceptions to Segregation (Refs. 22, 23, 24 and 25);
- Topic Report on Fire and Explosions (Refs. 26, 27, 28,29, 30, 31);
- Topic Report on Internal Flooding (Refs. 32, 33, 34, 35 and 36);
- Topic Report on Pipe Whip and Jet Impact (Refs. 37, 38, 39, 40, 41 and 42);
- Topic Report on Dropped and Collapsed Loads (Refs. 43, 44 45, 46 and 47);
- Topic Report on Internal Blast (Non-Combustible Explosion) (Refs.48, 49, 50, 51 and 52);
- Topic Report on Combined Hazards (Refs. 53, 54, 55, 56 and 57);
- Topic Report on Miscellaneous Hazards (Refs. 58, 59 and 60);
- Topic Report on Internal Hazards in Main Steam Tunnel Room (Refs.61, 62, 63 and 64);
- Topic Report on Doors on Class 1 Barrier (Refs. 65, 66, 67 and 68);
- Topic Report on Internal Hazards Inside PCV (Refs.69, 70, 71 and 72);
- Topic Report on Internal Missile – Conventional Internal Missiles (Refs. 73, 74, 75, 76, 77, 78);
- Topic Report on Internal Hazards inside Main Control Room (Refs. 79 and 80);
- Topic Report on HVAC Penetrations on Class 1 Barriers (Refs. 81 and 82);
- Topic Report on Turbine Disintegration (Refs. 83 and 84); and
- Internal Hazards Barrier Substantiation Report (Refs. 85, 86, 87, 88, 89 and 90).

32. In addition to the above, many other reports have been referenced by the RP and submitted to ONR in the course of Step 4 of the GDA. These have been assessed and referenced as appropriate in section 4 of this assessment report.

33. The safety case submissions structure reflects the claims made. For each document multiple revisions have been submitted which either report the progress made building by building or to reflect responses to ONR's RQs and ROs.

3.2 Safety Case Submissions Addressing ROs

34. During GDA, I identified significant gaps in the RP's internal hazards safety case that needed to be addressed through ROs. A number of ROs were cross-cutting with other assessment disciplines, but included specific actions relevant to internal hazards:

- RO-ABWR-0012 – Presence of Single Doors on Class 1 Nuclear Safety Barriers (Ref. 10);

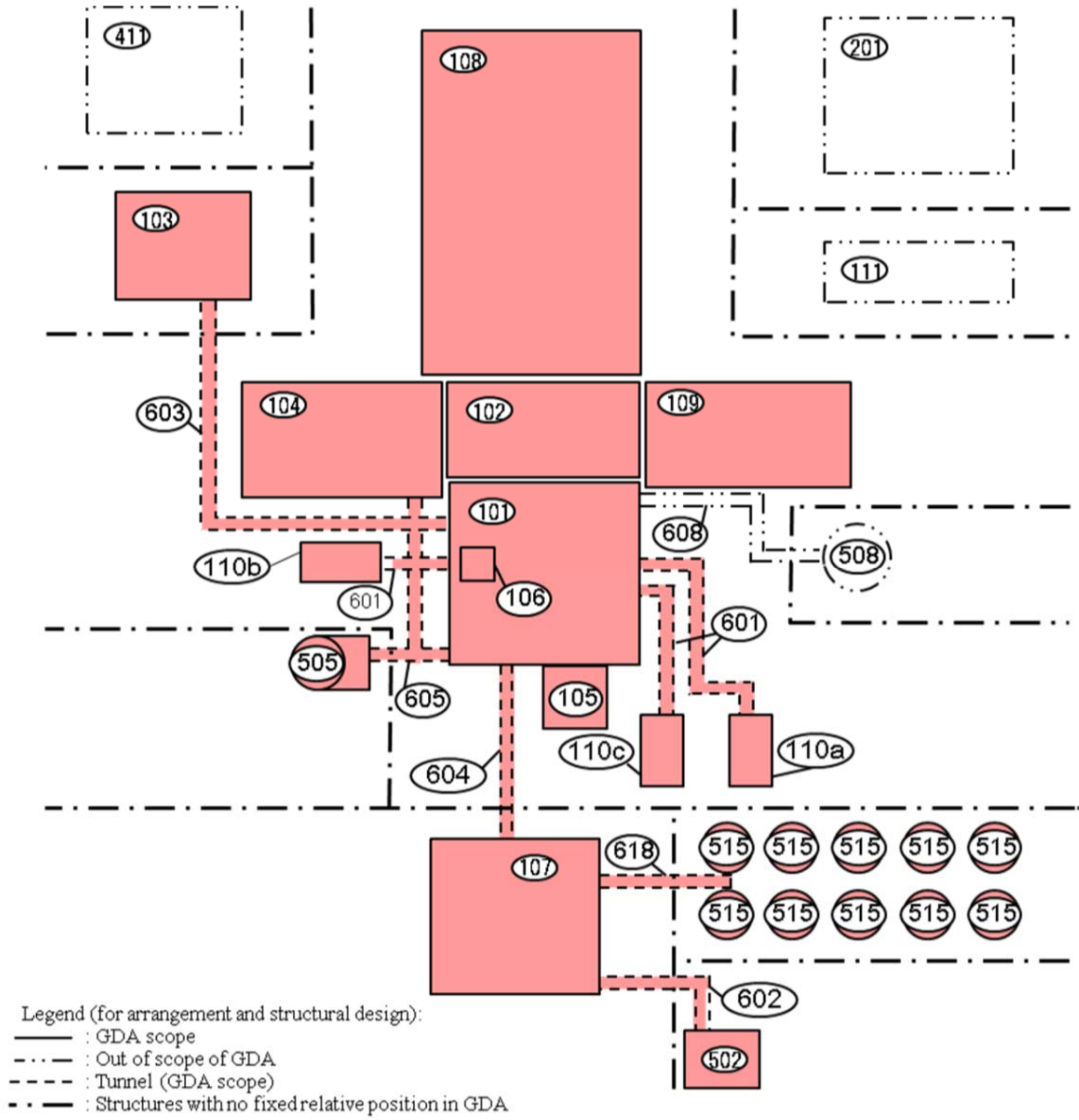
- RO-ABWR-0020 – Internal Hazards Safety Case for the Main Steam Tunnel Room (Ref. 91);
- RO-ABWR-0044 – Demonstration UK ABWR has been designed to safely manage radiolysis gases generated under normal operations (Ref. 12);
- RO-ABWR-0056 – Demonstration that adequate optioneering has been carried out for the removal of Spent Fuel from the Reactor Building (Ref. 11);
- RO-ABWR-0078 – Exceptions to Segregation (Ref. 92);
- RO-ABWR-0079 – Turbine Disintegration Safety Case (Ref. 93); and
- RO-ABWR-0082 – Substantiation of Class 1 Barriers against Internal Hazards Loads (Ref. 9).

35. The RO's were addressed via the Topic Report submissions given above.

3.3 UK ABWR Generic Building Layout

36. In order to put into context my assessment it is prudent to briefly describe the generic building layout and their significance to safety. The Overview of UK ABWR Civil Structures document (Ref. 94) gives all nuclear safety civil structures. Figure 1 below shows the generic plot plan for the UK ABWR.

Figure 1: Generic Building Layout.



Reactor Building – 101 (R/B)

37. The R/B houses safety related plant and equipment (A-1 and A-2) essential to delivering the Fundamental Safety Functions. The civil structure is a safety Category A, safety Class 1 and seismic Category 1. This plant and equipment is located in three mechanical safety divisions and four C&I safety divisions to provide redundancy and diversity, with each division separated by concrete barriers at all levels of the building. The Reactor Building contains the Primary Containment Vessel (PCV) as well as sections of the main steam line and Main Steam Tunnel Room (MSTR).

Control Building – 102 (C/B)

38. An internal hazard within the C/B has the potential to damage monitoring and remote intervention signals and equipment, which could have an adverse effect on reactor safety. The civil structure is a safety Category A, safety Class 1 and seismic Category 1. Similarly to the R/B, the C/B is divided into safety divisions to separate the signals and equipment associated with each division. The C/B also houses sections of the

MSTR and the MCR, which contains SSCs from multiple divisions.. The walls surrounding the MCR are classified as Class 1 non-divisional barriers.

Heat Exchanger Building – 103 (Hx/B)

An internal hazard within the Heat Exchanger Building has the potential to damage heat exchangers and pumps that are part of the Reactor Cooling Water System (RCW) and the Reactor Service Water System (RSW), which provide cooling water to systems required to support reactor safety systems such as the Emergency Core Cooling System (ECCS), which include systems such as the Residual Heat Removal System (RHR) and the High Pressure Core Flooder (HPCF).The civil structure is a safety Category A, safety Class 1 and seismic Category 1. Similarly to the R/B, the pumps and heat exchangers are located in three safety divisions segregated by divisional barriers.

Turbine Building – 108 (T/B)

39. The Turbine Building main purpose is to house the equipment that converts thermal energy from the reactor steam into electrical energy. The Turbine Building also contains sections of the high integrity Main Steam Line (MSL) and MSTR's A-1 non-divisional barriers. . Additionally it houses equipment associated with the off-gas treatment system and thus contains a possible radiological hazard. The civil structure is a safety Category B, safety Class 2 and seismic Category 2/1A.

Backup Building – 107 (B/B)

40. Equipment and systems located within the Backup Building provide additional resilience to the primary safety systems to respond to frequent and infrequent faults and severe accidents. It does not contain any A-1 safety systems but it houses class 2 SSCs. No safety divisions are designated in this building. The civil structure is a safety Category A/B, safety Class 2 and seismic Category 1.

Emergency Diesel Generator Buildings - 110 (EDG/B)

41. All three EDG/B contain an emergency diesel generator which is an A-1 SSC. These can provide emergency electricity supplies to the UK ABWR safety systems. These three redundant, independent and physically segregated systems are in place to mitigate the consequences of a Loss of Offsite Power (LOOP) event. The civil structure is a safety Category A, safety Class 1 and seismic Category 1.

Radiological Waste Building – 104 (Rw/B)

42. The civil structure is a safety Category C, safety Class 3 and seismic Category 2/1A. It does not contain any A-1 SSCs. The design of this building is at concept stage. The RP assumed that an internal hazard will not compromise any SSCs delivering FSFs. The RP proposed to assess this building post GDA in the detailed design and site specific phase of the project.

Filter Vent Building – 105 (Fv/B)

43. The Fv/B contains the filtration and monitoring equipment to enable gases released within the PCV in an emergency situation to be vented into atmosphere. It does not contain any A-1 SSCs. The civil structure is a safety Category A/B, safety Class 1/2/3 and seismic Category 1. The RP assumed that an internal hazard will not compromise any SSCs delivering FSFs. The RP proposed to assess this building post GDA in the detailed design and site specific phase of the project.

Service Building -109 (S/B)

44. It does not contain any A-1 SSCs. The civil structure is a safety Category C, safety Class 3 and seismic Category 3/1A. The RP assumed that an internal hazard will not compromise any SSCs delivering FSFs. The RP proposed to assess this building post GDA in the detailed design and site specific phase of the project.

Service Tunnels

45. The service tunnels considered for GDA consists of the following connections.

- Tunnel 601A (R/B – EDG(A));
- Tunnel 601B (R/B – EDG(B));
- Tunnel 601C (R/B - EDG (C));
- Tunnel 602 (B/B – LOT);
- Tunnel 603A (R/B – Hx/B(A));
- Tunnel 603B (R/B – Hx/B(B));
- Tunnel 603C (R/B – Hx/B(C));
- Tunnel 604-2 (B/B - R/B);
- Tunnel 604-3 (B/B - R/B);
- Tunnel 605 (CST – R/B and Rw/B); and
- Tunnel 618 (FLSS - B/B).

46. Tunnels 601, 603 and 605 contain divisional equipment. Tunnel 601 and tunnel 603 are split into three parallel connections each carrying a single division. These connections are separated by Class 1 barriers. Tunnel 605 contains four divisions of C&I SSCs. Tunnel 604 is split into two separate branches and thus internal hazards within each individual branch are considered. All tunnels are at concept design stage. A multidiscipline tunnel access optioneering study was nevertheless conducted by the RP within step 4 of GDA (Ref. 95).

Yard

47. The Yard does not contain any A-1 SSCs or radiological material.

3.4 UK ABWR Internal Hazards Safety Case Philosophy and Approach

48. The RP's primary safety philosophy for the UK ABWR is to ensure the ability to achieve the FSFs following any identified internal hazard within the design basis. Each of the following five FSFs must be maintained at all times (Ref. 15):

- FSF1: Control of reactivity and ability to achieve emergency reactor shutdown;
- FSF2: Fuel cooling to prevent fuel damage;
- FSF3: Long term heat removal, including removal of decay heat and containment venting;
- FSF4: Confinement/containment of radioactive materials; and
- FSF5: Others, including support to safety systems, fuel handling, remote shutdown capabilities, instrumentation and monitoring, alternative power supplies and emergency measures.

49. The implementation of this safety philosophy in the UK ABWR design is based upon redundant and diverse safety systems that deliver the FSFs. Three mechanical divisions and four control and instrumentation (C&I) divisions are provided, each of which contains redundant SSCs capable of carrying out the FSFs.

50. The safety divisions are in general separated by robust barriers (designed to safety Class 1 standard to withstand all relevant internal hazard challenges) which act to

contain a hazard in an affected safety division and prevent the spread of the hazard to a different safety division.

51. The SSCs claimed as the principal means of delivering a Category A safety function are classified as Class 1. Any SSCs that are claimed as a secondary or diverse means of delivering a Category A safety function must be at least Class 2.

52. The Safety Case Development Manual (SCDM) (Ref. 96) for the UK ABWR sets out the following criteria for provision of safety measures, applicable to all operational states:

53. For frequent reactor design basis faults (initiating event frequency $>10^{-3}$ per year), at least two lines of protection are provided to deliver the FSFs. The SSCs claimed as the principal means of delivering Category A safety function are Class 1 (hence an A-1 SSC) and those claimed as the secondary or diverse means are at least Class 2 (hence an A-2 SSC). For infrequent reactor design faults (initiating event frequency 10^{-3} to 10^{-5} per year), at least one line of protection is provided and the SSCs claimed to deliver the safety function is classified as Class 1.

54. The RP considered the following internal hazards (PCSR and Topic Report on Approach to Internal Hazards. Refs. 15, 97 and 98, respectively):

- Internal fire and explosion;
- Internal flooding, including immersion, steam release and spray;
- Internal pipe whip and jet impact;
- Internal blast;
- Internal dropped and collapsed loads;
- Internal conventional missiles;
- Turbine disintegration;
- EMI and Radio Frequency Interference (RFI); and
- Miscellaneous internal hazards (on site hazardous materials, methane hazard, pipeline accidents and transport accidents).

55. The internal hazard assessment identifies the Class 1 SSCs which are at risk in the event of an internal hazard and evaluates the availability of suitable and sufficient safety measures. The RP considered that the availability of diverse backup systems is regarded as good practice in providing confidence that numerous safety measures are always in place even if a highly conservative internal hazard assessment postulates the loss of a number of safety systems. Table 1 below shows the A-1 and A-2 safety systems available in the UK ABWR (Ref. 99).

Table 1: UK ABWR Major A-1 and A-2 Safeguard and Mitigation Safety Systems.

Safety Function	Category and Class	Safeguard/ Mitigation Systems	Mechanical Support Systems (FSF5: Others)	C&I Support Systems (FSF5: Others)	Power Source Support Systems (FSF 5: Others)
FSF1: Reactivity Control	A-1	• Reactor Protection System (RPS) and Control Rod Drive System (CRD)	• Heating, Ventilating and Air Conditioning Systems (HVAC)	• Safety System Logic & Control (SSLC	• EDGs • Class 1 Batteries
	A-2	• Standby Liquid Control System (SLC) • Recirculation Pump Trip (RPT) • Feedwater Runback • Alternative Rod Insertion (ARI)	• HVAC • Emergency Equipment Cooling Water System (EECW)	Hard Wired Backup System (HWBS)	• Backup Building alternative generators (BBGs) • Backup Building Batteries
FSF2: Reactor Core Cooling	A-1	• Reactor Core Isolation Cooling System (RCIC) • High Pressure Core Flooder System (HPCF) • Residual Heat Removal System / Low Pressure Core Flooder System (RHR/LPFL) • Safety Relief Valves (SRV) - Safety valve function and Automatic Depressurisation • System (ADS)	• HVAC • Reactor Building Cooling and Service Water (RCW/RSW) • N2 ADS accumulator	SSLC	• EDGs • Class 1 Batteries
	A-2	• Flooder System of Specific Safety Facility (FLSS) • Reactor Depressurisation Control Facility (RDCF)	• HVAC • EECW	HWBS	• BBGs • Backup Building Batteries
FSF3: Long-term Heat Removal	A-1	• RHR Shutdown Cooling Mode (SDC) • SRV - Manual depressurisation function	• HVAC • RCW/RSW	SSLC	• EDGs • Class 1 Batteries
	A-2	• FLSS • Containment Venting	• HVAC • EECW	HWBS	• BBGs • Backup Building Batteries
FSF4: Radiological Containment	A-1	• Main Steam line Isolation Valve (MSIV) • SRV • Primary Containment Isolation System (PCIS) • PCV • Secondary Containment	HVAC	SSLC	• EDGs Class 1 Batteries

3.5 Internal Hazards Safety Case Claims and Arguments

56. The internal hazard assessment for UK ABWR uses a claims, arguments and evidence approach to demonstrate that the consequences due to an internal hazard are acceptable and confirm that suitable and sufficient safety measures are in place to maintain the plant in a safe manner during and after the internal hazard. A route map to the RP's claims, arguments and evidence of all internal hazards documents is given in Ref. 100 (Claim-Argument-Evidence Map of Internal Hazards Document).

57. The top-level safety claims are:

General Claim IH_SFC_5-7.1: Internal Hazards do not prevent the delivery of the Fundamental Safety Functions.

General Claim IH_SFC_5-7.2: The consequences of any Internal Hazard are limited to one division, except for areas covered by General Claim IH_SFC_5-7.3.

General Claim IH_SFC_5-7.3: Where there are exceptions to physical segregation, sufficient A-1 or A-2 signals and equipment are available, during and after an Internal Hazard, to fulfil the Fundamental Safety Functions.

58. The UK ABWR design is such that **IH_SFC_5-7.1** is principally delivered by the provision of physically segregated divisions of A-1 safety-related equipment providing the same function through the use of A-1 barriers (**IH_SFC_5-7.2**). The Class 1 divisional barriers are designed to prevent a hazard (single or combined) in one division from affecting safety systems in an adjacent division and support claim **IH_SFC_5-7.2**. In addition, in some specific locations claims are also made on Class 1 non-divisional barriers which provide the safe function as the divisional barriers.

59. The provision of these Class 1 barriers, with the aim of terminating the hazard or fault progression, is the primary safety measures claimed within the internal hazards safety case for the UK ABWR.

60. Tables 2 and 3 present a general overview of where the main safeguard systems providing the first line of protection to ensure reactivity control, reactor core cooling, long term heat removal and containment are physically located within the hazard compartments for R/B and C/B (Ref. 41).

Table 2: Segregation of key Class-1 equipment in compartment delivering the FSFs in the R/B.

Division of SSCs	Hazard Compartment	Primary Safeguard in Compartment				Main Support Systems in Compartment	
		FSF 1	FSF 2	FSF 3	FSF 4		
I	RB1001	RPS/CRD A*	RCIC (A) RHR/LPFL A	RHR/SDC A	PCV isolation valves*	RCW A	EC&I Div I
	RB1002					RCW A RBEEZ HVAC A HECW A	EC&I Div I
	RB1101/2						
II	RB2001	RPS/CRD B*	HPCF B RHR/LPFL B	RHR/SDC B		RCW B	EC&I Div II

Division of SSCs	Hazard Compartment	Primary Safeguard in Compartment				Main Support Systems in Compartment	
		FSF 1	FSF 2	FSF 3	FSF 4		
	RB2002					RCW.B RBEEZ HVAC B	EC&I Div II
	RB2101						
III	RB3001		HPCF B RHR/LPFL B	RHR/SDC B		RCW C	EC&I Div III
	RB3002					RCW C RBEEZ HVAC C HECW C	EC&I Div III
	RB3101						
IV	RB4001						EC&I Div IV
	RB4002						EC&I Div IV
	RB4003/4/5						
N/A	RB5101/2						

Table 3: Segregation of key Class-1 equipment in compartment delivering the FSFs in the C/B.

Division	Hazard Compartmenl	Key Class 1 Equipment in Compartment
I	CB1001	• SSLC Panels (Div I) • Class 1 DC 115V Battery A (Div I) • Class 1 DC Power Supply System (Div I) • Class 1 AC I&C PS (Div I) • Class 1 AC UPS (Div I) • Cables • CBEEE(A)Z HVAC Systems (Div I) • HECW Systems (Div I) • HECW A Systems (Div I) • HECW Valves
II	CB2001	• SSLC Panel (Div II) • Cables (Div II) • Class 1DC Power Supply System (Div II) • Class 1 AC I&C PS (Div II) • Class 1 AC UPS (Div II) • Class 1 DC 115V Battery B (Div II) • CBEEE(B)Z HVAC IDiv II) • HECW systems (Div II) • CBEEE(B)Z Supply Air Treatment Facility (Div II) • HECW B Systems (Div II)
III	CB3001	• SSLC Panels (Div III) • Cables • CBEEE(C)Z HVAC (Div lll) • HECW(Div III) • CBEEE(C)Z Supply air facility (Div lll) • HECW C Equipment (Div III)

Division	Hazard Compartmenl	Key Class 1 Equipment in Compartment
IV	CB4001	• SSLC Panels (Div IV) • Control Cable • Class 1 DC Power Supply System • Class 1 AC UPS • Cables • Class 1 DC 115V Batterv D

61. The RP also argued that even with a loss of two A-1 divisions due to combined internal hazard (loss of divisional barrier) and accounting for the most limiting single failure (failure of a Class 1 Switchboard), the UK ABWR still has sufficient A-1/ A-2 SSCs available to maintain the FSFs. See Table 4 below (Topic Report on Combined Hazards, Ref. 57). The RP claimed that this bounds any postulated failure of a Class 1 barrier due to combinations of internal hazards or beyond design basis single hazards.

Table 4: Systems Available to deliver the FSFs on loss of two A-1 divisions and Accounting for Single Failure Criterion of a Class 1 Switchboard (Ref. 57, Table G-7)

FSF	Systems Available		Essential Support Systems for Remaining SSCs					
			Power Supply		C&I		SSLC	HWBS
	A-1	A-2	A-1	A-2	A-1	A-2	A-1	A-2
1	CRD	SLC	Fail Safe	B/B	Fail Safe	Fail Safe	Segregated physically and diverse power supplies	Segregated physically and diverse power supplies
2	ADS	RDCF, FLSS	DC Battery Supply (Remaining division)	B/B	Fail Safe	Fail Safe	Segregated physically and diverse power supplies	Segregated physically and diverse power supplies
3	ADS	RDCF, FLSS, AC, FCVS	DC Battery Supply (Remaining division)	B/B	Fail Safe	B/B, Manual	Segregated physically and diverse power supplies	Segregated physically and diverse power supplies
4	PCIS	-	Fail Safe	-	Fail Safe	-	Segregated physically and diverse power supplies	-

62. Although the general argument is that safety-related equipment from the same division is segregated by Class 1 barriers, there are some exceptions to this arrangement. Where this is the case, either sufficient A-1 SSCs are qualified to deliver the FSFs under the conditions of the internal hazard event, or the A-1 SSCs are protected in some way from the consequences of the event such that delivery of their FSF is not prevented. Therefore, the internal hazard safety case for these areas is not based on divisional barriers, and **IH_SFC_5-7.3** applies instead. The RP submitted the following reports where segregation by barriers is not practicable:

- TR on Exceptions to Segregation (Refs. 21, 22, 23, 24 and 25);
- TR on Internal Hazards in Main Steam Tunnel Room (MSTR) (Refs.61, 62, 63 and 64);
- TR on Internal Hazards inside the Primary Containment Vessel (PCV) (Refs. 69, 70, 71 and 72); and
- TR on Internal Hazards inside Main Control Room (MCR) (Refs. 79 and 80).

63. Claim **IH_SFC_5-7.3** is delivered by a combination of equipment qualification or the provision of sufficient A-1 or A-2 SSCs.

4 ONR STEP 4 ASSESSMENT

64. This assessment has been carried out in accordance with ONR internal guidance on the “Purpose and Scope of Permissioning” (Ref. 5).

4.1 Overview of Assessment Approach

65. My assessment is divided into various sections reflecting my assessment strategy as set out in section 2, and the RP’s internal hazards submissions for the various buildings and plant locations.

66. My assessment of internal hazards including internal fire and explosion, blast, internal flooding, steam release, pipe whip and jet impact, conventional internal missiles, turbine disintegration and dropped and collapsed loads is presented in sections 4.2 to 4.9. These sections cover plant locations outside containment where segregation by barriers is generally the primary means of ensuring delivery of FSFs.

67. The assessment of areas where the case is not built upon segregation by barriers, including the Primary Containment Vessel (PCV), the Main Steam Tunnel Room (MSTR) and the Main Control (MCR) is presented in sections 4.10 to 4.13.

68. My assessment of the RP’s case for combined hazards, miscellaneous hazards and EMI is covered in sections 4.14 to 4.16, respectively.

4.2 Internal Fire and Explosion Safety Case

69. Fires in nuclear plant arise from the ignition and combustion of flammable or combustible inventories in the presence of an oxidiser (typically oxygen from air).

70. Fires can damage SSCs that deliver FSFs as a result of thermal radiation or direct flame impingement, leading to degradation or combustion of components.

71. Vapour Cloud Explosions (VCEs) arise from the ignition of flammable gases or vapours (used or generated during normal operation or under fault conditions) in confined or congested conditions which result in acceleration of the flame front to produce significant overpressure effects.

72. Depending on the subsonic or supersonic characteristics of the flame progression, explosions can involve deflagration and/or detonation phenomena, respectively.

73. Blast waves from deflagration or detonation events interact with surrounding SSCs including nuclear safety barriers and can lead to failure.

74. Overpressure generated by High Energy Arcing Faults (HEAFs) following failure of High Voltage (HV) Switchgear is also addressed in this section.

75. In addition to the above explosion hazards, significant overpressure can arise from sudden releases of stored energy, including failure of high pressure gas or steam vessels and pipework. This is covered in the Internal Blast section 4.3 of this assessment report.

76. The RP presented the assessment of fire and explosion hazards for A-1 buildings in the UK ABWR design including the R/B, C/B, Hx/B and T/B. During GDA Step 4, the RP submitted the following documentation in the area of fire and explosion hazards:

- The Pre-construction Safety Report (PCSR) (SE-GD-0127) revision C (Refs. 15);
- Topic Report on Internal Fire and Explosion (BKE-GD-0018) revisions 2 to 5 (Refs. 28, 29, 30 and 31);

- Detailed Analysis of Fire Modelling and Barrier Response (BKE-GD-0048) revisions 0 to 2 (Refs.101, 102 and 103);
- Topic Report on Safe Management of Radiolytic Gases Generated Under Normal Operations (SE-GD-0250) revisions 1 to 4 (Refs. 104, 105, 106 and 107); and
- Supporting Information for the Topic Report on Safe Management of Radiolytic Gases Generated Under Normal Operations (SE-GD-0428) revision 0 to 2 (Refs. 108, 109 and 110).

77. My assessment of the above submissions is discussed in the sections below.

78. The analysis of fire and explosion hazards in areas where protection is not based on segregation (e.g. inside the PCV, MSTR and MCR) were presented by the RP in separate reports for those areas (Refs. 72, 64 and 80) and are assessed separately in sections 4.11, 4.12 and 4.13, respectively.

4.2.1 Requesting Party's Safety Case for Fire and Explosions

79. The UK ABWR fire and explosion safety case claims are addressed via the generic internal hazard claims discussed in section 3.5.

80. The safety case on fire and explosion, for all areas where segregation by divisional Class 1 barriers is provided, is principally based on claim **IH_SFC 5.7.2** "*The consequences of any internal hazard are limited to one safety division"*. This is achieved by limiting the severity of fire and explosion hazards to a single division by Class 1 divisional barriers, and by the provision of suitable and sufficient redundant and/or diverse SSCs in other divisions. Class 1 barriers are in the case of the UK ABWR the three-hour fire resistant reinforced concrete (RC) walls and slabs, and penetrations through those barriers being designed to deliver equivalent resilience in the event of a fire.

81. For areas where divisional segregation is not considered to be reasonably practicable, the fire and explosion safety case is based on the provision of sufficient A-1 or A-2 signals and equipment to fulfil the FSFs. This requires qualification of SSCs to perform in the event of a hazard (fire or explosion) or the A-1 SSCs to be protected from the consequences of the event so that delivery of FSFs is still achieved.

82. In addition to safety divisional barriers, non-safety divisional Class 1 barriers are also claimed to provide fire compartmentation in specific areas, for example, the C/B.

83. In addition to fire compartmentation, the UK ABWR safety case incorporates engineered measures other than barriers, including fire detection and suppression systems (fire sprinklers, foam suppression) as defence-in-depth measures in specific locations.

4.2.2 Assessment of Internal Fire Hazards

4.2.2.1 Scope of Assessment

84. My assessment of the RP fire case covers all the submissions listed in section 4.2 and associated references in those reports to ensure sufficient evidence for substantiation of the claims has been provided.

85. The areas chosen to assess the internal fire case were limited to the following:

- Suitability and sufficiency of claims;
- Fire analysis methodology, assumptions and exclusions;
- Substantiation of three-hour fire compartment barriers;
- Margins of safety and suitability of bounding arguments; and

- Suitability of penetration design philosophy.

4.2.2.2 Assessment of Claims and Arguments

86. Delivery of the safety claims **IH_SFC 5-7.2** (*the consequences of any internal hazard are limited to one division*, except for areas covered by Claim **IH_SFC_5-7.3**) is principally achieved by three-hour fire barriers which provide the segregation required between Class 1 SSCs.

87. A claim on three-hour fire barriers is aligned with my expectations and ONR's SAPs EDR.2, EKP.5 and EHA.5. It is also in line with international guidance, including Western European Nuclear Regulators' Association (WENRA) - Safety Reference Levels for Existing Reactors (Ref. 111) and IAEA NS-G-1.7 (Ref. 112). The RP has chosen to make these barriers from reinforced concrete (RC), as a default for the ABWR.

88. In addition to the Class 1 divisional fire barriers separating redundant SSCs, the RP included measures to detect and limit the spread of fire within safety divisions. Systems provided include Class 3 fire detection and alarm, smoke control, manual firefighting and fixed fire suppression and non-divisional fire barriers.

89. The fire detection and alarm, smoke control, manual firefighting and fixed suppression systems are described in the Topic Report on Fire Safety Strategy, revision 3 (Ref. 113).These are not explicitly claimed on the internal fire case, however, they have been credited, for specific fire compartments, in the relevant Hazard Schedule and classified according to their nuclear safety significance as C-3 (Category C, Class 3). I judge the provision to be adequate and in line with ONR SAPs EHA.16 and SAP para. 273 (c).

90. As part of my assessment, I sampled areas of the R/B with combustible loading e.g. rooms G31 (fire compartment RB3001), G32 (RB1001) and G36 in (RB2001). The specific Class 1 barriers in the R/B are R-W-B1-G31, R-W-B1-G306A, R-F-B1-G31, R-D-B1-FG31, R-W-BM1-G31 and R-F-1F-G41. Both the Divisional Boundary maps (Ref. 114) and Fire Zone drawings (Ref. 115) identified the expected three-hour, Class 1 fire barrier provision appropriately.

91. The hazard schedule in Appendix B.5 (Fire and Explosion Hazard Schedule for the R/B) of the Topic Report on Internal Fire and Explosion revision 5 (Ref. 31) identified the unmitigated consequences (fire spread across multiple divisions), the claimed hazard safety function (three-hour Class 1 fire barriers to contain the fire within the division of origin so that the FSFs are delivered). The SSCs claimed to be available to deliver the FSFs in the respective safety division were consistent with the claimed measures for the above locations.

92. Rooms G31, G32 and G36 do not contain fixed fire suppression systems. This is consistent with the hazard schedule and the rooms' role in evacuation routes. These rooms are covered by the fire main outlet in line with conventional requirements as provided in the Topic Report on Fire Safety Strategy revision 3 (BKE-GD-0041) (Ref. 113).

93. Sections 4.2.2.3 and 4.2.2.4 provide my assessment of the fire analysis methodology and of the evidence provided by the RP to substantiate the above claims.

4.2.2.3 Assessment of Fire Analysis Methodology

94. The RP carried out a room-by-room assessment for the following buildings within the scope of GDA (R/B, C/B, Hx/B, T/B, B/B, EDG/B and Service Tunnels). The fire analysis methodology included identification of combustible load, identification of SSCs and estimation of natural and forced ventilation rates. The RP used the above information to rank the UK ABWR rooms in terms of fire load and ventilation rates (forced and natural ventilation) (Ref. 31).

95. At the end of Step 2 of GDA and following RQ-ABWR-0089 (Ref. 116) and RQ-ABWR-0758 (Ref. 117), the RP relocated the 3 Emergency Diesel Generators (EDGs) (at Level 1F) and 3 day tanks (at Level 3F) (with a capacity of 17,000 l of diesel fuel in each tank) from the R/B to dedicated segregated buildings. This change removed a significant fire hazard from the UK ABWR R/B design and is in line with ONR SAPs EKP.1 and EHA.13.

96. The RP subsequently developed a set of representative rooms for detailed fire analysis using a multivariable choice method (Ref. 31). The representative rooms included those with the highest fire loading, high ventilation rates and representative geometries (including low ceiling rooms, corridors and shafts).

97. For the representative set of rooms, the RP performed fire modelling with the Consolidated Fire and Smoke Tool (CFAST), developed by the US National Institute of Science and Technology (NIST) and extracted time-temperature profiles that were compared against the standard fire curves in BS EN 1363-1 (Ref. 118), BS EN 1363-2 (Ref. 119) and UL 1479 (Ref. 120). Diverse fire models were also applied as CFAST results were compared with Fire Dynamic Tools (FDT) models for the same set of rooms.

98. The approach followed by the RP is largely reasonable. However, a number of areas fell short of my expectations on RGP, and I therefore raised a number of regulatory queries: RQ-ABWR-0754 (Ref. 121), RQ-ABWR-0961 (Ref. 122), RQ-ABWR-0962 (Ref. 123) and RQ-ABWR-1230 (Ref.124). The queries targeted the following aspects of the fire analysis and modelling performed:

- The assessment of fire compartment barriers on a room-by-room basis, as opposed to modelling a worst case, compartment-wide fire loading to full burnout.
- The lack of supporting calculations to demonstrate that fire progression within a fire compartment and the combined fire loading on single Class 1 barriers shared by multiple rooms did not fail the barrier.
- The screening out of rooms from further assessment where fire loadings were below 1000 MJ/m^2 – this was not in line with ONR SAP EHA.14.
- The margins available on the withstand of barriers in the C/B Emergency Battery Rooms, where low ceilings and large combustible inventories result in upper layer temperatures close to the standard fire curve in BS EN 1363-1 (Ref. 118).
- Application of engineering judgement to justify whether fires extend to over three hours;
- The need for assessment of localised fires, particularly hydrocarbon fires and densely-packed cable fires in the proximity of compartment barriers.
- Clarification on the cable design to be used in the UK ABWR and heat release rates applied in fire modelling.
- Clarification on whether any cabling inventories had been excluded from the assessment based on the use of cable wrapping or fireproof metal conduits.
- Consideration of uncertainty in the heat release rates in cable fire modelling.
- Consideration of radiative heat transfer in addition to flame impingement in hydrocarbon pool fire modelling.

- Consideration of escalation of pool fire from single tank failure to neighbouring tanks.
- Clarification on the role of manual and fixed fire suppression measures as part of the safety case.

99. The RP responded to the above points and RQs in the following documents (Refs. 125, 126, 127 and 128). In my opinion the RP responses confirmed that, subject to detailed design and further fire modelling as indicated in the assessment findings in sections 4.2.2.4 and 4.2.2.5 below, the claimed measures on Class 1 barriers and penetrations can be substantiated.

4.2.2.4 Assessment of Evidence Provided on Fire Barriers Substantiation

100. The UK ABWR reactor design claim **IH_SFC_5.7-2** is primarily fulfilled by RC barriers segregating divisions of SSCs delivering A-1 functions.

101. The RP claim on the three-hour RC fire barriers is in line with my expectations and ONR's SAPs EKP.5, ECS.2 and EHA.17. It is also in line with international guidance (Refs. 111 and 112).

102. The response of RC barriers to fire loading was documented in the Barrier Substantiation Report revision 2 (Ref. 87), which initially evidenced that not all walls would meet the minimum axis distance and depth of concrete cover in BS EN 1992-1-2 Table 5.4 (Ref. 129).

103. I raised this issue in RQ-ABWR-1302 (Ref. 130) for the RP to explain the internal fire hazard assessment acceptance criteria and why the RGP of providing 50mm minimum axis distance was not adopted. I also noted that there was no tolerance for introducing larger steel rebar if required.

104. The RP confirmed that BS EN 1992-2 (Ref. 129) would be adopted and reinforcement drawings would be produced to provide the evidence that the minimum axis distance and depth on concrete cover meets the requirements of the standard. I liaised with the Civil Engineering Specialist inspector and this is captured as part of assessment finding ONR-NR-AR-17-013 (Ref. 131).

105. With regards to local fire effects, the RP followed the acceptance criteria in BS EN 1992-1-2 (Ref. 129), based on a maximum average temperature rise over the whole of the non-exposed surface of 140º C. The RP also considered that the temperature of the first layer of steel reinforcement must not exceed 400º C, when the tensile strength of structural elements are considered to reduce by approximately 30%, according to the "Isotherm method" in section 4.2 of BS EN 1992-1-2.

106. The RP studied local effects from hydrocarbon pool fire and predicted a maximum temperature rise over the whole of the non-exposed surface well below the 140º C. The RP considered that flame impingement on the walls would give rise to a temperature of 1200º C. The assessment methodology was based on NUREG 1805 (Ref. 132) and the Heskestad method (Ref. 133) was applied to estimate the flame height. Where there is no flame impingement, the RP estimated the temperature using a cylindrical solid flame model to derive temperature profiles of the ceiling, columns and wall front faces. A similar approach was followed to determine the temperature profiles on doors according to BS EN 1363-2 (Ref. 119). I considered that these are adequate approaches to estimate pool fire consequences.

107. In RQ-ABWR-1230 (Ref. 124), I queried how the RP applied the methodology to modelling pool fires in the C/B and, specifically, room 104, which houses two 2,200 litre Motor Generator (MG) set Lubricant Oil Tanks in relatively close proximity from each other. The RP demonstrated in the Topic Report on Detailed Analysis of Fire and

Explosion Modelling and Barrier Response revision 2 (Ref. 103) that it had developed conservative estimates of the front face temperatures from ceilings and walls. The centreline plume temperature was used to estimate the front face temperature of the ceilings. The RP also acknowledged that bunds were needed in order to contain the pool of flammable liquid and substantiate the divisional barriers. However, it was not clear that bunds would be provided for locations other than where needed to substantiate the divisional barrier (this is addressed as part of assessment finding **AF-ABWR-IH-02**).

108. As part of RQ-ABWR-1230 (Ref. 124), I also challenged the RP's assumption that the effect of fire within one room will bound fire compartment-wide fires. A fire in a single room can spread to an adjacent room through a non-divisional barrier or penetration. Where the rooms share a divisional boundary, the initial mean temperature of the barrier as the fire spreads will be higher than when the rooms are modelled in isolation. The RP in response provided additional CFAST modelling which substantiated the divisional barrier shared by rooms G36 and 322 in division II of the R/B (Ref. 128). Following this, I challenged the results provided, as the modelling did not consider natural ventilation through non-divisional doors, in contrast with the fire analysis methodology. The RP subsequently provided the upper gas layer temperatures for both rooms, which predicted higher temperatures than those estimated on the room-by-room assessment (thus indicating that the bounding effect did not arise from a single room, although the difference was not large) (Ref. 134). In line with this observation, I am raising an assessment finding to seek substantiation of fire compartment barriers against the spread within fire compartments. This is consolidated in assessment finding **AF-ABWR-IH-01**. Whilst the above is a shortfall in the fire modelling undertaken by the RP, the combined analysis of rooms 322 and G36 showed that the compartment barriers can be substantiated for a challenging high fire loading area without changes to layout or combustible inventories. I therefore judge that full substantiation is achievable by further analysis and/or minor design changes. These would not challenge the generic layout and therefore the significance of the shortfall does not merit a GDA issue to be raised.

109. I also queried the exclusion of rooms from high fire loads from the assessment, for example R/B G31, which contains the largest energy density in the R/B (3,158 MJ/m^2), and had been treated as completely unventilated. The RP provided revised mechanical and natural ventilation flow rates for the room to support that the fire effects were bounded by those of room G36 (Ref. 31). I considered that the assessment conclusion was appropriate within the bounds of the GDA, however I am raising an assessment finding to ensure that the substantiation of fire barriers is reviewed and updated as the combustible inventories are confirmed or evolve during detailed design.

110. I also challenged the Heat Release Rate per Unit Area (HRRUA) used to model thermoset cable fires (Crosslinked polyethylene - XLPE/SLPE), which was below the upper range of values documented in NUREG/CR-7010 (Ref. 135). The RP referred to the use of inbuilt values in Fire Dynamic Tools (FDT) for the same type of cables, and confirmed that a 10% increase would not challenge the substantiation of barriers. I was satisfied that the justification was appropriate.

111. I also challenged the margins of safety available for the C/B Emergency Battery Room division III, room No. 304, where the upper layer temperature is close to the standard fire curve in BS EN 1363-1 (Ref. 118) and, specifically, how the following points affected the safety margin (Ref. 124):

- The combustible inventory used to model the fire. Battery covers were the only combustible inventory considered, with the exception of minor contributions from transient inventories;
- The heat release rate value reference from published literature, which did not acknowledge a combined uncertainty of approximately 10%; and

- The absence of cabling from the combustible inventory, when the room is known to have cable penetrations.

112. The RP in response provided evidence to support the use of the HRR peak value and that a 10% increase would have an effect very similar in scale to the transient load assessment, for which the barriers had been substantiated. The RP also considered that the cabling inventory would have a negligible effect in the upper layer temperature. This is presented in revision 2 of the Detailed Analysis of Fire and Explosion Modelling and Barrier Response (Ref. 103).

113. In RQ-ABWR-1230 (Ref. 124), I queried the derivation of combustible inventories and whether any cabling inventories had been excluded from assessment on the basis of defence-in-depth protective measures such as encasement, use of fireproof metal casing or cable wrapping. The RP clarified that “small cabling” in conduits had been excluded from assessment, but these were a “very small” when compared with “large cabling” (power, C&I) which had all been included. I judge that, based on the analysis provided, margins are available to accommodate additional inventories, but concentration of small cabling in specific locations could result in significant fire loadings. I have, therefore, considered that an assessment finding is appropriate in this area and included the requirement in **AF-ABWR-IH-01**.

AF-ABWR-IH-01 – As the Requesting Party carried out limited compartment-wide fire modelling and did not consider the full combustible inventories (e.g. “minor” cabling or cabling in ducts) in their assessment, the licensee shall complete the fire modelling to:

- **Demonstrate that the divisional barriers are substantiated against the worst-case fire conditions resulting from fire spread across rooms within a fire compartment.**
- **Include all cable inventories, detailed routing and transient loads, and confirm the fire resistance of the compartment barriers.**
- **Demonstrate that appropriate mechanical and/or natural ventilation rate data have been taken into consideration in the above calculations.**

114. The Topic Report on Internal Fire revision 5 (Ref. 31) provides the fire analysis within the scope of GDA. As part of my assessment, I sampled the results provided for the R/B and C/B, which house the majority of A-1 systems. The design included fire barrier provision in other buildings such as the Hx/B, the T/B and the B/B, with a range of three-hour and two-hour barriers. This provision is not supported by quantitative fire modelling. The fire analysis evidenced very high fire loading from hydrocarbon storage in specific rooms, including: T/B room 310 (Main Turbine Lube Oil Tank room), B/B room 412 and room 416 (Diesel Generator Fuel Day Tank rooms). I judge that the fire barrier provision requires further justification, with reference to quantitative consequence analysis. Also, the reasonably practicability of alternative fuel storage locations outside buildings, provision of bunds and the rating of the fire barriers in line with the expectations from ONR SAPs paragraph 268 and principles EHA.13 and EKP.1 have not been fully demonstrated.

AF-ABWR-IH-02 – The Requesting Party’s safety case does not fully demonstrate that combustible inventories have been reduced so far as is reasonably practicable in locations such as the Turbine building and the Back Up Building. As a result, during the site specific phase the licensee shall minimise them and develop features, controls and procedures to demonstrate:

- **Hazard reduction at source by removing inventories from within buildings (e.g. relocation of combustible inventories such as day tanks to outside the Back Up Building) so far as is reasonably practicable.**

- **The sustained integrity of all fire barriers including those in the Turbine and Back Up buildings against the fire loading as these barriers have not been characterised.**
- **That the spread of liquid releases is prevented by provision of bunding or other measures in line with UK Relevant Good Practice.**

115. Overall the Barrier Substantiation Report revision 5 (Ref. 90) provided the requisite information relating to the substantiation of the RC barriers.

116. Based on the adoption of BS EN 1992-2 (Ref. 129) and with the exceptions of the points for further justification highlighted in the assessment findings, I am satisfied that the design of the RC barriers will provide the level of protection required to ensure segregation of SSCs in line with their nuclear safety classification requirements.

4.2.2.5 Substantiation of Dampers and other Penetrations

117. In the UK ABWR, Heating Ventilation and Air Conditioning (HVAC) system ducts penetrate through Class 1 divisional barriers and therefore the design of these penetrations should maintain the functionality of the Class 1 barriers.

118. The RP undertook a programme of work to identify all HVAC penetrations in Class 1 barriers and reviewed their purpose with the aim of eliminating them so far as is reasonably practicable. Passive measures e.g. fire resistant ductwork and active measures (fire dampers) were adopted where the penetrations could not be eliminated. This is documented in Ref. 81.

119. The RP demonstrated that internal hazards including not only fire, but also maximum flood heights, pipe whip and jet loading, dropped and collapsed loads, internal missile and internal blast were considered in the location of HVAC penetrations (Ref. 81). The design requirements for penetrations are recorded in the penetration design guideline (Ref. 136) and design rules (Ref. 137).

120. The RP provided evidence of categorisation and classification of HVAC penetrations in accordance with the HVAC system and divisional barrier classification (Ref. 81). The RP also confirmed the provision of fire dampers in series to prevent the spread of internal hazards between safety divisions where there is potential for internal hazard progression through Class 1 barriers and there is no conflict with the reliability of the HVAC system.

121. Based on the above, I am content that the approach followed, during GDA, does not preclude the UK ABWR from implementing fire damper designs in line with UK RGP, including the provision of fire dampers in series, as the design progresses to the detailed design stage.

122. However, the specific design standards for penetrations, dampers and associated SSCs were not specified by the RP during the GDA Phase. The detail design of penetrations should be undertaken during the site specific stages and should address all penetrations against all relevant internal hazards cases. I have therefore raised **AF-ABWR-IH-03** accordingly.

123. The proposed UK ABWR design included single doors on Class 1 barriers segregating safety divisions within the R/B. These doors are required to withstand internal hazard loadings equivalent to those of the Class 1 barriers.

124. I therefore raised RQ-ABWR-0090 (Ref. 138) requesting Hitachi-GE to provide the philosophy/ strategy for the use of single doors on Class 1 barriers within the R/B. This should have identified the key claims associated with this approach including how the single failure criterion was addressed.

125. The RP’s response to RQ-ABWR-0090 (Ref. 139 and 140) highlighted the following:

- The design included 44 single doors across Class 1 nuclear safety barriers within the R/B.
- The doors were self-closing as much as possible otherwise they would be monitored to ensure they would be closed. The RP considered that the doors were unlikely to be left open.
- The RP considered the installation of a local alarm to satisfy the single failure criterion, and also that the alarm would initiate personnel action to close the door, thus reducing the likelihood that the door will be kept open in the event of an internal hazard. The door alarm would only be necessary during normal operations and the RP considered it as “defence-in-depth” (DID) measure.
- The RP considered the installation of double doors between different divisions as an alternative option, but it only assessed it qualitatively, and concluded that the double doors would degrade the function of accessibility, evacuation and maintainability.

126. I considered that the RP’s response to RQ-ABWR-0090 was not robust and noted the following points:

- The RP did not demonstrate that it had reviewed the number of single doors on safety Class 1 barriers with an aim to reduce their number. Additionally, the layout of key buildings was complex and showed limited evidence that layout had been initially optimised according to the principle of hazard minimisation in ONR’s SAP ELO.4.
- The provision of a local alarm was not in line with the relevant good practice established in the UK, where local alarms are provided for fire doors of lesser significance, but alarms to a permanently manned station are provided for doors of higher nuclear significance.
- In the UK, operational experience has identified failures in door closure mechanisms and events where doors have been deliberately wedged open. In addition to the audible alarms, there may be maintenance and inspection requirements, administrative controls and safety tours to ensure that these nuclear safety barrier doors are able to perform their required safety function.
- Implicit claims on operative response to a local alarm had been made but no further justification was provided.
- The RP raised concerns with regard to the provision of a second door degrading the functions of accessibility, evacuation and maintainability. I consider that the extra door in a lobby configuration is not a barrier for fire-fighting, but an extra defence in depth measure. UK Building Regulations require a lobby approach around stairs for firefighting access. Provided the doors can be readily opened, then double doors provide additional layer of protection to people from fire and smoke. The slight delay in opening a second door is vastly outweighed by additional safe escape time provided by the second barrier. Double doors may restrict movement of large items but do not necessarily prevent the movement. In any case, access requirements can be planned and door widths adjusted without necessarily increasing the size of the opening in the Class 1 nuclear safety barrier by adopting a lobby approach.

127. Based on the above, I raised RO-ABWR-0012 (Ref. 10). This RO included action RO-ABWR-00120.A1: “*Review the current design and use of the single doors on Class 1 nuclear safety barriers*”. The key objectives of the RO were as follows:

- Demonstrate that the number of single doors on Class 1 nuclear safety barriers is minimised;
- Review the feasibility of providing a second door, where reasonably practicable; and

- If it was necessary to retain some single doors, provide a robust demonstration that local and remote alarms are provided in line with the relevant good practice (current fleet and previous GDA) established in the UK.

128. The review of Class 1 doors in the R/B undertaken by the RP, which is presented in Topic Report of Doors on Class 1 Barriers (SE-GD-0190) revision 3 (Ref. 68), resulted in the elimination of 7 doors through Class 1 barriers, the provision of double doors (lobbied configuration) in 23 locations and remote alarms in line with UK RGP in 14 locations where introduction of additional doors was demonstrated to be grossly disproportionate. The remote alarm system classification will be addressed during the detailed design post GDA, but my expectation is that the remote alarm will be appropriately classified.

129. However, as the RP provided Fire Zone Drawings for the Hx/B (310QD02-089) (Ref. 141), I discovered the introduction of additional, single cross-divisional doors through A-1 barriers on the 1F and 2 F floors and the absence of second doors / removal of previous lobby configurations for rooms 415, 414 and 516. I therefore raised RQ-ABWR-1393 (Ref. 142) to question this approach and ensure that learning from RO-ABWR-0012 was applied throughout the UK ABWR design.

130. The RP responded in Ref. 143 that lobby configurations would be adopted for Class 1 doors in the revised design including H-D-1F-410, 412, 413, 414, 511 and 514, and door alarms would also be provided (in line with RO-ABWR-0012 expectations) in the division III access doors (personnel access). The RP confirmed that equipment openings (not used for personnel access) will consist of metal plate covers which are bolted in place and not opened during normal operations.

131. Based on the above, I was satisfied that the generic design provision of doors on Class 1 barriers in the UK ABWR meets UK RGP, subject to further design specification against internal hazards to be carried out during the detailed design stage.

AF-ABWR-IH-03 – Given that the substantiation of nuclear safety significant barriers requires all barrier components to withstand all relevant internal hazards, the licensee shall develop the design specification for all penetrations including Heating, Ventilation and Air Conditioning (HVAC) penetrations, fire dampers, doors, door monitoring systems, hatches, infill panels / block work in line with UK relevant good practice.

132. Overall, I have raised three assessment findings in relation to the substantiation of the UK ABWR design against internal fire hazards. The findings specifically address shortfalls in the fire modelling conducted, the definition of combustible inventories and substantiation of barrier components such as penetrations and doors. In all three cases and through responses to targeted RQs, the RP has provided evidence for specific locations showing that margins are available in the generic design to fully substantiate the claims. The assessment findings individually or in combination are not of sufficient significance for a GDA issue to be merited, as they do not challenge the generic layout of the UK ABWR. However, I judge that these findings are needed to ensure that the risk associated with internal fire are reduced SFAIRP during the detailed design and the site specific assessment stages.

4.2.3 Assessment of Internal Explosions Hazards

4.2.3.1 Scope of Assessment

133. The RP's explosion hazard analysis methodology was presented in conjunction with the fire methodology in revision 3 of the Topic Report on Fire and Explosion (Ref. 29) and consisted of 4 steps:

- Step 1 – Identification of safety-classified, A-1 SSCs;
- Step 2 – Identification of fire and explosion hazard sources;
- Step 3 – Fire and explosion hazards characterisation; and
- Step 4 – Identification of safety measures.

134. The RP's applied specific hazard assessment methodologies (Steps 2 and 3) according to source of the explosion hazard (oil mist, hydrogen ignition or High Energy Arcing Fault, HEAF).

135. The analysis of each explosion source by the RP and my assessments are discussed in the sections below.

4.2.3.2 Assessment of Claims

136. The RP's safety case for explosion hazards is supported by the same claims as the fire case presented in section 4.2.1. My assessment of the claims is provided in section 4.2.2.2.

4.2.3.3 Assessment of Oil Mist Hazards Methodology and Application

137. The RP initially proposed (in revision 2 of the Fire and Explosion report; Ref. 28) to screen out systems for oil mist explosion hazards based on an operating pressure threshold value of 300kPa. I challenged this approach in RQ-ABWR-0754 (Ref. 121) and RQ-ABWR-0961 (Ref. 122), since lower pressure differentials are known to result in fluid atomisation (depending on material physical properties and orifice diameter) as highlighted in HSE Research report 980 (Ref. 144).

138. The RP subsequently developed an assessment methodology, as presented in revision 1 of the Detailed Analysis of Fire Modelling and Barrier Response (Ref. 102), which comprised of the following steps:

- Step 1: Characterisation of oil mist hazards, including identification of fluid combustible materials in pressurised systems;
- Step 2: Determination of the oil mist ignitibility and calculation of droplet Sauter Mean Diameters;
- Step 3: Estimating the droplet size distribution and screening out the fraction considered to rainout (diameters larger than 100μm); and
- Step 4: Evaluation of the explosion hazard and effects on divisional barriers;
- Step 5: Consideration of further analysis and potential design changes.

139. The revised methodology is largely based on the guidelines recently developed by the HSE-sponsored Joint Industry Project on flammable oil mist hazards (Ref. 145) and, in my opinion, represents relevant good practice in the field.

140. The RP selected a generic, commercially available turbine lubricating oil to determine mist ignitability and droplet size and distribution, according to the physical and chemical properties of fluid within the plant design and operating conditions.

141. As part of my assessment, I sampled the RP calculations that determined the proportion of the leak that is considered to form a mist. I judge that the RP has applied the methodology appropriately and reached reasonable conclusions in terms of credibility and magnitude of the explosion hazard.

142. The assessment of barrier response to oil mist explosions followed the approach in ACI 349-06 (Ref. 146), and used custom calculations to determine utilisation factors for bending and shear failure. The RP presented the results in the Detailed Fire Analysis of Barrier Response Topic Report revision 2 (Ref. 103). Whilst the barriers were considered to withstand the overpressure levels predicted, I noted the potential for cliff

edge effects as a result of the limited margin available in the HVAC Emergency Cooling Water (HECW) refrigerator compressor and motor lubricant. This is recognised in the RP's Assumption Issue Register Information System (AIRIS) entry IH-IR-0001; however, there is wider need for the assessment to reflect the specific lubricant fluids to be used. I therefore consider appropriate to raise an assessment finding for this effect to be addressed during detailed design when the lubricant oil and operating conditions and limits are selected (see **AF-ABWR-IH-05**). Whilst there is a need to demonstrate that the existing assessment is bounding (hence the above finding), I judge that the shortfall does not challenge the generic design of the UK ABWR. This is because there is margin in the design of the barriers or substantiation is achievable with minor design changes (e.g. addition of spray guards, change of fluid specification etc.).

4.2.3.4 Assessment of Hydrogen Explosion Assessment Methodology

143. Boiling Water Reactor (BWR) technology, including the UK ABWR, generates relatively large stoichiometric quantities of hydrogen and oxygen under normal operations, due to radiolysis of water in the Reactor Pressure Vessel (RPV).

144. Radiolytic gases can accumulate over periods of time in plant piping and vessels under low flow conditions, and give rise to internal explosions if ignited.

145. Similarly, explosive atmospheres can arise from the release, accumulation and delayed ignition of radiolytic gases within plant compartments and therefore pose an internal hazard.

146. Hydrogen inventories are also held in the UK ABWR as part of the generator cooling systems, injection system and calibration of hydrogen detection systems (e.g. in T/B) as per hazard schedule, and the potential for releases and ignition leading to hydrogen deflagration or detonation was acknowledged in the RP's case.

147. The RP's assessment methodology for hydrogen explosion hazards was proposed in revision 1 of the Detailed Analysis of Fire Modelling and Barrier Response (Ref. 102) and consisted of 4 steps:

- Step1: Characterisation of the hazard based on the inventory, system design layout and safety features;
- Step 2: Determination of the flammable cloud size for confined volumes;
- Step 3 Evaluation of barrier response to hydrogen explosion modelled as a 2,4,6-trinitrotoluene (TNT equivalent mass, with acceptance criteria as follows: barrier rotation lower than 2 degrees and utilisation factors on bending and shear below 1; and
- Step 4: Further analysis and consideration design changes.

148. The RP's explosion hazards assessment as a result of accumulation and ignition of radiolytic hydrogen was initially based on the approach developed by the Japan Nuclear Technology Institute (JANTI), as presented in revision 0 of Management of Radiolytic Gases Topic Report (Ref. 147).

149. The JANTI guidelines determine whether the Lower Explosivity Limit (LEL) is exceeded somewhere in branch piping based on the level of "ventilation" provided by turbulence generated by fluid flow in the steam lines. In contrast with JANTI, and in the UK Regulatory context, Regulation 6 (4a and d) of the Dangerous Substances and Explosives Atmospheres Regulations (DSEAR) 2002 (Ref. 148) requires that measures should be applied, subject to reasonable practicability, to reduce the quantity of dangerous substances to a minimum and to prevent the formation of an explosive atmosphere, including the application of appropriate ventilation. The DSEAR Approved Code of Practice (ACOP) (Ref. 149) also provides concentrations levels

below which control by ventilation may be considered adequate. This typically equals 25% of the LEL (or 50% where additional safeguards are provided to prevent the formation of a hazardous explosive atmosphere).

150. Given that the concentration of hydrogen in the UK ABWR steam is initially around 2 ppm (well below the LEL), I challenged the application of the JANTI methodology, as it implied that accumulation of hydrogen in pipework (up to Lower Flammability Limit [LFL] levels) would not be prevented and concentrations marginally below LFL do not result in a credible explosion hazard. As part of the Step 3 assessment and in conjunction with the Reactor Chemistry inspector, I raised RO-ABWR-0044 (Ref. 12).

151. RO-ABWR-0044 required the RP to identify all potential areas in the UK ABWR design (within the process and plant) which may be susceptible to the formation of flammable atmospheres, either directly or following the accumulation of radiolysis gases. Action RO-ABWR-0044.A2 is relevant to internal hazards. It required the RP "*to undertake a consequence analysis based on a worst case unmitigated scenario and evaluate the impact of an explosion (including consequential events) on structures, systems and components*". The RO also required the RP to address all relevant aspects of UK Health & Safety legislation, specifically the requirements of the Dangerous Substances and Explosives Atmospheres Regulations (DSEAR) 2002 and associated ACOP. RO-ABWR-0044 also required the RP to implement all reasonably practicable measures to address the vulnerable areas in the UK ABWR design, following hazard identification and consequence modelling.

152. As part of the resolution of RO-ABWR-0044 (Ref. 150), the RP reissued the Topic Report on Safe Management of Radiolytic Gases (revision 2) (Ref. 105), which included a revised assessment methodology, and progressed with pipework layout analyses to identify and remove locations susceptible to radiolytic hydrogen accumulation. Following my review of this report, I raised RQ-ABWR-1078 (Ref. 151) to challenge a number of aspects of the assessment methodology and results, including:

- The topic report continued to refer to the LFL concentration (as opposed to a fraction of LFL such as 0.25 LFL) as the criterion value for flammability assessments within pipework. This was not aligned with the DSEAR ACOP (Ref. 149) or met the expectations of ONR SAPs e.g. ERL.4 and EHA.14.
- The RP's view was that hydrogen released at concentrations at or below the LFL would not result in explosion hazards. My expectation was that the assessment should consider the potential for hydrogen stratification and uneven accumulation, e.g. in confined spaces, or high points where ventilation is poor (leading to a localised flammable envelope which could not be directly around the leak point).
- The RP proposed the use of the TNT equivalence approach to quantify explosion hazards from radiolytic hydrogen. I challenged the use of the TNT approach as it can underestimate overpressure levels from combustible explosion hazards (Ref. 152). Alternative models such the Multi Energy Method (MEM) or Computational Fluid Dynamics (CFD) could be more appropriate. I also challenged the stated conservatism in the models and assumptions in the JANTI guidelines (e.g. the STANJAN code) in comparison with other codes and international experience developed by Karlsruhe Research Center (FZK) following the Brunsbüttel Nuclear power station (Germany) pipe break incident.
- The RP's stated that explosions within plant would be addressed in the Internal Blast and Missiles Topic Reports but these reports specifically excluded explosion hazards as a result of ignition of flammable atmospheres.
- The RP had estimated the time for build-up of hydrogen concentrations to flammable level in the water treatment systems and provided a high level description of the design features that would prevent or mitigate accumulation (e.g. ventilation). Failure of ventilation was acknowledged to result in

accumulation of hydrogen above 25% LFL within relatively short periods of time i.e. 1, 8 and 10 days for the Powder Resin Storage Tank, Filter Crud Storage Tank and Clean-up Water (CUW) Backwash Receiver, respectively. Ventilation parameters (such as flow rate) were said to be alarmed for operators to detect ventilation failure, however, no information was provided as to how the plant would be kept in a safe state (no accumulation of radiolytic hydrogen) upon loss of ventilation.

- Similarly, the risk of leakage of accumulated radiolytic gases from vessels e.g. the CUW Backwash Receiver Tank had been considered to be negligible since the tanks would operate at slightly negative pressure. I queried how the negative pressure is maintained in these systems including equipment, SSCs, associated claims and arguments.
- The off-gas system design was not optimised to reduce hydrogen accumulation and explosion risks. Specifically, there were locations where hydrogen would be above the LEL e.g. the 2nd stage Steam Jet Air Ejector (SJAE) during normal operation. My expectation was that a fraction of LEL (25% of LEL) should be used as the criterion for flammability assessment.
- The RP also considered that hydrogen concentration would be below 25% LFL in the Safety Relief Valve (SRV) lines (Appendix D1.1 of the Supporting Document revision 0 [Ref.108]) which assumed equal distribution across the four SRVs lines. However, the isometric representation provided in the document showed an upward slope in the connections from the Main Steam line which would result in preferential accumulation in the highest line.
- The design of the condensing chambers connected to the RPV and Main Steam lines presented in (Ref. 105) resulted in hydrogen accumulation and was therefore not supportive that the risks have been reduced to ALARP.
- The RP acknowledged Operational Experience (OPEX) data that showed that hydrogen accumulation and ignition within SRV branches had occurred in the past and proposed the use of spring loaded SRVs as opposed to solenoid pilot SRVs. I requested that the RP presented the design features of the replacement design, including drawings and OPEX available on the proposed valve to demonstrate that the risk had been reduced to ALARP.
- The RP also stated that the normal operating range for the concentration of hydrogen in the feedwater was considered to be from 0.15 to 0.3 ppm in the Hydrogen Water Chemistry (HWC) and on-line Noble Metal Chemical Addition (NMCA) regime and quoted 2 ppm hydrogen concentration in steam as the reference for assessment. I challenged the RP to confirm whether the 2 ppm level credited either or both NMCA and oxygen injection, and the effect that low rates/ loss of NMCA, oxygen and hydrogen injection could have on local accumulations.

153. I was broadly content that the RP's response to RQ-ABWR-1078 (Ref. 150) addressed the points raised in some of the areas, namely:

- The RP adopted the use the 25% LEL as maximum concentration of hydrogen (as opposed to the LEL).
- The RP also confirmed that application of the JANTI methodology was restricted to determining whether sufficient turbulence was generated by flow to prevent accumulation.
- The RP undertook a programme of pipework layout review to remove "dead legs" / pipe work with an upward slope where hydrogen could accumulate as steam condensates and low flow or lack of circulation prevents mixing and evacuation of the accumulated hydrogen. This approach resulted in a total of 54 vulnerable areas eliminated by layout changes, primarily in the T/B. I was satisfied that, for these locations, the design changes proposed by the RP eliminated the hazard posed by unfavourable pipework geometries from the design, and therefore the potential for accumulation is eliminated in line with

UK regulations and the changed design aligned with expectations from ONR SAPs EKP.1 and EHA.13.

- Regarding hydrogen stratification and accumulation in high points outside plant, the RP responded in Reference (Ref. 153) that Brownian motion would prevent accumulation of hydrogen by gravity in poorly ventilated locations. Given that detailed pipework layout and ventilation design is not complete, and that hydrogen is known to stratify in high points of poor air circulation e.g. from fugitive leaks, I consider that it is appropriate to raise an assessment finding **AF-ABWR-IH-04** so that the gap is addressed during detailed design.
- The RP modelled hydrogen ignition and explosion in confined spaces (tanks) using the TNT equivalent model. Given the geometry of the UK ABWR rooms in relation to the size and location of the source, the above approach is reasonable. The RP studied the response of the Rw/B walls using UFC-3-340-02 (Ref. 154) and confirmed that barrier utilisation and rotation would not exceed design capacity.
- Regarding the modelling of gas releases (hydrogen leaks), the RP used the Det Norske Veritas (DNV) Phast process hazard analysis software tool to estimate the size of the cloud to the LFL concentration level and modelled ignition as a stoichiometric mixture. Although the approach provides indicative values, it is not entirely aligned with my expectations as the dispersion model is not specifically developed to address indoor releases. Lower averaged concentration levels (e.g. 0.5 LFL) are also frequently used as reference to estimate the size of the flammable clouds in consequence modelling (pockets of gas reaching LFL may be present locally). The RP provided barrier rotation and shear utilisation values which supported substantiation. Whilst there is some design margin (rotation and bending), I consider this should be revisited during detailed design and once ventilation information and in-building dispersion models are available. I have reflected this point in **AF-ABWR-IH-04**.
- Regarding the design of the condensing chambers, the RP considered alternative design options and concluded that a change to downward sloping lines should be implemented to minimise the potential for hydrogen accumulation. Although the RP has not confirmed the design within GDA, I am satisfied that it has identified it as an issue that will be progressed as part of normal detailed design considerations.
- In relation to the potential differential accumulation of hydrogen across SRV lines, I was satisfied that the RP provided calculations to demonstrate that the highest SRV would still not exceed 25% of the LEL upon preferential accumulation.
- In relation to my query on hydrogen levels in main steam as a result of hydrogen and oxygen injection faults, I am satisfied that these have been addressed in the reactor chemistry assessment report and associated submissions, and are not repeated here for conciseness (Ref. 155).

154. Separately to the assessment of steam systems, radwaste liquid systems, hydrogen injection and generator cooling system leaks documented above, I have assessed the RP's hydrogen hazards case for the off-gas system. My assessment is documented in the section below.

4.2.3.5 Off-gas (OG) System Assessment

155. Generation of radiolytic hydrogen in the main steam is intrinsic to boiling water reactor technology.

156. As steam is condensed, hydrogen is extracted with the non-condensable gases and radioactive species to the off-gas system for abatement prior to discharge to atmosphere.

157. The design of the off-gas system is described in the UK ABWR submissions in the Radwaste area namely: Topic Report on ALARP Assessment for Off-gas System revision 4 (Ref. 156) and the Off-gas System Basis of Safety Case revision 5 (Ref. 157). The off-gas system involves two stages of steam injection with intermediate condensation, prior to hydrogen recombination and further moisture removal. The off-gas stream is then driven through charcoal beds to allow decay of radioactive noble gases species.

158. There is documented OPEX from US, German and Japanese plants showing elevated hydrogen concentrations upon loss of hydrogen recombination and, also, charcoal bed fires (Ref. 156).

159. The Topic Report on ALARP Assessment of the Off-gas System revision 4 (Ref. 156) acknowledges that, during normal operation, the system concentrates hydrogen to 15.5-15.7% at the Steam Jet Air Ejector (SJAE) condenser and inlet to 2^{nd} stage SJAE. This level is above hydrogen LEL in an oxygen and steam system (~14.5%) and considerably higher than the level of hydrogen in the main steam (2 ppm).

160. Revision 3 of the Topic Report on ALARP Assessment for the Off-gas System (Ref. 158) stated that hydrogen analysers will sample the OG stream after the 2^{nd} stage SJAE, and after the OG cooler condenser, in order to detect abnormal hydrogen concentrations that could result from degraded performance in SJAE dilution and recombiners. The RP considered that hydrogen detection and off-gas isolation had been implemented and, therefore, implementation of other options was not deemed to be reasonably practicable.

161. I considered that the above approach discounted measures aimed at reducing the hazard at source (eliminating or preventing hydrogen accumulation) on a balance of risk with other measures that were lower in the hierarchy of risk control. The approach was therefore not aligned with Paragraph 6 of DSEAR, which requires that "*Substitution shall by preference be undertaken, whereby the employer shall avoid, so far as is reasonably practicable, the presence or use of a dangerous substance at the workplace by replacing it with a substance or process which either eliminates or reduces the risk*".

162. Accordingly, I raised RQ-ABWR-1410 (Ref. 159) to ensure that:

- Options to prevent hydrogen build-up in the off-gas system were appropriately defined and evaluated based on their own risk reduction merit; and
- All reasonably practicable measures were incorporated in the design.

163. The RP's response to RQ-ABWR-1410 (Ref. 160) provided an optioneering study including further options such as dilution of the off-gas stream by inert gas, provision of an additional re-combiner upstream from the point of elevated hydrogen concentration, and use of alternative means of extractions e.g. a Mechanical Vacuum Pump (MVP). Whilst the optioneering resulted in the implementation of a high temperature alarm in the Charcoal Absorber, the RP deemed all options aimed at reducing hydrogen concentration at the 2^{nd} stage SJAE to be grossly disproportionate.

164. In my assessment of the scoring and optioneering, I noted that the RP rated options aimed at reducing hydrogen levels upstream from the re-combiner (to below 25% of the LEL as per DSEAR ACOP) as not providing a safety benefit because it considered the SJAE as a Class 3 component that was not relied upon to provide a nuclear safety function. My view is that prevention of hydrogen accumulation, the subsequent off-gas system isolation, unnecessary scram and conventional safety issues have a safety benefit which should be acknowledged and therefore the assessment falls short of my expectations and ONR SAP EHA.13.

165. I judged that, on that basis, options including early re-combination (e.g. by provision of an additional re-combiner) have been discounted prematurely and, in conjunction with the Radwaste assessor I raised RQ-ABWR-1514 (Ref. 161) for the RP to confirm whether the option had been foreclosed by the generic design.

166. I was satisfied that the RP confirmed that the design offers sufficient flexibility for the future licensee to install an early stage of recombination so that hydrogen concentration remains below 25% LFL in the off-gas system, however, this has not been incorporated in the baseline design of the UK ABWR. I consequently fully support the assessment finding raised by Radwaste Specialist assessor in this area.

167. Downstream from the off-gas system re-combiners, the RP considered introducing flame arresters, automatic isolation on high temperature in the charcoal beds etc. as an additional measures. In line with the observations above, my view is that the assessment is not conclusive and therefore an assessment finding is appropriate (see **AF-ABWR-IH-04)**.

168. The RP discussed how the potential for hydrogen deflagration, detonation and charcoal bed fires had been considered in the design of the system. The RP presented that the design pressure of the system had been defined so that it is able to withstand the overpressure from potential detonations between the main condenser and the OG condenser. In relation to this, I requested in RQ-ABWR-1410 (Ref. 159) that the RP clarified:

- How the transition from deflagration-to-detonation had been considered in the design, and specifically, the geometric considerations used to define whether transition to detonation was credible during normal operation and fault conditions.
- The potential for hydrogen accumulation under fault conditions and unmitigated consequences of ignition in pipework.
- Justification that the effect of the reflected shock wave had been considered in the design of the OG system including pipework, components and structural supports.

169. The RP considered deflagration and transition to detonation based on qualitative geometry considerations such as pipe lengths and also stated that if it were to occur, then the opportunity for shock reflection would be minimal. I therefore judge that an assessment finding is required to ensure that, during detailed design of the pipework and off-gas system components, the licensee confirms that transition to detonation and damaging effects do not occur upon ignition and flame progression (see **AF-ABWR-IH-04**).

170. In the substantiation of pipework integrity following hydrogen ignition, the RP also considered that deflagration would result in a peak pressure around 8 times the operating pressure, and detonation would result in a peak pressure around 18 times the operating pressure, in line with recommended values in the Light Water Reactor Hydrogen Manual (Ref. 162). Whilst I am broadly satisfied with the use of these values as an indication of overpressure levels, they are based on hydrogen-air-steam systems.

171. The Radwaste Specialist Inspector has highlighted that the composition of the off-gas stream is oxygen-rich, in which case the use of these values is not conservative. This is supported by references such as Liberman et al. (Ref. 163), which report peak pressures of 22 times the initial pressure in a detonation of a hydrogen-oxygen-steam system). Also, according to Schroeder et al. (Ref. 164) deflagration peak pressures in oxygen rich systems are around 9.75 times the initial pressure at around 60% hydrogen (such as is the case in the analyser lines).

172. The RP's response to RQ-ABWR-1410 (Ref. 160) acknowledged that the reflected shockwave would exert pressures higher than the deflagration and detonation and considered that pipework and supports would withstand them given the seismic qualification of the system. However, this could not be confirmed within GDA. In light of the above, I judge that it is appropriate to raise it in assessment finding **AF-ABWR-IH-04**.

173. The RP's response to RQ-ABWR-1410 query 7 stated that it was considered unlikely that the recombiner would represent a source of ignition in fault conditions when the hydrogen concentration would support detonation in pipework and off-gas components. This is not in line with my expectations, as the minimum ignition energy of hydrogen is negligibly small and therefore static electricity, hot surfaces (preheater, recombiner) would be sufficient to ignite the gas with concentrations in the flammable envelope. Whilst this is a shortfall in the assessment, I consider that hazardous area classification, equipment specification for control of ignition sources is in the scope of detailed design and it is therefore appropriate to raise an assessment finding. I judge that **AF-ABWR-IH-04** captures the requisite work to resolve this shortfall.

174. As part of my assessment in RQ-ABWR-1410, I challenged the RP to demonstrate how learning from OPEX on charcoal bed fires in BWR off-gas systems in Japanese and German plant had been considered in the UK ABWR design. Specifically, I queried the characteristics of the charcoal beds that would support:

- The assumed integrity of the steel vessel upon a charcoal fire and how it would be suppressed; and
- The assumed confinement of the fire to a single charcoal bed (there are 4 in series in the proposed design).

175. The RP explained the cause of the German BWR charcoal bed fire and acknowledged that, although the integrity of Charcoal Adsorbers had been sustained during the event, the response of the UK ABWR charcoal bed to a fire had not been studied within the design substantiation and safety documents supplied in GDA.

176. The RP also provided temperature profiles to justify that the fire would not spread to the second charcoal bed until the first bed is consumed (10 days). Whilst I am broadly content that the calculations align with observations from German BWR OPEX, the rate of charcoal combustion was limited by oxygen concentration in the off-gas stream and it had therefore assumed that the structural integrity of the vessel is maintained during the fire. Consequently, I judge that it is appropriate to incorporate this point to the assessment finding below:

AF-ABWR-IH-04 - As the assessment of hydrogen hazards has not demonstrated that the explosion risk has been reduced to as low as reasonably practicable, the licensee shall confirm that the following has been addressed and incorporated into the internal hazards safety case:

- **All reasonably practicable options are implemented to prevent hydrogen build-up during normal operation and fault conditions, with a suitable safety margin.**
- **The potential for deflagration and transition to detonation is eliminated so far as is reasonably practicable.**
- **There is suitable and sufficient provision for inerting and purging of the flammable atmospheres.**
- **Hazardous area classification has been undertaken and there is control of ignition sources at all times.**
- **The equipment specification is such that it would withstand peak pressure and impulse associated with deflagration and detonations, and the effect of oxygen rich mixtures has been considered.**

- **The off-gas system pipework, components, Turbine Building barriers and penetrations are confirmed to withstand the peak pressure, impulse and reflected shock wave.**
- **The off-gas charcoal bed vessels and components withstand the thermal and pressure loads associated with charcoal bed fires without loss of structural integrity.**

177. As part of RQ-ABWR-1410, I queried the rooms/ compartments where leakage of off-gas could result in the build-up of a flammable atmosphere, the consequences of immediate and delayed ignition and how the system would be able to reveal leaks.

178. The RP's response credited the HVAC system to dilute off-gas system leaks and to provide room temperature and radiation detection as the trigger of an alarm to operators. It also considered that the calculated room temperature and hydrogen concentration profiles confirmed that high temperature alarms in the rooms would be raised before hydrogen build-up to flammable levels even in the absence of HVAC system dilution.

179. Revision 4 of the off-gas system ALARP Topic Report (Ref. 156) acknowledged that disruptive failure of off-gas system pipework (e.g. as a result of detonation inside pipework) has the potential to damage the temperature and/ or radiation detectors and therefore impair the off-gas system isolation function. Based on this, I judge that the current provision is adequate, provided that it is demonstrated during detailed design that the pressure boundary of the system is maintained upon ignition as captured in the assessment finding **AF-ABWR-IH-04** above.

180. I also note that whilst substantiation of non-divisional barriers associated with the off-gas system rooms has not been completed in GDA for the most part, I am satisfied that this shortfall has been identified by the RP and is captured by a separate assessment finding on barrier substantiation (**AF-ABWR-IH-10**).

181. Overall I am content that, in response to targeted RQs and ROs through GDA, the RP has made extensive changes to pipework layouts to reduce the potential for radiolytic hydrogen accumulation. The RP has also provided evidence of Class 1 barrier substantiation and, where residual explosion risks remain, it identified a number of design changes which can be implemented subject to licensee choices. Based on this, I judge that the above provides sufficient evidence that the generic layout of the UK ABWR will not be challenged during the site-specific assessment stage (hence a GDA issue not being merited). The assessment findings are nevertheless needed to ensure that all reasonably practicable measures are implemented, and the explosion modelling and overall case are revisited and informed by detailed design considerations.

4.2.3.6 Assessment of HEAF Hazards Assessment Methodology and Application

182. The RP case considered the potential for High Energy Arcing Faults (HEAF) to occur when SSCs operate at voltages greater than 440 V. I am satisfied that the assessment methodology included identification of SSCs operating at those voltage conditions and therefore the expectation from ONR SAP EKP.1 is met.

183. The RP considered the SSC design will be to BS EN 62271 (Ref. 165) and the energy would be vented through the top of the switchgear. The RP used a short current of 31.5 kA based on a representative switchgear (Ref. 103).

184. As the RP noted specific switchgear and the short current value would place a constraint in the design of the barriers, I discussed with the electrical engineering inspector, who in turn questioned the proposed 31.5 kA fault current value. He noted a higher 63kA fault current as the stated rating of the switchgear (Ref. 166). Although

there is margin available in the capacity of the barriers shown in Ref. 103, the assessment is not conservative and barrier withstand remains to be fully substantiated. I therefore judge that the barrier response calculations need to be revisited in line with the assessment finding below.

AF-ABWR-IH-05 – The Requesting Party's analysis to demonstrate barrier substantiation against High Energy Arcing Faults (HEAF) is not consistent with the switchgear specification in the Electrical Engineering submissions and the oil mist explosion assessment assumed a single exemplar fluid to derive evidence of barrier substantiation. The licensee shall therefore use the specific switchgear fault current, and the physical and chemical properties of the specific oils selected during the site-specific design stages to confirm that the barriers are suitably substantiated against HEAF and oil mist explosions.

185. The assessment finding above questions the assumptions supporting the RP's oil mist explosion and HEAF safety cases and expresses the need for further modelling and confirmation during the detailed design and site-specific stages. Whilst resolution of this finding is open to licensee choices and may require design changes, I judge that there is either sufficient margin in the design of the barriers or the changes required will be minor and will not challenge the generic layout of the UK ABWR. A finding is nevertheless needed to ensure that the risk associated with both types of explosions are reduced SFAIRP during the detailed design and site-specific assessment stages.

4.2.4 Outstanding issues

186. In addition to the findings raised as part of my assessment in section 4.2.5 below, the Topic Report on Safety management of radiolytic gases generated under normal operating conditions has identified that the following aspects of the case have not been completed during GDA:

- Implementation of spray guards (HECW system). This has been captured by the RP in its Assumption Issue Register Information System (AIRIS) entry IH-IR-0001.
- Implementation of oil bunds on the RIP MG Set (AIRIS IH-IR-0002-please note separate Assessment Finding on the provision of bunds generally).
- Void filling in the ceiling of T/B room 322 to prevent hydrogen accumulation (AIRIS IH-IR-0003) and change to hydrogen pipework in the T/B (AIRIS IH-IR-0004).
- The design of the Reactor Vessel Instrumentation system (RVI) condensing chambers in the RPV pressure and level monitoring and Main Steam Line flow monitoring systems and the potential for accumulation of radiolytic hydrogen presented in the Topic Report on Safe Management of Radiolytic Gases generated under normal operations revision 4 (Ref. 110) is based on an assumed design and needs to be confirmed during detailed design. This is recorded as AIRIS entry **IH-IR-0013**.
- The ALARP assessment for the Reactor Pressure Vessel Head Spray (RPVHS) line for accumulation of radiolytic gases is to be re-revisited during detailed design. This is also recorded as AIRIS entry **IH-IR-0013**.

187. During Step 4 of GDA, the RP has made extensive pipework layout improvements to eliminate the potential for radiolytic hydrogen accumulation as documented in Reference 110. I am also satisfied that the RP has proactively recorded outstanding issues in AIRIS and these are within the scope of detailed design to be addressed by the future licensee.

4.2.5 Assessment Findings

188. During my assessment of the fire and explosion safety case, 5 residual matters were identified for a future licensee to take forward in their site-specific safety submissions. Details of these matters are contained in Annex 5.

189. As documented in the above assessment sections, these matters do not undermine the generic safety submission either individually or in aggregation, and are primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages. These items are captured as assessment findings.

190. I have recorded residual matters as assessment findings if one or more of the following apply:

- site specific information is required to resolve this matter;
- resolving this matter depends on licensee design choices;
- the matter raised is related to operator specific features / aspects / choices;
- the resolution of this matter requires licensee choices on organisational matters; and
- to resolve this matter the plant needs to be at some stage of construction / commissioning.

191. Assessment findings are residual matters that must be addressed by the licensee and the progress of this will be monitored by the regulator.

192. In addition to the above 5 residual matters from the fire and explosion safety case assessment, there are also assessment findings identified in other technical disciplines including radwaste and reactor chemistry for a future licensee to take forward post GDA. These assessment findings require internal hazards input or have an impact on the internal hazards analysis considerations and therefore need to be addressed holistically.

4.2.6 Conclusions on Internal Fire and Explosion Hazard Assessment

193. The RP undertook a significant amount of work in fire and explosion hazard identification and consequence modelling. This has resulted in revised consequence analysis, pipework layout changes, the introduction of engineered measures such as bunds and flange guards, which are in line with my expectations.

194. From an internal hazards perspective, I am satisfied that the design changes completed during the GDA process have resulted in the elimination of radiolytic hydrogen explosion hazards in numerous locations. I am also content that sufficient evidence of substantiation of Class 1 divisional barriers has been provided for both fire and explosion hazards.

195. I have nevertheless identified a number of assessment findings and outstanding issues for the future licensee to take forward. These findings addressed the need for revisiting the fire modelling as the design progresses (to include all combustible inventories), substantiation of barriers against full compartment burnout, specification of dampers and penetrations, and demonstrating withstand of the barriers against explosions and HEAF as the civil engineering design evolves.

196. Notwithstanding the above shortfalls and as documented against each case in turn I judge that the RP has provided confidence that there is reasonable flexibility in the design to accommodate these changes without major layout modifications.

4.3 Internal Blast Safety case

197. Internal blast refers to the sudden release of energy from pressurised systems and components which results in shockwaves of sufficient magnitude to cause damage to structures and plant.

198. This section specifically refers to non-combustible blast hazards, where the release of energy arises from pressurised systems and components and does not involve combustion.

199. The effects from shockwaves associated with combustible blast hazards are presented in the fire and explosion section 4.2 of this report.

200. In the UK ABWR, internal blast can arise from loss of pressure boundary events involving high pressure steam and other gases such as nitrogen and air.

201. When the shockwave interacts with plant, fragments /missiles can be ejected. Missile generation and strikes from failure of pressurised systems are covered in the conventional internal missiles section 4.7 of this report.

202. The RP presented the internal blast case in the following submissions:

- The Pre-construction Safety Report (PCSR) revision C (Refs. 15);
- Topic Reports on Internal Blast (SE-GD-0199) revisions 2 to 4 (Refs. 50, 51 and 52);
- Internal Blast Modelling report (SE-GD-0474) revisions 0 and 1 (Refs. 167 and 168);
- Barrier Substantiation Report (BKE-GD-0019) revisions 2 to 5 (Refs. 87, 88, 89 and 90); and
- Civil Structure Evaluation Report (LE-GD-0322) revisions 0 and 1 (TRIM Refs. 169 and 170).

203. My assessment of the RP's submissions on internal blast is presented below. In line with other sections of this report, the scope of assessment and the assessment of the RP claims and arguments are presented first. Next, I discuss my views on the RP's analysis methodology and consequence assessment results. Finally, I present my assessment of the RP's evidence of the substantiation of barriers delivering the internal claims together with the applicable assessment findings to be taken forward by the future licensee.

4.3.1 Requesting Party's Internal Blast Safety Case

204. As it is generally the case in UK ABWR Internal Hazards Safety claims, the three general Internal Hazards claims (**IH SFC 5-7.1**, **IH SFC 5-7.2** and **IH SFC 5-7.3**) apply to internal blast.

205. Claims **IH SFC 5-7.1** – "*Internal Hazards do not prevent the delivery of Fundamental Safety Functions*)" and **IH SFC 5-7.2** – "*the consequences of any internal hazards are limited to one safety division*" are delivered by RC Class 1 barriers, unless the area has been identified as an exception to segregation (where IH SFC 5-7.3 applies).

4.3.2 Assessment of Internal Blast Hazards

4.3.2.1 Scope of Assessment

206. My assessment covers all RP's submissions in the area of internal blast during Step 4 of GDA, and the associated internal hazards and civil engineering reports, where substantiation of the barriers against internal blast has been presented.

207. The areas chosen to assess the internal blast submissions were limited to the following:

- Suitability and sufficiency of the safety case, and the claims and arguments made in this area;
- Analysis methodology and assumptions;
- Justification of systems excluded from analysis; and
- Substantiation of the claims made, including the blast modelling results, consequence analysis and response of SSCs to blast.

208. The sections below cover the areas of my assessment.

4.3.2.2 Assessment of Claims and Arguments

209. The RP's claim on Class 1 divisional barriers is in line with ONR's SAPs EDR.2, EKP.5 and EHA.5 and IAEA guidance (Ref. 171).

210. All Class 1 barriers claimed against internal blast are listed in revision 5 of the Barrier Substantiation Report (Ref. 90).

211. A hazard schedule for internal blast scenarios was provided in revision 4 of the Topic Report on Internal Blast (Ref. 52). The hazard schedule included the internal blast scenario, frequency, unmitigated consequences, hazard safety function, categorisation and classification of the safety function and mitigated consequences. However, the blast hazard schedule is generic in nature as it does not include specific blast events other than representative scenarios of locations and barrier designs across the UK ABWR. Specifically, the hazard schedule contained the following blast sources:

- High pressure pipes and vessels in rooms with no penetrations in the divisional barrier (R/B, C/B and Hx/B).
- High pressure pipes and vessels in rooms where there are penetrations in the divisional barrier (R/B, C/B and Hx/B). This entry represents the hazard impact on adjacent divisions when the blast is transmitted through penetrations e.g. doors.
- High pressure pipes and vessels in the T/B. This entry represents scenarios not bounded by the representative case (large steam inventories in the T/B).
- High pressure pipes and vessels in the B/B, EDG/B, Rw/B, FV/B, S/B, Yard and Service Tunnel, where there could be potential damage to A-2 systems (B/B).

212. The hazard schedule did not explicitly identify the rooms where the above hazards sources are present in the UK ABWR.

213. The RP claimed Class 1 barriers for the protection of adjacent divisions in the R/B, C/B and Hx/B (although it is noted that there are no blast sources in the Hx/B), and considered that pressure relief in the vessels and pipework would provide a level of defence in depth.

214. With regards to the T/B, the RP considered that there is no potential for a blast from non-combustible sources to result in a radiological release and therefore no claims against internal blast were made in that building. This assumes that a blast in the T/B

has no potential to disrupt the off-gas system and I have raised a separate assessment finding **AF-ABWR-IH-06** on the need for evidence to discount domino effects and substantiation of RC barriers in the T/B against blast.

215. I judge that the above approach, although inconsistent with other hazard schedules is generally appropriate to the analysis and evidence provided by the RP as part of GDA. Assessment finding **AF-ABWR-IH-14** captures the gaps and inconsistencies found across hazard schedules in internal hazards as detailed in this assessment report.

216. Finally, as part of my assessment of the hazard schedule, I questioned the failure frequency quoted for blast hazards (infrequent event).

217. The RP considered that failure of Class 3 pipework to be a frequent fault in the Pipe Whip and Jet Impact Topic Report revision 3 (Ref. 40) but the same pipework is considered to give rise to internal blast only infrequently. Following my query in RQ-ABWR-1401 (Ref. 172), the RP responded that failure of the Class 3 pipes had been considered frequent because there was insufficient evidence to justify it as an infrequent event (Ref. 173).

218. Whilst I do not consider the RP's assumption to be fully supported, I am content that the dominant pressure part failure hazard (pipe whip and jet impact) was considered as a frequent event and the RP has characterised and substantiated the Class 1 barriers against internal blast appropriately, as presented in section 4.3.2.3.

4.3.2.3 Assessment of Blast Analysis Methodology and Consequence Assessment

219. In the assessment of internal blast, the RP followed a 4-step approach in line with that used for the assessment of other internal hazards. The 4 high level steps were as follows:

- Step 1 – Identification of safety classified, A-1 SSCs.
- Step 2 – Identification of Internal Blast hazard sources; The RP selected the high pressure components in each room from data collated in the Room Data Sheets (e.g. R/B data sheets in Ref. 174) for each relevant building in turn.
- Step 3 – Internal blast hazards characterisation:
  - The RP classified each high energy pressure component into one of four categories: vessels, gas (non-steam) piping system, water (pressurised) piping and steam piping. For each of those systems, the RP estimated the equivalent blast energy in MJ. Subsequently, the RP selected the most challenging consequences based on the location of the potential blast, the blast energy, the type of media and the geometry/ layout of the room.
  - The RP determined the capacity of the weakest wall and assessed the most onerous blast against this wall to establish a bounding case.
  - All cases governed by the bounding case were therefore substantiated in this way.
  - Following the assessment of the R/B, the RP detected cases that would not be substantiated using the bounding arguments initially made. The RP assessed these cases separately.
- Step 4 – Identification of safety measures.

220. The RP assumed that all pressure vessels could undergo brittle failure resulting in an instantaneous release of energy. The RP also assumed that the entire energy of the fluid is converted into the blast wave. I am satisfied that this approach is conservative and aligned with ONR SAPs (EHA.7).

221. The RP assumed that pressurised gas in pipes and vessels would behave as an ideal gas. Although an ideal gas behaviour assumption is certainly applicable to gases at

around atmospheric pressure, it is not generally valid for high energy systems. However, the assumption results in conservative estimates of the explosion energy.

222. To estimate the consequences of vessel rupture, the RP applied the “Brode equation” and determined the energy of the explosion and TNT equivalence according to the method presented in Volume 1, Appendix L of the R3 Impact Assessment Procedure (Ref. 175). The RP also increased the TNT equivalent by 20% in line with the recommendations in UFC 3-340-02 (Ref. 154). It also acknowledged that, as the TNT equivalence does not provide shockwave results, a sensitivity tests to demonstrate application in the substantiation of the UK ABWR barriers was needed and presented it in the Blast Modelling Report (Ref.167).

223. With regards to the failure of high pressure gas piping, the RP used the R3 methodology (Ref. 175) to determine the characteristic size of the explosion and volume of gas contributing to the blast energy. It then estimated the peak overpressure, the reflected overpressure and impulse to determine the TNT equivalent mass.

224. The RP calculated the blast energy associated with failure of high energy steam systems by estimating the expansion energy and assuming all the energy is transferred into the blast wave. I judged that this approach is highly conservative and therefore adequate to produce bounding estimates.

225. As part of my assessment of the methodology presented in the Topic Report on Internal Blast revision 2 (Ref. 50), I raised RQ-ABWR-1075 (Ref. 176) and RQ-ABWR-1401 (Ref. 172) to gain understanding on the following aspects:

- The limited information provided on the characteristics of the specific blast source considered to bound blast hazards (other than an equivalent TNT mass).
- The RP’s assessment substantiated 250mm thick RC wall panels subjected to non-combustible blast loads. However, many panels also have service penetrations and encast items, and this can significantly affect their span properties.
- The use of the TNT equivalent method without further justification.
- The RP’s assumption that the effects of multiple blasts would not superimpose upon each other if such a sequence of blast events was to occur.
- Discrepancies between Room Data Sheets (which acknowledged the presence of SSCs in specific rooms) and the Internal Blast Topic report which did not consider SSCs to be present.
- Absence of an Internal Blast hazard schedule, a list of qualified SSCs or substantiated barriers.
- The credit given to venting of blast from the room of origin e.g. through blowout panels present to avoid pressurisation of compartment upon steam releases.
- The assumed distances between blast sources and barriers, and between blast sources.
- The RP’s application of blast damage criteria, as it used human harm criteria to assess damage to SSCs.

226. The RP responded to the above points in Reference 177, which I considered addressed the points raised appropriately:

- The RP described the blast source used to derive the bounding case, and it studied the effect of penetrations in the transmission of blast waves to adjacent rooms. It also provided estimates of blast wave decay versus distance and sensitivity studies on the blast wave characteristics to support that the TNT equivalent approach was conservative.

- The RP resolved the discrepancies between the room datasheets and the effect on SSCs quoted in the report, provided a hazard schedule and changed the SSC blast impact criteria from human harm data to relevant responses of SSCs to overpressure events using the Explosion Handbook (Ref. 180) as a reference.

227. The RP subsequently revised and reissued the internal blast Topic Report to include the assessment of the T/B, the Rw/B, the Fv/B, S/B, Yard and Service tunnels.

228. My assessment of the revised report highlighted the following shortfalls, which I raised separately in RQ-ABWR-1401 (Ref. 172):

- The characteristic size of the explosion sources, "φ" was not calculated appropriately, as the velocity of sound in the high pressure media had invariably used data for air, as opposed to pressurised nitrogen or steam. I requested that the RP revised the calculations, corrected the TNT and checked the impact of this change on the substantiation of Class 1 barriers and SSCs.
- The RP's response to RQ-ABWR-1244 (Ref. 178) had identified the reasons why the failure frequency of Class 3 pipework outside the PCV and MSTR was considered to be a frequent fault and I had accepted the values used. However, the Internal Blast Topic Report revision 3 considered an internal blast for all systems (steam and gas) from Class 3 pipes as an "infrequent fault". I requested that the RP explained the inconsistency.
- The RP used HSE Research Paper 285 section 3.6 (Ref.179) to conclude that sensitive equipment would not be seriously damaged when subjected to pressure below 50kPa. I noted that the HSE Research report reproduced thresholds from the Gas Explosion Handbook (Ref. 180) which showed that significant damage to equipment can occur at significantly lower pressure levels (for example instruments damaged at 0.07-0.10barg or 7-10kPa; inner parts of a cooling tower damaged at 0.10barg or 10kPa, or instrument cubicle unit controls damaged at 0.20barg or 20kPa). I therefore indicated that the 50kPa threshold did not meet my expectations and the impact of lower threshold values should be investigated.

229. The RP responded in Reference 173, which acknowledged the calculation error and provided the appropriate TNT equivalent results in revision 4 of the Topic Report (Ref. 52). The RP also adopted more conservative impact criteria (0.07barg) as the threshold for blast damage on SSCs.

230. In revision 4 of the Topic Report on Internal Blast (Ref. 52), the RP acknowledged that pressurised water can give rise to a Boiling Liquid Expanding Vapour Explosion (BLEVE) or blast source if it is superheated. In order to assess the blast consequences, the RP identified the pipework containing pressurised water where the design temperature is above the superheat limit of water (280ºC) at the design pressure of the systems.

231. The RP noted that the majority of the systems would not operate at temperatures above the superheat limit and therefore it considered that the potential for BLEVE was minimal.

232. Specifically, T/B system water piping was considered not to pose a risk of blast as a result of the operational regime. I judged that this is appropriate in so far that the future licensee sets appropriate limits and conditions of operation and associated plans and procedures to prevent exceeding the pressure and temperature which would give rise to blast in those systems (see **AF-ABWR-IH-16**).

233. Nevertheless the RP also acknowledged that there are three T/B systems which are operated above the superheat limit, and therefore there is an inherent risk of BLEVE:

- The RCIC line transfer drain line from the turbine inlet to the main condenser which also passes through C/B 210;
- MS piping containing water is identified in T/B room 312 and room 413; and
- The Feedwater Heater Drain system (HD) piping connected to the Moisture Separator Reheater (MSR) 2nd stage preheater (T/B rooms 504 and 505 on floor 2F and room 213 on floor M2F).

234. The RP provided TNT equivalence calculations for these systems in Reference 51. I sampled the calculations and I am satisfied that the results for the first two cases are below 3kg TNT equivalent. The latter case (HD piping) has much higher TNT equivalents at around 20kg TNT, which is in my view also a fair representation of the magnitude of the hazard.

235. The RP then considered that the potential to disrupt the off-gas system based on distance (15m) and isolation functions would be minimal. However, I judge that this does not take into account the potential for blast wave reflection and the conclusion is not supported by quantitative barrier response analysis hence the need for assessment **AF-ABWR-IH-04**.

4.3.2.4 Assessment of Barrier Substantiation Including Penetrations

Barrier Substantiation

236. The UK ABWR structures forming hazard compartments are primarily made of RC but also include penetrations including doors, ducts, hatches and blockwork.

237. The RP's approach to substantiate the barriers against a blast hazard is based on a representative bounding example which studied the impact of an onerous blast source on the weakest RC wall in the UK ABWR (a 250mm thick wall with 16mm diameter rebar at 200mm centres as reinforcement).

238. The RP selected a 1m wide, 3m high barrier span and considered that the TNT mass would be 300mm away. It also considered that the response of this span would be conservative of the conditions experienced by Class 1 barriers. The RP estimated the dynamic response of the RC wall using UFC 3-340-02 and accepted a limiting rotation for a moment hinge in the wall under blast loading when it is below 2 degrees. I discussed this approach with the civil engineering inspector which judged it to be acceptable (Ref. 182).

239. Following the initial assessment and, as the work to characterise the blast sources continued to include systems in the T/B, the RP identified blast sources which were more onerous than the representative example. The RP studied those cases on a one-by-one basis. This is generally appropriate for GDA.

240. Substantiation of the response of the RC barrier against blast loading is presented in the Internal Blast Modelling Report revision 1 (Ref. 168). As part of my assessment of barrier substantiation, I sampled the withstand of barriers not bounded by the example barrier used for substantiation (the 250mm RC barrier against a 3kg TNT equivalent). This involved a check on the substantiation of barriers in T/B rooms 421, 416, 215 and 213, where the blast source is in the order of 20kg of TNT equivalent.

241. Rooms 412 and 413 of the T/B are the Main Stop Valve and Turbine Control Valve and the No. 1/2 Feedwater Heater & Main Steam Piping Access room, respectively, which contain 750mm diameter main steam pipework. The RP identified that the thinnest walls for those rooms are 500mm and 800mm in thickness and the design pressure and temperature of the piping was considered in the internal blast calculation as 302º C and 8.62 MPa, respectively. Following RQ-ABWR-1401, the RP re-calculated the TNT equivalent load on those barriers from each main steam line as 15.8kg and

provided barrier rotations of well below 2 degrees (based on a single line failure and assuming that no other of the main steam lines fail).

242. The RP subsequently considered that combined blasts (domino effects to the remaining MS lines) would not occur. This was justified qualitatively by stating that the neighbouring pipes would need to undergo a large deformation before failing and that it was very unlikely that the rest of the pipes would rupture. Based on the justification provided, I am not satisfied that the adjacent MS lines have been fully substantiated against an internal blast of 15.8kg TNT equivalent magnitude. Therefore, the domino effects have in my view been discounted prematurely and do not meet the hazard characterisation expectations laid out in ONR's SAP EHA.1. As a result I have raised assessment finding **AF-ABWR-IH-06**.

243. Separately, the RP considered domino effects as a result of blasts originating from a single air receiver vessel burst in the EDG/B, resulting in the failure of the adjacent air receiver. Whilst the RP credited the wider catchment area for the blast wave arising from the two tanks (thus resulting in a lower barrier rotation value), failure of a single receiver, which concentrates the blast wave on the barrier (estimated as per UFC-3-340-02) does result in rotation values close to the 2 degree limit for the thinnest wall in proximity to the tank.

244. I have recorded the need to address domino effects from blast as the following assessment finding:

AF-ABWR-IH-06 - As the exclusion of consequential failure of pressurised components from assessment is not fully justified, the licensee shall demonstrate that blast domino effects do not take place in the UK ABWR so far as is reasonably practicable. This includes providing evidence to support the following:

- **The assumed integrity of high energy pipework, including the main steam lines, following internal blast in the Turbine Building. This is because non-divisional barriers have only been substantiated against a single line blast.**
- **High trinitrotoluene (TNT)-equivalent sources in the turbine building do not impact the off-gas system and that there are no cliff edge effects associated with a single air receiver blast.**

245. Whilst the above finding requires the RP to demonstrate that blast hazards do not result in unacceptable consequences (radiological releases or failure of Class 1 barriers), I judge that the additional evidence is achievable by further analysis or minor changes (e.g. protection of SSCs). These minor changes would not challenge the generic layout of the UK ABWR and therefore the significance of the shortfall does not merit a GDA issue to be raised.

246. To gain confidence in the RP's case, I also sampled room 103 in R/B, which contains high pressure piping and a Hydraulic Control Unit containing pressurised nitrogen, and R/B room 110 (the RHR Pump room). The RP ruled out high energy water pipework as a blast source as the temperature was considered to be below the superheat limit of water (at 280ºC).

247. The RP estimated the TNT equivalent for the pressurised nitrogen inventory and determined that the equivalent mass is well below 3kg TNT.

248. I sampled the calculations, and besides the issues reported in RQ-ABWR-1401 (which were resolved in revision 4 of the Topic Report on Internal Blast), I judged them to appropriately reflect the load imposed upon the barrier and its response.

249. I am satisfied that the RP has demonstrated the withstand of RC Class 1 barriers against internal blast loading with a suitable level of confidence, based on the thicker barrier (300 mm) than the representative case (250 mm) in the above example.

Penetrations Substantiation

250. In those cases where there are penetrations on the Class 1 barriers, the RP estimated the potential transmission of the blast wave through the penetrations e.g. HVAC ducts, open divisional doors using the Air3D model (Ref. 183). I am broadly satisfied with the use of this tool to model blast-structure interactions in three dimensional domains.

251. Following application of Air3d, the RP concluded that the effect of the blast wave would have dissipated within 150-500mm from the impacted barrier and, therefore, that SSCs needed to support the delivery of FSFs from the adjacent division are undamaged. The RP subsequently presented the estimated overpressure on the nearest SSC from the neighbouring division in the Internal Blast Modelling report revision 1 (SE-GD-0474) (Ref. 168).

252. I sampled a number of cases as part of query 4 of RQ-ABWR-1401. The predicted overpressures on the targets in adjacent divisions were above the 7kPa in the Explosion Handbook (Ref. 180) which I consider as a more appropriate threshold for damage to instrumentation than 50kPa.

253. Following my query on damage thresholds, the RP’s response (Ref. 173) addressed two examples:

- Room 103 in R/B where a blast impacts the Core Flow Instrumentation room 107 in R/B; and
- Room 121 in R/B where a blast source impacts the CRD Instrumentation and Valves and Core Flow Instrumentation in room 118 in R/B.

254. The RP acknowledged that the SSCs would be affected and concluded that the FSFs would still be delivered as the SSCs had been designed to fail safe.

255. The design characteristics that support the failsafe response and delivery of FSF credited were not explicitly described and therefore my judgement is that the expectations of ONR SAP EDR.1 are not fully met. I therefore consider that further evidence should be provided as part of **AF-ABWR-IH-11**, raised on the substantiation of failsafe responses against internal hazards.

256. The RP also concluded that the propagation of blasts in R/B rooms 327 and 640 are bounded by the case presented in Appendix H.2 of the Blast Modelling Report (room 118) where overpressures on SSCs on the other side of the open penetration (doors) had been predicted to be in excess of 50kPa. The RP concluded that a 50kg door would deliver the blast mitigation required.

257. The specification of doors and all other penetrations against internal hazards including blast have not been provided in GDA and will be the subject of further work during the detailed design phase. Whilst this is a shortfall (as captured in **AF-ABWR- IH-03)**, I welcome the RP’s attempt at minimising blast propagation through penetrations and I expect that the RP will specify all doors and penetrations to eliminate internal blast effects on neighbouring divisions so far as is reasonably practicable. Based on the loadings available, I judge that this prospective specification of penetrations as being compatible with commercially available options (which are open to licensee choices), without the need to major changes to the UK ABWR layout.

4.3.3 Outstanding Issues

258. The assessment of the RP's Internal Blast submissions has shown that a number of issues remain outstanding at the end of GDA, including:

- Substantiation of doors and penetrations under blast loading. The response of doors to blast loading has not been studied in Step 4 of GDA beyond a generic 50 kg door. The RP should revisit this assessment in the detailed design stage once door details are available.
- The assessment of the B/B, Fv/B, Rw/B, S/B, Yard and Service Tunnels was said to be based on System P&IDs and component/ piping lists from the Japanese ABWR data, as information on the UK ABWR design was not available at the time of analysis. The RP should revisit these assessments to demonstrate that there is no divergence from the case substantiated in GDA once the UK ABWR data is generated in detailed design.

259. Whilst the above can be considered matters for detailed design (e.g. selection of door designs, confirmation of specific SCCs design features in relation to the Japanese ABWR and/or qualification of SSCs), I judged **AF-ABWR- IH-03** to be necessary as the specification of penetrations and doors (to determine the selection of specific designs) has not been provided in GDA.

260. I am nevertheless satisfied that the RP have documented the outstanding issues for closure following GDA and recorded them in the Assumption Issue Register Information System (AIRIS) (IH-IR-0006 and IH-IR-0015). I judge that this would ensure that they can be adequately followed up and closed out once **AF-ABWR-IH-03** has been addressed.

4.3.4 Assessment Findings

261. During my assessment of internal blast, one assessment finding was identified for a future licensee to take forward in their site-specific safety submissions. Details of this matter are contained in Annex 5.

262. This matter does not undermine the generic safety submission and is primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.3.5 Internal Blast Hazard Assessment Conclusions

263. I am satisfied with the level of analysis undertaken by the RP and the documents submitted in the area of internal blast during Step 4 of GDA. The RP developed analysis methodologies which are appropriate to the type of blast hazard sources (pressurised gas, water or steam), and selected bounding scenarios to substantiate the Class 1 barriers of the UK ABWR design.

264. The RP has also demonstrated that sufficient systems remain available to deliver the FSFs based on the substantiation of Class 1 barriers in the R/B. Cross divisional effects as a result of blast transmission across doors and penetrations require, however, further evidence during detailed design phase.

265. The substantiation of T/B RC barriers has considered the potential for a single blast (from failure of a single MS line) exclusively. However, the RP discounted the potential for domino effects (multiple line breaks and blasts) qualitatively. I have therefore raised an assessment finding for the future licensee to address the gap as part of detailed design.

266. Notwithstanding the above, I judge that the RP has provided confidence that there is reasonable flexibility in the design to address this finding without major layout modifications.

4.4 Internal Flooding Safety Case

267. Flooding hazards occur due to leakage or failure from any structure, pipework or tanks containing fluids. Accumulation of flood water could cause SSCs delivering FSFs to fail. This assessment considers flooding events initiated either inside buildings or outside of buildings but within the generic site boundary. Flooding initiated as a result of external flooding outside of the site boundary is assessed by the external hazards assessors (Step 4 Assessment of External Hazards for the UK ABWR, Ref. 181).

268. Key document submissions for internal flooding during GDA Step 4 were:

- Pre-Construction Safety Report – Chapter 7 Internal Hazards (Ref.15);
- GA91-9201-0001-00091 - Topic Report on Internal Flooding, revisions 0 - 4 (Refs. 32, 33, 34, 35 and 36); and
- GA91-9201-0003-02122 – Internal Flooding Evidence Report, revisions 0 and 1 (Refs. 184 and 185).

269. There were multiple revisions of the above Topic Report and Evidence Report. Each revision reflected the development of the safety case or reflected ONR's Regulatory Queries. My assessment is focused on the final versions of each of the document submissions.

4.4.1 RP's Internal Flooding Safety Case

270. The RP's overarching safety claims are summarised in section 3.5 of this assessment report. The internal flooding safety case is primarily based on Claim **IH_SFC 5.7.1**- "*Internal Hazards do not prevent the delivery of Fundamental Safety Functions*", and Claim **IH_SFC 5.7.2**- "*the consequences of internal hazard are limited to one safety division*".

271. These are achieved by limiting the inventory, implementation of Class 1 structural barriers, engineered flow paths and equipment qualification.

272. However, the RP identified "*Exceptional flood paths*" (Ref. 15) which have the potential to challenge multiple divisions. For these cases, the safety case is based on claim IH_SFC 5.7.3 whereby there are sufficient A-1 or A-2 signals and equipment available to fulfil the FSFs. The multiple divisions that may be challenged are located in the R/B basement (level B3F) and the C/B basement (level B3F). The Emergency Core Cooling System (ECCS) is located in the basement of the R/B. However, the RP states that any required function by the ECCS in the R/B will not be challenged by a flooding event. The RP also states that no Class 1 SSCs are contained with the C/B basement and therefore argued that no fundamental safety functions would be challenged.

273. The RP's safety case concluded that in the event of a design basis internal flood being realised, suitable and sufficient SSCs will remain available to maintain the plant in a safe state.

4.4.2 Scope of Assessment

274. The assessment strategy in section 2 was used to formulate the scope. The Topic Report on Internal Flooding (Ref. 36) covered the flooding hazards as a result of immersion, spray release and steam release. This section covers the assessment of immersion and spray release hazards only. The assessment of steam release is assessed separately under section 4.5 of this assessment report.

275. My assessment scope was limited to:

- The internal flooding methodology;
- Sampling the suitability and sufficiency of the claims and arguments; and

- Substantiation of the claims made.

276. Sources of flooding were identified in the Topic Report on Internal Flooding. These were the R/B, the Hx/B, C/B, T/B, B/B, EDG/B, ST, S/B, Fv/B and the Yard (Topic Report on Internal Flooding, Ref. 36).

277. Although the Rw/B is listed as being considered, there is no data available in the Appendix of the Topic Report on Internal Flooding. The RP has stated that this will be assessed at detailed design stage (Ref. 36). However, I have not sampled the Rw/B as part of my GDA assessment as there are no Class 1 SSCs and it is outwith the sampling strategy given in section 2.4.

278. The areas chosen in my assessment of the internal flooding safety case followed the sampling strategy given in section 2 and were limited to:

- The R/B excluding inside PCV; The assessment for internal flooding postulated to occur inside the PCV will be covered under section 4.11;
- The C/B rooms which surrounded the MCR, excluding inside MCR. The assessment for internal flooding postulated to occur inside the MCR will be covered under section 4.13.
- The Hx/B;
- The T/B; and
- The S/Ts.

279. Except for the buildings listed in the last two bullet points, these buildings and areas contain the key Class 1 SSCs which deliver Category A functions. The T/B is a Class 2 structure but contains sections of the Main Steam Line (MSL) and some A-1 instrumentation. The Service Tunnels also have cross-cutting impacts, including some A-1 piping. Flooding hazards in the MSTR and hazards as a result of chemical or toxic releases are covered under sections 4.12 and 4.15 respectively.

4.4.3 Internal Flooding Methodology

280. There are a number of revisions of the Topic Report on Internal Flooding (Refs. 32, 33, 34, 35 and 36). Early revisions were provided in GDA Step 3 (Refs. 33 and 34, revisions 0 and 1) and covered the development of the internal flooding safety case of the R/B. I assessed these revisions and issued Regulatory Queries RQ-ABWR-0427 and RQ-ABWR-0488 (Refs. 186 and 187), which required the RP to clarify flooding methodology. I also issued RQ-ABWR-0846 and RQ-ABWR-01485 (Refs. 188 and 189) which sought clarification on flooding substantiation and where omissions would be addressed. Other buildings were added in revision 4 of the Topic Report (Ref. 36). My internal flooding GDA Step 4 assessment is based on the latest revision of the Topic Report.

281. The RP uses the basis that an internal flood is deterministically assumed to occur as a result of gross failure of pipes, vessels and components containing fluids. The RP used the following methodology to carry out a deterministic analysis of internal flooding:

- Identified potential sources of internal flooding;
- Defined the area considered;
- Identified flooding compartments;
- Identified flooding paths;
- Identified SSCs required for safety;
- Calculated internal flooding volume;
- Identification of internal flooding protection and mitigation features;
- Set criteria for acceptability of flood depths; and
- Barriers subjected to postulated floods were assessed for hydrostatic load withstand capability.

282. The above deterministic approach is broadly in line with my expectations and I consider it to be in line with the IAEA Safety Guides NS-G-1.11 and SSG-2 (Refs. 171 and 190) and with ONR SAPs EHA.1, EHA.12 and EHA.15.

4.4.4 Assessment of Claims and Arguments

283. As there are no specific claims made on the prevention of internal flooding hazards, the RP's main claim on protection against internal flooding is by hazard barriers between safety divisions and engineered flood routes. All barriers claimed against internal flooding are identified in the Topic Report on Internal Flooding (Ref. 36) and the Civil Structure Evaluation Report for Barrier Substantiation (Refs. 170 and 171, revisions 0 and 1). The claim on barriers is in line with ONR's SAPs, EKP.5 and EHA.5.

284. I focused my assessment on the R/B and noted five different flooding compartments (Topic Report on Internal Flooding revision 4 Ref. 36). These flooding compartments are:

- Safety division I;
- Safety division II;
- Safety division III;
- Safety division IV; and
- Basement Annulus.

285. The flooding philosophy for the R/B is that any flood water will initially remain within the safety division of origin on the upper levels. The flooding source and inventory are identified in the Topic Report on Internal Flooding (Ref. 36). The flood water then drains via identified flow paths or claimed "engineered flood routes" until it reaches the Basement Annulus and pools across the basement.

286. The engineering flood routes are identified in the Internal Flooding Evidence Report (Refs. 184 and 185). These are via door gaps, stairwells / elevator shafts, unsealed penetrations and floor gratings. Bounding cases were summarised in the PCSR (Ref. 15). I sampled the flood path for the Reactor Core Isolation Cooling System (RCIC) Pump room 113 as this was noted to be a bounding case. The RP showed that in the event of a flood from an upper floor level, the flow paths directed water via channels, sills and floor grating until the water reached the final destination within the R/B basement annulus.

287. In the event of pooling, it was claimed that equipment in the R/B basement annulus would be qualified for immersion and that any immersion would not challenge the emergency cooling. The RP did not credit the drains from intermediate floors as additional flow paths (Topic Report on Internal Flooding, Ref. 36) and therefore there are no claims made on the drains (Response to RQ-ABWR-1485, Ref. 191). As the RP provided arguments that there was provision of multiple measures to prevent the hazard progression, I considered this draining philosophy via engineered flood routes to be acceptable and in line with ELO.4 and EKP.3.

288. As a defence in depth measure, the RP also argued that pipe and vessels have mostly welded joints which would be designed to ASME and ANSI standards and would be part of regular Examination, Maintenance, Inspection and Testing (EMIT). This would reduce the likelihood of pipe and equipment failure.

289. I also sampled engineering flood measures. The RP has proposed 0.2m RC steps / sills on doors to reduce the likelihood of flood water spreading outside the room of origin and that doors, door frames and door locking mechanisms are designed to withstand the flood depth (Topic Report on Internal Flooding, Ref. 36, Figure A-33).The

0.2m figure appears to be a design criteria figure. There is no evidence to confirm why the 0.2m figure is adequate and why the design will not be challenged.

290. I requested more clarification via Regulatory Query RQ-ABWR-1485 (Ref. 189). The RP confirmed that in the R/B, flood doors are designed to withstand water to a height of 4m and non-flood doors have a hydrostatic capability of 0.3m in the opening direction (Ref. 189). Divisional doors have been identified for the R/B and the C/B in the Divisional Boundary Map (Ref. 114). However a door schedule giving details of the functional intent will be provided at the site specific stage (Ref. 189).

291. In considering the RP's defence-in-depth measures, I sampled the RP database AIRIS (Ref. 192) to check whether the assumption of SSCs being located above the maximum flood height was captured. This was omitted from the database dated July 2017, but the RP confirmed as part of Regulatory Query RQ-ABWR-1485 that this assumption was subsequently included in AIRIS (AIRIS Ref. IH-IR-0012).

292. Where the safety case claims that equipment remains dry, the RP confirmed that this equipment would be located on a pedestal or at height. Time-based assessments were not produced in GDA to determine the time that would be available before equipment and SSCs are affected. Therefore the sensitivity of the facility to potential faults and the margins of conservatisms are unclear. I consider that this is not in line with SAPs EKP.2, and ERL.4. Therefore I am raising an assessment finding for the licensee to undertake further flooding analysis to ensure that where equipment is located at height, including those on pedestals and sills, are suitable and sufficient; see **AF-ABWR-IH-07**.

293. To cover areas where flooding may affect more than one safety division such as the R/B basement annulus, there is an additional internal flooding sub-claim:

IH_F_SFC_5-7.3.1: *Where flooding affects multiple Class 1 divisions, protection features such as flood barriers or qualification of individual SSCs will be such that the consequences of a design basis flooding event in one division will not prevent SSCs in neighbouring divisions delivering their fundamental safety functions (FSFs).*

294. For equipment becoming wetted in areas where flooding may affect multiple divisions, the RP stated that equipment qualification would be addressed at detailed design. My expectation was that there may have been available equipment data from the Japan ABWR or OPEX. The RP did not provide adequate arguments to support claim **IH_F_SFC_5.7.3.1**. and therefore I did not consider the demonstration to be in line with SAP EQU.1. Therefore, I am raising an assessment finding to ensure that equipment is suitably qualified; see **AF-ABWR-IH-08**.

295. I was initially concerned that flooding may affect Service Tunnels as they contained multiple divisions and linked buildings. Therefore I sampled service tunnel numbers 603 and 604. Tunnel 603 links the Hx/B and the R/B but there appear to be interconnections to other tunnels, whereas Tunnel 604 starts from the B/B and then separates into three divisions before linking into the R/B at three different locations. I sought clarification as part of RQ-ABWR-0934 (Ref. 193) as it was unclear what fluid systems were in the tunnels and what features prevented a flood from spreading to adjacent tunnels.

296. The RP confirmed that that both tunnels 603 and 604 contained a number of water systems along with cabling (Topic Report of the Tunnel Access Optioneering Study, Ref. 95). The explanation of all the different water systems was described in System Code Names and Abbreviations (Ref. 194). The RP clarified that the Class 1 barriers and double doors were designed in tunnel 603 and that there was a Class 1 barrier between the R/B and tunnel 604 (Ref. 195). The service tunnels are currently at the early stages of design and follow an approach in line with EKP.3. Therefore I am

satisfied with the response. However, the assessment of service tunnels will be considered further once the detailed design becomes available.

4.4.5 Assessment of Substantiation of Internal Flooding Claims

297. For a postulated flooding event on the upper floors of the R/B or C/B, the plant configuration directs the water to the lowest floor level via engineered flow paths. The RP argued that no analysis was required apart from the basement of the R/B and the C/B. The exception to this was the Hx/B which had a sufficient flood height, and as such, the RP acknowledged that slabs on the floor above the basement was analysed.

298. To obtain confidence, I sampled the R/B layout. The R/B B3F contains an outer flood compartment which links to the corridors. Rooms where SSCs are required for safety are located in the inner compartment of the R/B B3F and are segregated by Class 1 flood barriers and doors. The B3F barrier design flood criterion was set at a 4m hydrostatic load (Ref. 36). All required Class A-1 barriers in the event of a flooding event at the B3F level are identified in the Topic Report on Internal Flooding (Ref. 36) and the Divisional Boundary Map (Ref. 114).

299. Any design basis flooding event flowing into B3F will affect a number of rooms: 101, 102, 103, 104, 105, 112, 120, 121, 122, 123, 151, 152, 153, 154, 155, 156, 157 and 158. The largest possible flood source internally is approximately 6400m^3 (Ref. 36 and evidence from calculation) from the suppression pool and the Condensate Storage Tank (CST).

300. I reviewed the Barrier Substantiation Report (Ref. 90) to check that barriers were adequately substantiated from the flood heights determined. This document refers out to the Civil Structure Evaluation Report for Barrier Substantiation (Ref. 170). This latter report identifies the affected barriers and the flood heights (Ref. 170). I also sought further clarification via RQ-ABWR-1485. Flood loads on the Class 1 barriers have been calculated using the ACI 349-2013 Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary (Ref. 196). Although this code is overdue an update, I liaised with civil engineering who confirmed that this is currently an internationally recognised code.

301. As there were omissions in the substantiation of claims, Regulatory Observation RO-ABWR-0082 (Ref. 9) was issued to the RP to ensure that an adequate demonstration of barrier substantiation is provided for all internal hazards. The RP has substantiated the thinnest wall against the flood load and argued that if the demonstration is provided then the thicker walls would therefore be substantiated and have additional safety margins. The RP provided example analysis for the R/B (floor B3F), the C/B (floor B3F) and the Hx/B (floor B1F). (Civil Structure Evaluation Report for Barrier Substantiation, Ref. 170). The analysis confirmed that the loadings in the R/B and the C/B were acceptable; but loading in the Hx/B was not. The RP increased the thickness of the barrier and re-ran the analysis which was latterly acceptable and in line with SAP EKP.EHA.6. The RP has captured the design modification in their AIRIS database as IH-IR-0005 – “Enhancement of Concrete Structure due to Barrier Substantiation Assessment against Internal Hazard Load”. I was generally satisfied with this approach from an internal hazards perspective.

302. I discussed the results of the internal hazards analysis summarised in the Civil Structure Evaluation Report for Barrier Substantiation (Ref. 167) with the civil engineering assessors. They concluded that the civil engineering safety case had not fully captured all of the internal flooding loads. I did not consider this to be in line with SAPs ECE.6 and EHA.12. Civil engineering has raised an assessment finding (Ref. 131) in their assessment report ONR-AR-NR-17-013 which is relevant to the internal hazard loadings on the barriers. Therefore no additional assessment finding is required within this internal hazards assessment report.

303. I sampled the flooding hazard schedule (Topic Report on Internal Flooding, Ref. 36). I judged that flood water from the fire protection system and inexhaustible water supplies were two key omissions from the safety case. I also noted that there was a contradiction in the safety case, as the Internal Flooding Hazard Analysis Methodology report (Ref. 197) stated that water from the fire protection system would be considered but the Topic Report on Internal Flooding (Ref. 36) stated that it would be excluded from GDA. This is not in line with SAPs SC.4, EHA.6, EHA.12 or FA.3.

304. There is an overarching assessment finding which captures the key actions for the licensee to ensure that the hazard schedule is alignment with the safety case (**AF-ABWR-IH-14**); and that the internal flooding safety case is completed (**AF-ABWR-IH-07**). Therefore no additional assessment finding is required.

305. I sought clarification under Regulatory Query RQ-ABWR-1485 (Ref. 189). The RP confirmed that the maximum water inventory from the fire protection system is 10,000m^3 (Ref. 191). This inventory is greater than the amounts identified in the Topic Report on Internal Flooding (Ref. 36). Therefore it is unclear whether the additional inventory would challenge the existing design and whether the analysis is adequately bounded. I do not consider this to be in line with SAPs EKP.2, EHA.12 or ERL.4. The assessment finding **AF-ABWR-IH-07** already captures the key action for the licensee to use detailed design information to undertake further analysis.

306. I liaised with PSA and fault studies to sample the substantiation for failure of the Spent Fuel Storage Pool (SFP). The fault studies assessor confirmed that the SFP liner failure was considered as a fault within the fault schedule (Topic Report on Fault Assessment, Ref. 99). A small leak was considered by the RP.

307. However, within the internal hazards safety case, the RP argued that "*catastrophic failure and flooding from the SFP is considered to be a beyond design basis event*." (Topic Report on Internal Flooding, Ref. 36). I judged this to be an omission in the internal hazards safety case as all hazards should be characterised in line with SAPs EHA.1, EHA.3 and EHA.12.

308. The PSA assessor also agreed that there were documentation shortfalls in the SFP section of the PSA as they should understand all the consequences from hazard events (Ref. 198).

309. From an internal hazards perspective, assessment finding **AF-ABWR-IH-07** already captures the key action for the licensee to use detailed design information to undertake further analysis, and includes the specific requirement for an assessment of the unmitigated effects of a flood from SFP failure.

4.4.6 Assessment Findings

310. During my assessment two assessment findings were identified for a future licensee to take forward in their site-specific safety submissions. Details of these are contained in Annex 5.

AF-ABWR-IH-07- Given that the Requesting Party's flooding safety case relies on the position relative to flood heights and sustained availability of Structures, Systems and Components (SSCs) during internal flooding events, the licensee shall use site-specific information to undertake further analysis, including sensitivity studies. This shall include:

- **Ensuring that the SSCs located above the maximum flood height, and those SSCs placed on pedestals above the localised floor height, are not challenged. The licensee shall also confirm the available margins and suitability of all engineered measures supporting the case.**

- **Determination of the maximum inventory of water including inexhaustible water supplies and assessment of their impacts on nuclear safety significant barriers and fundamental safety functions.**
- **Determination of the consequences of a catastrophic Spent Fuel Storage Pool (SFP) failure resulting in an internal flood hazard.**

AF-ABWR-IH-08 - As the Requesting Party's safety case relies on the qualification and sustained availability of SSCs during flooding scenarios, the licensee shall ensure that equipment that could be potentially submerged / wetted and have an impact on Class 1 SSCs are suitably qualified.

311. The above findings specifically address shortfalls in the substantiation of SSCs claimed to be available in areas affected by internal flooding. Full substantiation may require minor design modifications such as specification of different pedestal heights or waterproofing. Design features of storage and isolation systems, which determine the maximum flooding inventories are subject to detail design considerations post GDA. I nevertheless found no evidence that measures to restrict the inventories had been foreclosed. I judge that the required further analysis will not challenge the generic layout of the UK ABWR and therefore the significance of the shortfall does not merit a GDA issue to be raised.

4.4.7 Conclusions on Internal Flooding Assessment

312. To conclude, the submission provides the requisite information relating to the identification of internal flooding sources, consequences analysis and the identification of safety measures. Suitable and sufficient claims have been made and these were generally supported by the requisite arguments and evidence. As part of my assessment, I have identified a number of assessment findings for the future licensee to take forward. These relate to shortfalls in the substantiation of SSCs claimed to be available and to the confirmation of design information and consequence analysis during the site specific and detailed design stages. These matters do not undermine the generic submissions and the layout of the UK ABWR design.

4.5 Steam Release Safety Case

314. Releases of steam following loss of integrity of high or medium energy systems containing water or water-based solutions can challenge delivery of FSFs as a result of pressurisation of compartments and environmental effects i.e. high temperature, humidity and/or condensation.

315. The RP presented the assessment of steam releases for a number of UK ABWR buildings in the following Step 4 submissions:

- The Pre-construction Safety Report (PCSR) (SE-GD-0127) revision C (Ref. 15).
- The Topic Report on Internal Flooding (SE-GD-0143) revisions 2 to 4 (Refs. 34, 35 and 36);
- Internal Flooding Evidence Report (SE-GD-0612) revisions 0 and 1 (Refs. 181 and 182);
- Barrier Substantiation Report (BKE-GD-0019) revisions 2 to 5 (Refs. 87, 88, 89 and 90); and
- The Civil Structure Evaluation Report for Barrier Substantiation (LE-GD-0322) revisions 0 and 1 (Refs. 169 and 170).

316. My assessment of the above submissions is presented in the sections below, which cover the following:

- The RP's safety case for steam release hazards;
- My assessment of the claims and arguments;
- Assessment of the RP's analysis methodology;
- Assessment of evidence provided for substantiation of Class 1 barriers; penetrations and steam release pathways including suitability and sufficiency of pressure relief provision including blowout panels; and
- Conclusion and assessment findings.

317. As stated previously, the analysis of steam release hazards for areas where there are exceptions to physical segregation such as inside the PCV and the MSTR is covered in sections 4.11 and 4.12.

4.5.1 The RP's Steam Release Safety Case

318. The RP's safety case for steam releases is built upon the same internal hazards claims as the rest of the case presented in section 3. The RP applied the generic internal hazard claims to develop specific flooding claims, which were said to apply to steam releases. These are as follows:

- **IH_F_SFC_5-7.1**: General internal flooding claim. "*Any internal flood event within the design basis will not prevent delivery of the fundamental safety functions".*
  The high level claim is supported by lower level claims that support the delivery of the high level claim:
  - **IH_F_SFC_5-7.2**: "*Limiting Flooding to a single Class 1 division. The Class 1 divisional barriers segregating neighbouring divisions will be such that the consequences of a design basis flooding event in one division will not prevent SSCs in neighbouring divisions delivering their Fundamental Safety Functions"*
  - **IH_F_SFC_5-7.3**: "*Where there are exceptions to physical segregation, sufficient A-1 or A-2 signals and equipment are available, during and after the internal flood, to fulfil the Fundamental Safety Functions".*
  - **IH_F_SFC_5-7.3.1**: "*Where flooding affects multiple Class 1 divisions, protection features such as flood barriers or qualification of individual SSCs will be such that the consequences of a design basis flooding event in one division*

will not prevent SSCs in neighbouring divisions delivering their fundamental safety functions".

319. There are no dedicated steam release claims in the Topic Report on Internal Flooding revision 4.

4.5.2 Assessment of the RP's Safety Case

4.5.2.1 Scope of Assessment

320. My assessment of the RP's steam release safety case covers all the submissions in above, the PCSR and associated references to ensure that substantiation of the claims has been achieved in line with ONR SAPs (Ref. 6) and the Internal Hazards TAG (Ref. 8).

321. From the safety case submissions listed above, I focused my assessment on the following topics:

- Suitability and sufficiency of the claims;
- Steam release analysis methodology, assumptions and exclusions;
- Substantiation of RC compartment barriers and blowout panels; and
- Margins of safety.

322. My assessment of the above topics is presented in the sections below.

4.5.2.2 Assessment of Claims and Arguments

323. Delivery of the safety claims, specifically **IH_F_ SFC 5-7.1** and **IH_F_ SFC 5-7.2** is achieved by a combination of RC barriers, suitably qualified doors and penetrations, and engineering pressure relief routes to atmosphere to ensure that the capacity of the barriers is not exceeded in a design basis steam release event.

324. Claims on RC barriers are aligned with my expectations and ONR's SAPs EDR.2, EKP.5 and EHA.5.

325. The provision of engineered steam release venting routes (where suitably placed and dimensioned to prevent the load capacity of the barriers and penetrations being exceeded) is also in line with ONR SAPs on pressure relief, specifically: EPS.3, EPS.4 and EPS.5. They are also in line with international guidance from IAEA (Ref. 171).

326. As part of my assessment of the claims and arguments, I sampled the hazard schedule for the R/B as presented in the Topic Report on Internal Flooding revision 4 (Ref. 36), and noticed that it contained the following:

- Two steam hazard entries related to releases within division I resulting from RCIC line breaks in two potential locations: room 113 (the RCIC Pump room) and room 412 (Valve Room A); and
- One entry for division II (a double ended guillotine break of the CUW line in room 112, the CUW Non-regenerative Heat Exchanger Room).

327. These were considered by the RP as the most significant steam releases, giving rise to bounding consequences on the R/B barriers.

328. With the aid of the UK ABWR Divisional Boundary Maps revision 5 (Ref. 114), I sampled the release sources and steam release paths to confirm whether the extent of the consequences (rooms affected) in the bounding cases had been adequately considered, and did not find inconsistencies.

329. The hazard schedule credits safety divisional barriers as a Class 1 SSC, and the engineered steam release routes and blowout panels as Class 3 SSCs, supporting the delivery of the FSFs by preventing compartment pressurisation and cross-divisional effects. The hazard schedule also lists the systems claimed to be available to deliver the FSFs via redundant equipment in separate divisions, following a steam release in either of the systems considered (RCIC or CUW).

330. The format and content of the hazard schedule is aligned with my expectations for the two sources studied in the R/B. It is nevertheless incomplete, as only the three bounding cases are presented. The hazard schedule needs to be developed, in line with the assessment finding on steam release raised in this section (**AF-ABWR-IH-09**), to demonstrate that compartmentation is sustained for all credible steam sources and release paths in the UK ABWR.

331. Notwithstanding the above, I judge that the approach and hazard schedule provided is appropriate within GDA, and has provided confidence that a suitable and sufficient schedule will be developed post-GDA, when all steam sources are characterised as pipework layouts are progressed and confirmed through detailed design.

4.5.2.3 Assessment of the Steam Release Assessment Methodology

332. The RP proposed a 7 step analysis methodology for steam release comprising of the following:

- Step 1 - Identification of the steam releases. This included characterisation of the source in terms of pressure, temperature, location, pipework routing, dimensions and protection features which may limit the magnitude of the release.
- Step 2 - Identification of steam compartments based on the location of pipework and SSCs relating to the above sources.
- Step 3 - Identification of SSCs required for safety, and the consequences of failure.
- Step 4 - Identification of steam release path from the room of origin through vent panels, unsealed penetrations including doors, drainage grating and ventilation ducts.
- Step 5 - Quantification of the steam release sources based on the system inventories and conditions, using the COMPACT model (Ref. 199).
- Step 6 - Identification of mitigation features including divisional segregation where relevant, and equipment qualification.
- Step 7- Assessment of steam release consequences, taking into consideration SSCs in the steam release path.

333. The above approach is broadly in line with my expectations, ONR’s SAPs EHA.1, EPS.3, EPS.4, EPS.5 and EHA.15 and IAEA Safety Guides NS-G-1.11.

334. As part of the Internal Flooding Evidence Report revision 1, the RP provided evidence of application of the COMPACT code to Pressurised Water Reactor (PWR) and ABWR design conditions. I did not assess the validation of the model, however, I am content that it has been used in PWR and ABWRs steam release simulations extensively.

335. The steam release assessments presented in the Internal Flooding Topic Reports revision 4 (Ref. 36), Barrier Substantiation report revision 5 (Ref. 90) and Civil Structure Evaluation Report revision 1 (Ref. 170) are restricted to two bounding cases (Clean-up water (CUW) and Reactor Core Isolation Cooling (RCIC) systems). I am satisfied that this is sufficient for GDA to give confidence that substantiation of the RC barriers and steam release paths can be achieved without significant changes to layout post-GDA. I have however raised an assessment finding (**AF-ABWR-IH-09**) for substantiation of the compartment barriers against the steam loads for the remainder

of steam systems and rooms not considered in the representative examples studied in GDA. My judgement on the adequacy of the evidence provided to support barrier substantiation and associated assessment finding is discussed in section 4.5.2.4 below.

4.5.2.4 Assessment of Evidence and Barrier Substantiation

336. As part of Step 1 of methodology, the RP identified the systems that were broadly considered to give rise to steam releases upon failure to be as follows: Heating Steam (HS), Heating Steam Condensate Water Return (HSCR), Main Steam (MS), CUW, RCIC and Feed water (FDW).

337. I judge that the above list appropriately captures the larger steam sources arising from normal operating conditions when the reactor is at power and is in my view suitable for GDA. I nevertheless note that systems, such as the RHR were initially considered as credible steam sources in other disciplines (e.g. PSA) and subsequently discounted, but the rationale has not been presented in the deterministic internal hazards. In particular, the consequences of steam releases from any systems excluded from assessment based on the operational regime (e.g. short duration of high energy or medium energy operating modes) should be provided in line with ONR SAPs (NT.2), and this is captured in the assessment finding presented elsewhere in this report (**AF-ABWR-IH-09**).

338. The RP presented the assessment of steam releases from rooms 113 and 412 (RCIC system release case) and room 112 (CUW system release) in the R/B as the bounding rooms in each respective steam release path. The RP also provided a qualitative justification of the bounding rooms for the CUW and RCIC steam release cases in the Internal Flooding Evidence report (SE-GD-0612) revision 1 (Ref. 185), and performed a check on room 412 to justify the selection of room 113 as bounding.

339. The rooms in the flow path have been assumed to have specific occupation factors of either 10% or 20% of the room volumes and areas. This is a generic assumption which I consider appropriate for GDA. However, it should be confirmed once equipment specification and room occupations are determined as part of detailed design.

340. In the steam outflow calculations, the RP assumed that full isolation would be achieved within 20 seconds of the RCIC pipework failure and within 40 seconds for the CUW case. I judge that crediting isolation of steam releases is appropriate, as long as reference to suitable performance claims for the SSCs in question is provided. This has not been the case in the steam release submissions and should be confirmed as highlighted in the assessment finding raised in this area (**AF-ABWR-IH-09**).

341. As part of my sampling, I checked the outflow calculations for the RCIC double ended guillotine break. I estimated the outflow of steam through a 136.6mm orifice (full diameter) in a pipe at 7.17MPa gauge to be around 154kg/s, which is virtually the same value used by the RP to model outflow from each pipe end. I am therefore content that the outflow calculations appear correct.

342. The RP has not performed compartment pressurisation calculations to explicitly substantiate the capacity of RC barriers for steam systems other than CUW and RCIC, or substantiation of RC barriers in rooms outside the cases considered bounding. Blowout panel designs and substantiation of penetrations are to be addressed post GDA during the detail design.

343. As part of the assessment, I also sampled the R/B Divisional Boundary Maps revision 5 (Ref. 114) to identify the steam release paths, Class 1 flood barriers and doors and found no issues.

344. The RP calculated the effective thickness of a wall in accordance with ACI 349-13 (Ref. 196) and applied a 20% margin for the impulsive force, also in accordance with ACI 349-13. This was presented in the Civil Structure Evaluation report revision 1 (Ref. 170).

345. The RP evaluated the capacity of two walls for the RCIC (700mm and 550mm thick) and another two walls for the CUW (800mm and 300mm) against the maximum overpressure in each respective room in turn. The 300mm wall was predicted to fail in bending and shear (Ref. 170) and the RP acknowledged that the blow out panel size to the exterior of the R/B would be resized to substantiate the barrier. The RP acknowledged that the design change may involve multiple panels to meet security requirements (Ref. 200) and has been captured in AIRIS (Ref. 192)

346. The RP stated that the blowout panels will be required to release at a pressure of 10kPa. I judge that this is appropriate, as long as the weakest wall is able to withstand higher pressures with a suitable safety margin and this should be confirmed during detailed design. This has been demonstrated for the MSTR barriers as presented in the Civil Structure Evaluation Report revision 1 (Ref. 170), but needs to be completed for the rest of the steam systems as captured in the assessment finding below (**AF-ABWR-IH-09**).

347. With regards to the steam assessment in buildings other than the R/B, the RP has acknowledged that the HS system is subject to change during detailed design. The HS receiver tank in C/B is planned to be moved to a different building. The RP also acknowledged that the HS and HSCR pipework route is subject to change through the R/B and that electric heaters instead of HS/HSCR will be used in the Hx/B. The RP also stated that the T/B structures would withstand a release through the blowout panel, however, substantiation has not been provided as part of GDA. The changes in the HS/HSCR will also affect the Rw/B, tunnels, B/B and S/B. The RP has not recorded this as an outstanding issue in their GDA submissions and I have therefore raised it in assessment finding **AF-ABWR-IH-09**.

348. As the assessment has not explicitly justified the bounding arguments, the HS/HSCR is subject to change during detailed design and the assessment of all systems and Class 1 barriers has not been provided, I have captured the requirement in the assessment finding below.

AF-ABWR-IH-09 - The Requesting Party’s assessment of safety-significant steam releases was limited to two systems, a reduced set of rooms and short release durations. The licensee shall therefore address the following as part of the site-specific assessment:

- **Evaluate all steam release sources (including those operating at high or medium energies for short periods of time).**
- **Demonstrate how engineered measures, SSCs design requirements and/or operator actions deliver the isolation times assumed.**
- **Ensure that the steam release compartments are able to withstand the maximum overpressure with a suitable margin.**
- **Ensure that the design requirements of SSCs essential to deliver claimed measures are adequately identified and subsequently inform SSC qualification requirements during detailed design. This includes, for example, the requirements on electrically-driven valves needed to isolate the Residual Heat Removal System (RHR) trains to enable injection via the Flooder System of Specific Safety Facility (FLSS) into the reactor well following loss of an operating RHR train.**

349. Notwithstanding the above points regarding the level of development of the steam release case in GDA, I judge that the evidence currently available (which relates to

three bounding rooms) is sufficient to demonstrate that substantiation of the steam release routes and compartment withstand can be completed without significant changes to the generic layout.

4.5.3 Outstanding Issues

350. The RP has acknowledged that the assessment provided as part of GDA was limited to two systems (the RCIC and CUW) and a set of barriers (including the weakest barriers) in three rooms which were considered to experience the highest levels of overpressure.

351. The RP has also acknowledged that full substantiation of the weakest wall in the CUW compartment required design change to ensure that there is a sufficient relief area to atmosphere to prevent pressurisation above the capacity of the wall.

352. The design of the HS/HSCR system is subject to change and therefore the assessment of the C/B, Hx/B, S/B, B/B and service tunnels has not been presented in GDA.

353. The RP captured the above points in AIRIS entries IH-IR-0017 and IH-IR-0005.

4.5.4 Assessment Findings

354. During my assessment of the steam release case one assessment finding was identified for a future licensee to take forward in their site-specific safety submissions. Details of this matter are contained in Annex 5.

355. This matter does not undermine the generic safety submission and is primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.5.5 Steam Release Assessment Conclusions

356. During Step 4, the RP undertook a significant amount of work to identify steam systems, sources, steam release paths and defined routes for pressure relief to atmosphere.

357. The RP has provided steam outflow results and pressure versus time profiles using the COMPACT model, and confirmed substantiation of three Class 1 barriers in the compartments studied. The RP has also identified design changes required to fully substantiate the barriers, and has provided indicative set pressures for the blowout panels to support that there will be sufficient margin for the barriers to withstand the pressure during a relief event.

358. I am content that, whilst substantiation of steam release compartments has not been completed for all sources and rooms, the RP has demonstrated that there is sufficient margin and flexibility in the design to deliver full substantiation as the design progresses through the detailed phase.

4.6 Pipe Whip and Jet Impact Safety Case

359. Pipe whip and jet impact are local dynamic hazards associated with the failure of pressurised parts.

360. Pipe whip occurs when a high pressure pipe fails in a double ended guillotine manner and the resulting energy release causes the pipe to whip.

361. Jet impact occurs when the fluid released from a failure of a pipe impacts upon nearby equipment or structures.

362. Both these phenomena could cause SSCs delivering the FSFs to fail including failure of divisional barriers.

363. The Pipe Whip and Jet Impact Topic Report primarily presents the assessment of the pipe whip and jet impact hazards for the R/B and C/B. Other safety classified buildings have also been considered, at high level, but their analysis was largely deferred to post GDA (Ref. 42).

364. The Topic Report on Pipe Whip and Jet Impact focuses on those areas where divisional barriers are present and therefore excludes pipe whip and jet impact associated with other areas where divisional barriers are not available such as inside the PCV, MSTR and MCR. These areas are assessed in sections 4.11 to 4.13, respectively.

365. During Step 4 of the GDA, the RP submitted the following key documentation in the area of pipe whip and jet impact:

- The Pre-construction Safety Report (PCSR) revision C (Ref. 15).
- Topic Report on Pipe Whip and Jet Impact revisions 2 to 5 (Refs. 39, 40, 41 and 42).
- Pipe Whip / Jet Impact Protection Design Specification revision 1 (Ref. 201)
- Initial Pipe Whip Assessment Results revision 0 (Ref. 202).
- Pipe Whip - Methodology Refinements for the R/B (Ref. 203).
- Refined Assessment results by Considering True Pipe Runs – Reactor Building revision 0 (Ref. 204) and 1 (Ref. 205).
- Pipe Whip – Methodology Refinements for the C/B revision 0 (Ref. 206).
- Refined Assessment results by Considering True Pipe Runs – Control Building (Ref. 207).
- Refined Assessment Results by Considering True Pipe Runs – Pipework with Low Frequency of Functional Failure (Ref. 208).

366. I subjected all the above submissions to assessment as discussed below.

367. In the following sub-sections I will cover the following:

- The RP’s safety case on pipe whip and jet impact;
- My assessment of the claims and arguments;
- My assessment of the methodology used in the pipe whip and jet impact analysis;
- My assessment of substantiation of the Class 1 barriers; and
- My conclusions and assessment findings.

4.6.1 RP’s Pipe Whip and Jet Impact Safety Case

368. The RP’s internal hazards safety case claims are given in section 3.2 above. The safety case on pipe whip and jet impact, for all areas where segregation by divisional barriers exists, is principally based on Claims **IH SFC 5-7.1** – “*Internal Hazards do not prevent the delivery of Fundamental Safety Functions*)” and IH SFC 5-7.2 – “*the*

consequences of any internal hazards are limited to one safety division". This is achieved by limiting the severity of pipe whip and jet impact to a single division by Class 1 divisional barriers, and by the provision of suitable and sufficient redundant and/or diverse SSCs located in other divisions.

369. In addition to the divisional barriers, non-divisional Class 1 barriers are claimed as they provide a safety function. Such areas where non-divisional Class 1 barriers are used to protect against the effects of pipe whip and jet impact include:

- Boundary walls between MSTR and T/B, C/B and R/B to protect the Main Steam line inside the MSTR;
- Boundary walls between the MCR and the C/B which are required to protect SSCs inside the MCR;
- PCV walls. The non-divisional barrier section of the PCV protects SSCs inside the PCV;
- Walls and slabs at B3F level of the R/B; and
- Walls and slabs at B3F level of the C/B.

370. The RP's safety case is also focused on single pipe failure. The RP indicated that pipe-to-pipe interactions outside containment, including combined consequential effects such as steam release or flooding were addressed in the Combined Hazards Topic Report (Ref. 57), which is assessed in section 4.14.

371. The RP's safety case on pipe whip and jet impact concluded that in the event of pipe whip and jet impact suitable and sufficient SSCs will remain available to maintain the plant in a safe state.

372. Revision C of the PCSR (Ref. 15) covers this aspect at high level and largely referred to revision 5 of the Topic Report on Pipe Whip and Jet Impact.

4.6.2 ONR's Assessment of the Pipe Whip and Jet Impact Safety Case Submissions

373. The assessment strategy in section 2 was used to formulate my assessment.

4.6.2.1 Scope of Assessment

374. My assessment covers all of the RP's submissions in this area. I assessed the PCSR, and sampled Topic Reports revisions and the relevant supporting submissions to obtain confidence on the requisite evidence and substantiation of the claims made.

375. The areas chosen to assess the pipe whip and jet impact case were limited to the following;

- Suitability and sufficiency of the safety case and the claims made in this area;
- Analysis methodology and assumptions;
- Justification of systems excluded from analysis; and
- Substantiation of the claims made.

376. The sections below cover the areas of my assessment.

4.6.2.2 Assessment of Claims and Arguments

377. The RP's claim on Class 1 divisional barriers for the R/B and C/B is in line with ONR's SAPs EDR.2, EKP.5 and EHA.5.

378. All barriers claimed against pipe whip and jet impact are listed in revision 5 of the Topic Report (Ref. 42) and in 'Refined Assessment Results by Considering True Pipe Runs' for the R/B (Ref. 205) and for the C/B (Ref. 207). These are also graphically presented

in the 'Divisional Barrier Map' which shows the location of the Class 1 divisional barriers for each level of all relevant buildings (Ref. 114).

379. Revision 5 of the Topic Report on Pipe Whip and Jet Impact (Ref. 42) also presented a hazard schedule which included the hazard source, event frequency, operating mode, unmitigated consequences, mitigated consequences, bounding design basis event and the ability to deliver the FSFs for the R/B, C/B and Hx/B. This hazard schedule does not reflect the location/ room number of the postulated event, the systems affected, the barriers and other safety measures claimed to deliver the FSFs. This is therefore not in line with ONR's SAP FA.8. The hazard schedule is also not in line with other hazard schedules developed during GDA in providing context for why claimed Class 1 divisional barriers are required against the pipe whip and jet impact hazard. This issue is captured in the assessment finding **AF-ABWR-IH-14**.

4.6.3 Assessment of Pipe Whip and Jet Impact Analysis Methodology

380. Initially, the RP presented its analysis methodology on pipe whip and jet impact in revision 2 of the Topic Report (Ref. 39). This was supported by the pipe whip and jet impact protection design specification (Ref. 201). The analysis methodology can be summarised in the following seven steps:

- Step 1: Define the area considered. The proposed analysis was performed on a room-by-room basis with bounding sets of rooms selected.
- Step 2: Identification of potential sources of pipe whip and jet impact:
    - The analysis focussed on the High Energy piping systems which have design conditions > 95°C and/ or > 1900 kPa gauge.
- Step 3: Identification of structures, systems and components.
- Step 4: Assess pipe whip and jet impact.
- Step 5: Magnitude of a credible pipe whip or jet impact hazard. Utilising the R3 Impact Assessment procedure (Ref. 175).
- Step 6 Assess pipe whip and jet impact frequencies.
- Step 7 ALARP assessment.

381. The Step 4 of the above methodology included the following key assumptions:

- Potential break locations include terminal ends, and locations where stress or usage factor exceed threshold and weld points.
- A full bore break in a pipe whip and jet impingement event is assumed to whip from a rigid point. It is conservative to assume that a pipe will whip from the elbow, branch point or nearest rigid point. From this location a free whipping point can be analysed assuming a fully plastic hinge.
- Potential sources of pipe whip and jet impact are screened out based upon the following criteria:
    - Proportion per year that system is functionally operational.
    - Pipe break frequency per year.
- The jet impact analysis is based upon geometry and physical properties evaluated as a function of time and space.

382. The RP identified a bounding set of 25 rooms within the R/B and assessed them. The RP concluded, in the revision 2 of the Topic Report, that the pipe whip and jet impact hazard would not prevent delivery of the FSFs.

383. I subjected revision 2 of the Topic Report on Pipe Whip and Jet Impact to assessment and I raised RQ-ABWR-0993 (Ref. 209), which detailed a number of shortfalls. These shortfalls were related to the selection of bounding scenarios including bounding rooms and pipe lines, screening out of lines due to low frequency, assumptions on break locations, assumptions on multiple pipe break and the overall cohesion of the document and consistency with other Topic Reports (e.g. exceptions to segregation).

The purpose of this RQ was to provide guidance and advice on the development of the pipe whip and jet impact safety case during step 4 of the GDA.

384. The RP responded to RQ-ABWR-0993 in Reference 210 and indicated that the next revisions of the Topic Report on Pipe Whip and Jet impact, the Topic Report on Combined Hazards and the Barrier Substantiation Report would provide the requisite clarity and cohesion on the issues raised in RQ-ABWR-0993.

385. As the pipe whip and jet impact analysis informs the categorisation and classification of plants systems from a structural integrity point of view, I liaised with the structural integrity assessor who initially raised RQ-ABWR-0426 (Ref. 211). This RQ sought clarity on the methodologies and assumptions used in the pipe whip analysis. The RQ focused on the following aspects:

- The conservatism of the guidance used for the classification of high energy and moderate energy pipework systems (high energy >95°C or >1900kPa, moderate energy <95°C or <1900kPa), and whether any analysis will be undertaken when the calculated margins between high energy and low energy are small.
- The conservatism of the pipe whip analysis undertaken;
- The exclusion of systems based on low utilisation criterion (1%).

386. The RP, in response to RQ-ABWR-0426, indicated that other guidance such as the IAEA safety standards (Ref. 171) and NUREG 800 (Ref. 212) use similar thresholds for high energy and moderate energy pipework systems (Ref. 213). It also indicated that the pipe whip impact evaluation evidence document will present the possible effects of moderate energy lines (Ref. 214). This document confirmed that moderate energy pipework is bounded by the high energy pipework. Revision 2 of the Topic Report on Pipe Whip and Jet Impact excluded moderate energy pipework and deferred the analysis to post GDA. Although in general the pipe whip effects of moderate energy pipes could be bounded by high energy pipes, the potential consequences from all those moderate energy pipes (including the combined consequential effects involving moderate energy lines) require evaluation and this is captured in **AF-ABWR-IH-10**.

387. With regards to the conservatism of the analysis, raised in RQ-ABWR-0426, the RP indicated that the pipe whip and impact evaluation evidence document (Ref. 214) would present the substantiation of the assumptions used in the pipe whip analysis. This document was the subject of detailed assessment by the structural integrity assessor (Ref. 215). The conservatism of the analysis is also the subject of the current assessment report.

388. In response to RQ-ABWR-0426 on the exclusion of all systems that operate on low utilisation criterion, the RP indicated that this assumption was based on a derived probability of 10^{-7} per year for these systems, and assumed that they can be treated similar to Very High Integrity (VHI) components. This response was not in line with my expectations and relevant good practice established in the UK and is further discussed below.

389. More recently, ONR's structural integrity inspector raised RQ-ABWR-1403 to capture ONR's comments on the structural integrity classification report (Ref. 216). A number of comments are relevant to pipe whip and jet impact analysis including break locations, size of break, time at risk arguments, consequences of small bore piping (<50mm), pipe-to-pipe interactions, consequential assessments and classification of various components. The assessment of RQ-ABWR-1403 is presented in the structural integrity assessment report (Ref. 215) and is reflected in the current assessment.

390. Revision 3 of the Topic Report on Pipe Whip and Jet Impact the RP presented its revised internal hazards analysis methodology for pipe whip and jet impact. Overall, this aligned with the analysis undertaken in other internal hazards areas (Ref. 40) and included the following four steps:

- Step 1 - Identification of safety classified SSC;
- Step 2 - Internal hazards identification pertinent to pipe whip and jet impact;
- Step 3 - Internal hazards characterisation pertinent to pipe whip and jet impact; and
- Step 4 - Identification of safety measures.

391. The RP in response to RQ-ABWR-993 also revised the analysis methodology for pipe whip and jet impact and presented a simplified conservative approach focusing on the pipe whip and jet impact damage to Class 1 divisional barriers which are used to segregate the SSCs delivering the FSFs. The analysis comprised of two main steps.

- Firstly the reaction force of the pipe is calculated; based on the design pressure;
- Secondly the impact energies and velocities of the pipe whip are calculated from the reaction force.

392. The RP included the following conservatism in the analysis:

- The length of whipping pipe is based on the dimensions of the room not the actual pipe run;
- The presence of pipe restraints or other components ignored;
- The worst case pipe whip impact for all of the walls and slabs in a room is determined and then it is assumed that this impact is against the Class 1 Divisional Barrier;
- The angle between the whipping pipe leg and the reaction force is always taken as 90º;
- The pipe supports present are not regarded as ‘restraints’ and therefore do not contribute to the removal of energy from the system; and
- It is assumed that all whipping energy is converted to impact energy.

393. The identification of all rooms in the R/B which have potential pipe whip and jet impact sources is in line with ONR SAP EHA.1. The analysis, however, was not based on actual pipe routings and therefore the approach adopted generated a worst case impact on the divisional Class 1 barriers. Revision 3 of the Topic Report on Pipe Whip and Jet Impact (Ref. 40) identified all Class 1 divisional barriers within the R/B that have resulted in unacceptable levels of scabbing and/or perforation as a result of the pipe whip. Revision 2 of the Barrier Substantiation Report confirmed that Class 1 barriers could not be substantiated against local effects from pipe whip in 15 cases, and 41 cases were predicted to result in scabbing (Ref. 87). The RP indicated that a more realistic analysis would demonstrate that the Class 1 divisional barriers can be substantiated against pipe whip impact and proposed to undertake the analysis post GDA. The RP also indicated that this may also involve design changes such as an increase in wall/ slab thickness, modifications to pipe layout, installation of pipe restraints and other passive measures such as localised shielding.

394. Although the approach was highly conservative, it was unrealistic as it did not reflect the true pipe runs and the design of the UK ABWR. It was, therefore, not in line with ONR’s SAP SC.4. I needed to obtain confidence that the pipe whip and jet impact analysis reflected the UK ABWR design, addressed all relevant systems, the claim on Class 1 divisional barriers could be substantiated within the timescales of the GDA, and that any future analysis would not result in major design modifications including plant layout changes. I raised RQ-ABWR-1231, RQ-ABWR-1302 and RQ-ABWR-1380

(Refs. 217, 130, 218). These RQs sought to obtain clarity and understanding of the following aspects:

- Application of the proposed revised methodology;
- Substantiation of Class 1 divisional barriers including penetrations;
- Consequential pipe breaks;
- The criteria and justification used to exclude some high energy systems from GDA assessment; and
- A robust demonstration that design changes and measures, which may be required following application of a detailed methodology, are not foreclosed by the generic design.

395. The RP in its response to RQ-ABWR-1231 deferred the full response to my queries to future revisions of the Topic Reports on Pipe Whip and Jet Impact, on Combined Hazards (relevant to consequential breaks) and the Barrier Substantiation Report (relevant to Class 1 divisional barriers performance) (Ref. 219).

396. Subsequently, the RP submitted revision 4 of the Topic Report on Pipe Whip and Jet Impact which further considered the pipe whip and jet impact hazards analysis for the R/B and C/B (Ref. 41). It is also noted here that the scope of this revision also included the EDG/B, Hx/B and B/B, but no results were presented for these buildings.

397. In revision 4 of the Topic Report, the RP further developed its analysis methodology and proposed the following three refined methodologies:

- First refinement. This takes into account the barrier locations within the room, and therefore considers the pipe whips on a barrier by barrier basis, as opposed to the room-by-room basis previously used.
- Second refinement. This takes into account the postulated hinge location along the pipe run based upon the pressure in the pipe and the physical properties of the pipe. This method provides more realistic pipe whipping lengths. This is not a bounding case, as any potential valves or added masses have not been considered.
- Third refinement. This determines if the pipe can strike the barrier and then determines the whip energy and velocity based upon the detailed pipe runs. The RP proposed to use this refinement post GDA.

398. Revision 4 of the Topic Report confirmed that for the R/B and C/B some of the Class 1 divisional barriers could not be substantiated in revision 3 of the Topic Report. The RP re-assessed the following Class 1 divisional barriers using the refined methodologies described above: for the R/B rooms 113, 115, 226 and 253, and for the C/B room 101. The results in revision 4 of the Topic Report gave confidence that the majority of the Class 1 divisional barriers can be substantiated.

399. The RP continued its analysis work using the revised methodology developed in revision 4 of the Topic Report and reported the progress made in revision 5 of the Topic Report on Pipe Whip and Jet Impact (Ref. 42). This revision finalised and confirmed the staged approach, and summarised the overall progress made in the pipe whip and jet impact analysis. The staged approach is summarised below:

- Bounding initial simplified assessment: A very conservative assessment was undertaken based on the maximum pipe lengths that could fit in the rooms as opposed to the actual pipe runs. The worst-case pipe whip impact for all of the walls and slabs in a room was determined and then it was assumed that this impact is against the thinnest Class 1 barrier in the room. For the R/B, 18% of the rooms were substantiated for scabbing and 77% were substantiated for perforation. For the C/B, 6% of the rooms were substantiated for scabbing and

28% have been substantiated for perforation. The initial pipe whip assessment results are given in Ref. 202.

- Consequence assessments: For a small number of cases the consequences of scabbing and the risk of damaging SSCs in the adjacent division, leading to the loss of the FSFs, was undertaken and shown to be acceptable. Five of the R/B rooms were substantiated using this approach.
- Barrier-by-barrier assessment - refined assessment 1: It was carried out for the rooms that were not substantiated using the initial assessment approach or the consequence assessments. The approach is the same as the initial assessment but the worst-case pipe whip against each barrier, as opposed against the whole room, is determined and each barrier is assessed. For the R/B, 45% of the barriers were substantiated for scabbing and 93% were substantiated for perforation. For the C/B, 47% of the barriers were substantiated for scabbing and all were substantiated for perforation. The results of the barrier-by-barrier refinement assessment are given in Ref. 203 and in Ref. 206 for the R/B and C/B respectively.
- Pipe layout check - refinement assessment 2. Actual pipe layout and room dimensions were taken from the 3D model. The following assumptions were included:
  - The pipe whip movements are based on the pipe and room dimensions and the expected hinge locations. The whip angle has not been limited to 90º as assumed for the initial assessment.
  - Conservatively the presence of pipe restraints and supports are ignored.
  - Conservatively the presence of other components in the room is generally ignored.

  The results of the pipe layout check for the R/B are given in Refs. 204 and 205; and for the C/B in Ref. 207.
- Modification options. This included increasing the thickness or reinforcement of the barrier, re-routing pipework, installation of protective barriers, installation of plating and installation of pipe restraints. No modifications were identified in the revision 5 of the Topic Report for the R/B. However, the analysis presented in revision 5 of the Topic Report was incomplete for a number of sections of the RHR, HPCF and FLSS systems that are pressurised for less than 1% of the time, and for the C/B.

400. Revision 5 of the Topic Report systematically identified the sources of pipe whip and jet impact, affected rooms and associated Class 1 divisional barriers for the R/B and C/B (Ref. 42). This is in line with ONR SAPs EHA.1.

401. Revision 5 of the Topic Report on pipe whip and jet impact presented the results of this staged approach and indicated that for the R/B all Class 1 divisional barriers can be substantiated. This statement was subsequently confirmed in a series of supporting submissions covering the initial pipe whip assessment results (Ref. 202) barrier-by-barrier analysis results (Ref. 203) and layout checks results (Ref. 205).

402. The RP indicated that the staged approach analysis for the C/B is ongoing. Subsequently to revision 5 of the Topic Report on Pipe Whip and Jet Impact, the RP submitted the results of the pipe whip methodology barrier by barrier assessment and assessment results by considering true pipe runs for the C/B (Ref. 206 and 207, respectively).

403. The analysis based on the as-designed pipe layout for both the R/B and C/B indicated that a pipe whip would not result in an impact on the Class 1 divisional barriers or that the impact is of very low energy. Therefore, not all Class 1 barriers are required to be claimed against the effects of pipe whip and jet impact. I therefore raised **IH-ABWR-AF-14** to ensure that only those class 1 barriers that provide protection against pipe whip and jet impact are claimed against pipe whip and jet impact.

404. In revision 5 of the Topic Report on Pipe Whip and Jet Impact, the RP stated that the jet loads have also been assessed and found to be bounded by the pipe whip impacts based on a simplistic assumption that the area at which the jet will affect the wall is greater than the pipe whip area. However, no justification has been provided taking into account the jet shape and profile. In addition, the refined analysis reported in References (Ref. 205 and in 207) focused on pipe whip analysis rather than jet impact. Therefore, there is a need to determine the jet load effects on the claimed Class 1 barriers using the as designed pipe work layout, and I therefore raise **AF-ABWR-IH-10**.

Break location

405. In the initial conservative analysis the RP assumed that all high energy pipes can present a failure point, independent of the location of welds, stress combinations or usage factor. For the refined assessment approach, based on the as designed pipe layout it was assumed that the pipe breaks could be at any of the weld locations (Ref. 42). The choice of the break locations is very important in demonstrating that the analysis undertaken is conservative. As discussed in the section below, the choice of break location is not justified as being bounding for all cases considered. This aspect was also a concern for the structural integrity inspector who raised RQ-ABWR-1382 (Ref. 220). It was clear that in some cases postulating failure at weld locations provides the largest whipping area but postulating failure solely at welded locations may not capture the bounding case. RQ-ABWR-1382 was assessed by the structural integrity assessor in Reference 215. In revision 5 of the Topic Report the RP recognised this shortfall in the analysis undertaken and raised an outstanding issue for all break locations to be considered post GDA as part of the detailed design and once the pipe layouts are finalised, and I therefore raise **AF-ABWR-IH-10**. I further considered and discussed this aspect in my assessment of the Barrier Substantiation Report and supporting documents in the section below.

Consequential pipe breaks

406. The analysis presented in the Topic Report on Pipe Whip and Jet Impact was based on a single pipe failure. In various locations within the ABWR design, high energy lines and moderate energy lines are in close proximity to each other and it is therefore conceivable that a pipe whip could initiate a domino effect where a number of adjoining lines could fail. This potential failure and type of failure of the adjoining lines would depend on the size of the whipping pipe and the target pipe(s).

407. Initially, the Topic Report on Pipe Whip and Jet Impact did not consider such failures and I queried the RP's strategy for assessing consequential pipe breaks in RQ-ABWR-1231 (Ref. 217). In response to RQ-ABWR-1231, the RP indicated that such events would be added to the scope of the Topic Report on Combined Internal Hazards. I assessed this topic report and with the exception of room 327 where the potential exists for pipe to pipe interaction between the FLSS and the RHR systems, this aspect has not been addressed (Ref. 208). Some additional pipe-to-pipe impacts are also presented in Reference 208 for Room 414, which is discussed below.

408. The RP also indicated that consequential line breaks were assigned as Beyond Design Basis events and were excluded on probabilistic grounds. I raised RQ-ABWR-1380 (Ref. 218) requesting the RP to provide me with the design philosophy adopted to deal with such events which, once implemented, would eliminate or minimise the possibility of pipe-to-pipe impacts and breaks. Also, in the areas where the design is not mature, I requested the RP to provide me with confidence that any future analysis, post GDA, will not result in major design modifications. The RP, in its response to RQ-ABWR-1380, stated that even in the unlikely event of consequential pipe breaks in the same room, the cooling function can be maintained by substantiating the Class 1 barriers. The RP also stated that subsequent revisions of the Barrier Substantiation Report

would also provide the requisite information (Ref. 221), but this aspect remains outstanding and I, therefore, raise **AF-ABWR-IH-10**, for the RP to consider all consequential pipe-to-pipe breaks (pipe break domino effect).

409. The issue of consequential pipe break was also queried by the structural integrity inspector who raised RQ-ABWR-1382 relevant to the case made inside PCV. This aspect is discussed in section 4.11 of this report and in the structural integrity assessment report ONR-NR-AR-17-037 - Step 4 Assessment of Structural Integrity for the UK ABWR (Ref. 215).

High Energy Systems Excluded from Analysis

410. The RP in the Topic Report on Pipe Whip and Jet Impact screened out a number of high energy lines from the assessment of pipe whip and jet impact based on low frequency once the utilisation factor (pressurised for <1% per year) has been taken into account.

411. This was not in line with ONR's SAP NT.2 which states that "*there should be control of radiological hazards at all times*". It is also ONR's expectation that "*the short duration of the increased risk should not be used as the sole argument for justifying risks are ALARP*" and that "*Any reasonably practicable step that can be taken to eliminate, reduce or mitigate increased risks should be taken even though the time of higher risk may be short*".

412. I initially raised RQ-ABWR-993 on this aspect as presented in the revision 2 of the Pipe Whip and Jet Impact Topic Report. The RP response was that pipes whose functional failure rate is assessed to be less than 10^{-7} per year have been assumed not to break in the ABWR Design Basis Analysis. Revision 3 of the Topic Report did not provide a justification for excluding a number of high energy lines from the analysis. I subsequently raised RQ-ABWR-1231 to obtain information, but in their response the RP deferred this to the next revision of the Topic Report on Pipe Whip and Jet Impact (Ref. 215). Given that the RP's responses to RQ-ABWR-993 and RQ-ABWR-1231 were unsatisfactory, I further raised RQ-ABWR-1310 requesting that the RP develop and present the deterministic case of all high energy lines excluded from the analysis based on low operating frequency. The RP in its response identified the following three systems: High pressure Core Flooder System (HPCF), Residual Heat Removal System (RHR) and Flooder System of Specific Safety Facility (FLSS) (Ref. 222). The response also claimed that there are sufficient redundant and diverse systems to provide fuel cooling and long term heat removal functions during pipe whip event affecting the HPCF or the RHR systems and that these are suitably segregated and separated. The RP assumed that failure of the FLSS will be a Beyond Design Basis (BDB) event and that sufficient redundant and diverse systems are available to provide fuel cooling function during a pipe whip event. The response did not include the justification needed. The RP indicated, however, that details of the above will be presented in revision 5 of the Topic Report on Pipe Whip and Jet Impact.

413. As the overall RP's response on this aspect was unsatisfactory and largely not in line with my expectations, I included action RO-ABWR-0082.A5 in RO-ABWR-0082, which requested the RP to "provide a safety case for the failure of those high pressure safety injection systems outside of containment that are tested periodically while the reactor is at power" (Ref. 9). This included identification of all relevant systems and location, characterisation of unmitigated consequences and identification of SSCs claimed to protect against the consequences of the failure.

414. The RP in response to action RO-ABWR-0082.A5 submitted Reference 208 – 'Refined Assessment Results by Considering True Pipe runs Pipework with Low Frequency of Functional Failure'. This document identified all systems and their location and presented a methodology to select a bounding case for assessment. The methodology

was based on whether the rooms containing the affected systems have thick barriers (in excess of 1700mm RC e.g. MSTR or PCV) and whether the barrier can be impacted by a whipping pipe. This approach reduced the number of rooms requiring assessment from 20 to 5 rooms. The rooms taken forward for quantitative analysis were rooms 110 (RHR division I), 326 (RHR division II), 327 (RHR + FLSS division I), 414 (HPCF + RHR division III) and G42 (FLSS division II). The RP concluded that no pipe whip would result in either perforation or scabbing of the Class 1 divisional barriers.

415. Whilst I am content with the methodology for identification of key areas for quantitative analysis and the analysis methodology applied, the analysis presented in Ref. 208 is based on selection of pipe break locations and pipe movement assumptions (e.g. for room 326) which were not articulated or justified in the submissions. Furthermore, for room 414, the RP identified pipework for the RHR and HPCF systems which are capable of impacting barrier R-W-1F-414. The RP also identified that since pipework from multiple systems is located in close proximity there is also the potential for pipe domino effects. The potential for simultaneously energised pipework leading to pipe domino was assessed by comparing the timing of each operational mode for the RHR and HPCF and this identified 2 bounding events:

- Two RHR lines operating simultaneously at an operating pressure of 2.03MPa (Case 1). This event however resulted in no whipping.
- A single HPCF line operating at a pressure of 8.12MPa (Case 2). This caused no scabbing or perforation. It is noted here that the domino effect of the HPCF and RHR lines hitting the divisional barrier was not presented.

416. The work undertaken in this area sufficiently addresses action RO-ABWR-0082.A5, however, as the selection of the bounding events and the consequences presented was based on the assumed timing of operation of lines RHR and HPCF, they require confirmation and justification during detailed design and this is reflected in **AF-ABWR-IH-10**:

AF-ABWR-IH-10 - As the Requesting Party's assessment of pipe whip and jet impact was based on a representative set of scenarios, break locations and targets, the licensee shall complete the local and global pipe whip and jet impact consequences analysis for buildings containing structures, systems and components important to safety using the as-designed pipe runs, and confirm that all barriers claimed against the pipe whip and jet impact are substantiated. This shall include:

- **Identification and assessment of all intermediate break locations and confirmation of the bounding pipe break locations used in barrier substantiation.**
- **Quantification of the jet impact load on barriers.**
- **Prediction of pipe movement, the consequential dynamic effects and impact on barriers shall be supported by appropriate modelling.**
- **Quantification of consequential pipe-to-pipe domino effects, for plant areas, and the effects on Class 1 barriers.**
- **Definition of timing of operations and the consequences of the bounding scenarios for all systems pressurised for <1% per year.**
- **Demonstration that consequences associated to failure of moderate energy systems are bounded by high energy systems.**
- **Substantiation of non-divisional Class 1 barriers claimed to provide protection against pipe whip and other internal hazards as appropriate.**

417. In the Barrier Substantiation Report (Ref. 90), the RP provided sufficient confidence that there is reasonable flexibility in the design to enable full substantiation post GDA. This may require minor design modifications such as improvements to structural

properties, installation of pipe whip restraints and steel plate reinforcement. The RP is confident that major layout modifications will not be required post GDA as a result of the outstanding work.

4.6.4 Assessment of Class 1 Barriers Substantiation Against Pipe Whip and Jet Impact

Class 1 Divisional Barriers

418. The Topic Report on Pipe Whip and Jet Impact identified all sources of pipe whip and jet impact and the Class 1 divisional barriers requiring substantiation.

419. As discussed in section 4.6.2 above, the RP's analysis methodology and substantiation was undertaken in a staged process with full substantiation of all relevant Class 1 barriers achieved on completion of the staged approach (using the as designed pipe layout check).

420. Similarly to the Topic Report on Pipe Whip and Jet Impact, the RP submitted four revisions of the Barrier Substantiation Report (revision 2 to revision 5 Refs. 87, 88, 89 and 90). These documented the development of evidence to support the claims made on Class 1 divisional barriers against the loads from all relevant internal hazards, including pipe whip and jet impact. The evolution of the BSR is briefly discussed below.

421. In revision 2 of the Barrier Substantiation Report (Ref. 87), the RP reported that a number of Class 1 barriers for the R/B are predicted to fail based on a simplified assessment methodology. The RP, at that stage, proposed to undertake substantiation of Class 1 barrier against pipe whip impact post GDA during the detailed design stage. This was not in line with ONR's SAP SC.4.

422. In revision 3 of the Barrier Substantiation Report (Ref. 88) the RP reported the progress made for a number of buildings (R/B, C/B, Hx/B, EDG/Bs and S/T) and summarises the results of the refined analysis presented in revision 4 of the Topic Report on Pipe Whip and Jet Impact. Revision 3 of the Barrier Substantiation Report also proposed completion of the barrier substantiation claims post GDA. This was based on the assertion that the pipe layout design is not mature enough hence the expectation that, during the detailed design, significant changes to the current pipework layout can take place.

423. In revision 4 of the Barrier Substantiation Report (Ref. 89) the RP reported the progress made with substantiation of all relevant Class 1 barriers using the refined methodologies discussed in section 4.6.2 above, whereas in revision 5 of the Barrier Substantiation Report (Ref. 90) the RP presented its complete substantiation of all relevant Class 1 divisional barriers for the R/B, C/B, Hx/B, EDG/Bs and S/T.

424. In addition, the RP submitted revisions 0 and 1 of the Civil Structure Evaluation Report for Barrier Substantiation (Ref. 169 and 170). This document provides the input data for the internal hazards structural calculations which includes the impact energy of the concerned hazard and the relevant barriers impacted.

425. I have assessed these documents and I raised RQ-ABWR-993, RQ-ABWR-1231, RQ-ABWR-1302, RQ-ABWR-1380 (Refs. 209, 217, 130 and 218). The aims of my RQs were to challenge and guide the RP on the evidence presented in the Barrier Substantiation Report in revision 2 and in the Topic Report on Pipe Whip and Jet Impact, and to also ensure that the claim on Class 1 divisional barriers is suitably and sufficiently substantiated during GDA. The RP's response to RQ-ABWR-1302 (in Ref. 223) and RQ-ABWR-1380 (in Ref. 221) clarified the overall progress made in the area of pipe whip and jet impact substantiation along with the development in the analysis

methodology. It also confirmed that revision 4 of the Barrier Substantiation Report would provide the requisite information.

426. As discussed in section 4.6.2 above, the RP adopted a staged analysis methodology for pipe whip and jet impact which initially resulted in a number of Class 1 divisional barriers being unsubstantiated against pipe whip and jet impact. This resulted in further analysis and additional submissions very late in the Step 4 of the GDA programme. Given the significance of the issue, I raised RO-ABWR-0082 which aimed to address all outstanding issues relevant to Class 1 divisional barrier substantiation (Ref. 9). RO-ABWR-0082 is also relevant to the substantiation of Class 1 divisional barriers against other internal hazards such as internal missile, dropped load and consequential effects. RO-ABWR-0082 outlined my regulatory expectations and included 5 regulatory observation actions. These are given below:

- RO-ABWR-0082.A1 **–** Hitachi-GE to develop a consolidated list of cases where Class 1 Nuclear Safety barriers have not been fully substantiated against all foreseeable Internal Hazard loads including combined consequential events.
- RO-ABWR-0082.A2 **–**Hitachi-GE to provide the proposed assessment methodologies, assumptions and base information needed for substantiation of the Class 1 barriers where different from the Step 4 methods e.g. R3 procedure.
- RO-ABWR-0082.A3 **–** Substantiation of a robust set of representative Class 1 barriers (which will cover the most challenging consequences and all the relevant internal hazards, combined loads and global effects) within the GDA step 4 timeframe.
- RO-ABWR-0082.A4 – The RP to provide justification that, where the specific barrier is not in the representative set, substantiation can be achieved without significant changes to layout**.**
- RO-ABWR-0082.A5 **–** This was discussed in section 4.6.2 above.

427. The RP responded positively to RO-ABWR-0082 and initiated additional analysis and substantiation for all outstanding Class 1 divisional barriers against all relevant internal hazards including pipe whip and jet impact. A number of additional supporting documents were submitted which are detailed in the RPs resolution plan for RO-ABWR-0082 (Ref. 224).

428. I subjected revision 5 of the Barrier Substantiation Report and its supporting document - revision 1 of the Civil Structure Evaluation Report for Barrier Substantiation to assessment and noted the following:

- The staged analysis methodology described in the Barrier Substantiation Report is aligned with the Topic Report albeit the latter needs updating to reflect the results of the BSR;
- The barrier substantiation matrix provides the status of substantiation for all relevant buildings;
- The analysis is suitably conservative for the break locations considered:
  - The analysis is based on conservative data (e.g. design pressure rather than operating pressure);
  - The analysis was performed using the empirical formulas provided in R3 Impact Assessment procedure (Ref. 175). The barriers effective thickness has been taken to be the actual thickness divided by 1.2 (in line with ACI349 Ref. 196) to ensure that it is at least 20% thicker than the required from empirical formulae to prevent local damage; and
  - The calculations were performed on the weakest section of each barrier.
- The BSR focuses on local effects;
- The BSR identified a number of design modification to RC to ensure substantiation of the relevant Class 1 barriers in the R/B. These have been captured in the RP database AIRIS as IH-IR-0005 - Enhancement of Concrete

Structure due to Barrier Substantiation Assessment Against Internal Hazards loads.

429. I sampled Refs. 205 and 207 for the R/B and C/B respectively and I noted the following:

- In some cases the choice of pipe break location resulted in conservative lengths of pipe whip (e.g. for R/B rooms 115 and 253). In a number of cases, however, the break location did not result in longest whipping pipe (e.g. R/B room 122), the break location was not stated (e.g. R/B room 151), the RP concluded that there is no impact to the barrier without any justification or selection of break location (e.g. R/B room 252 or in C/B room 209 and 212).
- In many cases the justification of the selected worst case scenario was not provided and this remained unclear from the available information.
- For room 113 in R/B the pipe whip appears to hit a column in the room. This impact was not further considered.
- In a number of cases for the C/B the worst impact case was based on an internal pressure of 101000Pa. This is below the threshold for high energy pipes and resulted in no credible pipe whip. No justification was provided.

430. From the above it is not always evident that the analysis undertaken and the results presented are bounding for all rooms considered, and I raised **AF-ABWR-IH-10** above. However:

- Some conservatism has been incorporated in the analysis including the barrier effective thickness and in that the analysis was performed on the weakest section of each barrier.
- The RP is confident that sufficient flexibility exists in the design to incorporate further minor design changes, should these be required post GDA.
- The detailed design of all pipe work and penetrations would be completed post GDA.

Given the position documented above, I am overall satisfied that during GDA the RP developed a suitable substantiation methodology, undertook sufficient substantiation work for the barriers and demonstrated that the Class 1 barriers could be fully substantiated post GDA without major design modifications.

Penetrations

431. The RP has submitted a number of documents in the area of penetrations on Class 1 divisional barriers including the following:

- The Penetration Design Guidance, (Ref. 136) which identifies the design requirements and guidelines to be considered during the design of penetrations.
- The Topic Report on HVAC penetrations in Class 1 barriers (Ref. 82) which provides a summary of the HVAC penetrations within the divisional barriers for the R/B and a methodology for the assessment of HVAC penetrations during the HVAC detailed design. The methodology prioritises the minimisation of the number of penetrations, followed by passive safety measures such as hazard-rated ductwork and active safety measures such as dampers.

432. The RP in the Topic Report on Pipe Whip and Jet Impact identified the following good practices that would be applied during the development of the detailed design for all penetrations (Ref. 42).

- Reduce the number and size of penetrations;
- Position penetrations away from potential pipe whip locations;

- Modify pipe layouts and locate SSCs in the adjacent division away from penetrations in the barrier to avoid damage;
- Install barriers or shielding to protect the penetrations from pipe whips and jet impacts; and
- Design large penetrations to withstand the pipe whips and jet impacts.

433. In the Barrier Substantiation Report, the RP considered that a whipping pipe will not be able to pass through a small penetration such as those provided for HVAC, electrical cable and piping routes and therefore will not affect Class 1 SSCs in adjacent divisions. This assertion, however, needs justification especially for the jet impact. The effects of pipe whip on large scale penetrations such as doors and hatches will be considered post GDA, during detailed design, in terms of design specification of the penetration and its sealing mechanism. This aspect is a generic issue applicable to all internal hazards and is covered by **AF-ABWR-IH-03**.

434. Overall, I considered that, during GDA, the RP has provided sufficient guidance on the design of all penetrations on Class 1 barriers for consideration during the detailed design post GDA.

Class 1 Non-Divisional Barriers

435. The RP has also listed in the Barrier Substantiation Report all RC barriers which do not separate safety divisions and compartments but which are required to support the delivery of the internal hazards safety claims by protecting safety critical SSCs from the effects of internal hazards. These barriers do not enclose areas that form hazard compartments or physically segregate diverse and redundant Class 1 SSCs within different safety divisions. These are listed in section 4.6.1 above:

436. During GDA, the RP did not substantiate these barriers against pipe whip and jet impact and identified an outstanding issue in the Topic Report on Pipe Whip and Jet Impact. The RP, however, indicated that these barriers are of the same construction as the divisional barriers. Some confidence was gained from the assessment of the PCV and MSTR areas discussed in this assessment report. I am, therefore, confident that the RP would be able to fully substantiate these barriers post GDA.

4.6.5 Outstanding Issues Raised

437. The RP in the Topic Report on pipe whip and jet impact and in the BSR identified outstanding work which will be undertaken post GDA during the detailed design of the pipe work layout. I have summarised these below:

- To evaluate all postulated pipe whip cases using the pipe layout checking method and substantiate all barriers including all those barriers remaining outstanding for the C/B. The RP recognised that the room layout for several buildings, as well as the detailed pipe run design for a number of systems, will be updated during the site specific stage. In the cases where the room layout, pipe specification (bore, pressure etc.) or pipe routing through the building (i.e. if a pipe runs through different rooms than currently specified) changes during the design development, the rooms will be re-assessed on a room-by-room basis.
- Consideration to be given to all potential break locations once the pipe layouts have been further developed.
- To evaluate all remaining building (T/B, Hx/B, Rw/B, S/B, Fv/B, Service Tunnels, Yard). The RP stated that these buildings either do not contain any high energy pipes or the design is to be completed post GDA.
- Moderate energy pipes ($T<95^{\circ}C$ and $P<1.90$ MPa) were generally dismissed by the RP as the potential damage could be bounded by the high energy pipes due the lower operating pressures. The RP, however, recognised that there

may be specific moderate energy pipes that cannot be bounded by high energy pipes due to their bore, which could pose a risk to Class 1 barriers and require assessment.

- To substantiate all non-divisional barriers.
- To evaluate all unclassified structures against pipe whip and jet impact which support the Class 1 barriers.
- To undertake global analysis. This analysis depends on the detailed piping layout and a number of parameters such as concurrent loads.
- To substantiate the penetrations and access openings. This analysis depends on the detailed piping layout.
- To complete an ALARP review on completion of the detailed design pipe whip and jet impact assessment.

438. These outstanding issues were captured in AIRIS as IH-IR-0007 – “*Outstanding issues in Topic Report on Pipe Whip and Jet Impact*”.

439. I considered the above outstanding issues in my assessment and I reflected them in the **AF-ABWR-IH-10**.

4.6.6 Assessment Findings

440. During my assessment one assessment finding (**AF-ABWR-IH-10**) was identified for a future licensee to take forward in their site-specific safety submissions. Details of this are contained in Annex 5.

441. This matter does not undermine the generic safety submission and is primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.6.7 Conclusions on Pipe whip and Jet Impact

442. The RP undertook and documented a significant amount of analysis in the area of pipe whip and jet impact.

443. I am satisfied with the work presented during GDA as the submissions provide information relating to the process and methodology used in the identification of pipe whip and jet impact failure events, characterisations of the consequences and identification of safety measures. I am also satisfied with the revised analysis methodology based on the as-designed pipe runs and with the process and methodology adopted in the substantiation of the barrier albeit the fact that substantiation depends on the choice of the break location. This work aided closure of RO-ABWR-0082 in this area.

444. However, as the detailed design of all pipework and for all buildings will be completed post GDA, the completion of the entire scope of the analysis will be undertaken post GDA during the licensing stage as a result of addressing assessment finding **AF-ABWR-IH-10**. The RP has provided sufficient confidence that there is reasonable flexibility in the design to enable full substantiation without major plant layout modifications.

4.7 Conventional Internal Missiles Safety Case

445. Disruptive failure of pressurised or rotating equipment in nuclear plant can result in energetic ejection of fragments which may impact on and cause the failure of SSCs delivering FSFs.

446. The assessment of disruptive failure of the UK ABWR main steam turbine is presented separately from conventional missiles in section 4.8.

447. The RP presented the assessment of conventional internal missiles for a number of UK ABWR buildings in the following Step 4 submissions:

- The Pre-construction Safety Report (PCSR) (SE-GD-0127) Revs. C (Ref. 15);
- The Topic Report on Internal Missiles (SE-GD-0346) revisions 1 to 5 (Refs. 74, 75, 76, 77 and 78);
- The Topic Report on Internal Hazards Barrier Substantiation (BKE-GD-0019) revisions 2 to 5 (Refs. 87, 88, 89 and 90); and
- The Civil Structure Evaluation Report for Barrier Substantiation (LE-GD-0322) revisions 0 and 1 (TRIM Refs. 169 and 170).

448. My assessment of the above submissions is presented in the sections below, which cover the following:

- The RP’s safety case for conventional missile hazards;
- My assessment of the claims and arguments;
- Assessment of the analysis methodology;
- Assessment of evidence provided for substantiation of Class 1 barriers and penetrations; and
- Conclusion and assessment findings.

449. The RP presented the analysis of conventional missiles for areas where SSC protection is not based on segregation in separate topic reports. My assessment of the conventional missile hazard cases in those areas (which are primarily the PCV, MSTR and MCR) are presented in sections 4.10 to 4.13.

4.7.1 The RP’s Internal Conventional Missiles Safety Case

450. The RP’s conventional internal missile case is supported by three high level safety claims which apply to all internal hazards and which have been presented in section 3 of this report: **IH SFC 5-7.1**, **IH SFC 5-7.2** and **IH SFC 5-7.3**.

451. The arguments put forward by the RP to ensure delivery of **IH SFC5-7.1** involve the provision of segregation, to prevent the conventional internal missile from impacting safety divisions outside the division where the hazard originates from.

452. In areas where there are exceptions to segregation i.e. no compartmentation by Class 1 RC barriers, the RP’s case is discussed in section 4.10.1.

453. In addition to the high level claims, the RP presented internal missile claims to deliver the high level claims, and each has detailed sub-claims to support delivery. The internal hazards conventional missile claims were as follows:

454. **IH CM SFC 5-7.1:** “*An internal missile event within the design basis will not prevent delivery of the fundamental safety functions*”. In Ref. 78, the RP considered that this claim is supported by Claim **IH CM SFC 5-7.1.1** “*Rotating equipment is only operated with the designed casing in place.*” This was introduced in the RP’s safety case as the performance of the casing (as a means to absorb energy and reduce the missile energy) is essential in substantiating that the RC barriers withstand internal missile impacts.

455. **IH CM SFC 5-7.2:** "*The Class 1 divisional barriers segregating neighbouring divisions will be such that the consequences of a design basis Internal Missile event occurring in one division will not prevent SSCs in neighbouring divisions delivering their Fundamental Safety Functions*". This claim was supported by two further detailed claims, which deal with the conceded scabbing damage to Class 1 barriers detected as the analysis of missile impact was performed through Step 4 of GDA:

456. **IH CM SF 5-7.2.1: Barrier integrity.** "*Class 1 divisional barriers segregating neighbouring divisions will be of sufficient integrity that conventional missiles are contained to the division which it occurs in*" (i.e. the missile does not perforate the barrier).

457. **IH CM SFC 5-7.2.2**: **Internal missile effect on neighbouring divisions**. "*Any effects from an internal missile event in one division (e.g. concrete scabbing) will not initiate a hazard event in a different division, and will not prevent SSCs in neighbouring divisions delivering their Fundamental Safety Function*".

458. It is noted that the sub-claims above, as extracted from the Topic Report on Conventional Missiles revision 5 (Ref. 78) are presented as three separate arguments in the PCSR **IH_CM_SFC_5-7.2.A1**, **IH_CM_SFC_5-7.2.A2** and **IH_CM_SFC_5-7.2.A3** of **IH_CM SFC 5-7.2**.

459. My assessment of the RP's claims and arguments is presented in section 4.7.2.2.

4.7.2 Assessment of Submissions on Internal Conventional Missiles

4.7.2.1 Scope of Assessment

460. My assessment of the RP's conventional missile claims covers all the submissions above, the PCSR and associated references to ensure that substantiation of the claims provided has been achieved in so far that it is expected within the scope of GDA.

461. From the safety case submissions listed above, I focused my assessment on the following topics:

- Suitability and sufficiency of the claims;
- Conventional Missile analysis methodology, assumptions and exclusions;
- Substantiation of RC compartment barriers; and
- Significance of conceded partial failures (scabbing) and SSC assessment
- Margins of safety.

4.7.2.2 Assessment of Claims and Arguments

462. Delivery of the safety claims, specifically **IH SFC 5-1.1**, **IH SFC 5-7.2,** and the dedicated internal missile claims **IH CM SFC 5-7.1**, **IH CM SFC 5-7.2** are totally or partially delivered by the Class 1 RC barriers.

463. Claims on RC barriers are aligned with my expectations and ONR's SAPS EKP.5, EDR.2 and EHA.5. They are also in line with international guidance from the IAEA (Ref. 171).

464. However, during Step 4 of GDA, it became apparent that full substantiation of the Class 1 RC barriers against all failure modes following missile impact had not been achieved and this resulted in the RP developing the claims further.

465. Specifically, the effect of partial failure of the barriers (via scabbing) is covered by sub claim **IH CM SFC 5-7.2.2** – "*Class 1 divisional barriers segregating neighbouring divisions will be of sufficient integrity that conventional missiles are contained to the division which it occurs in*" (i.e. the missile does not perforate the barrier).

466. Combined and Consequential effects associated with damage to the barriers (other than perforation, which is not conceded) are covered by separate claims in the combined internal hazards case assessed in section 4.14.

467. The RP addressed partial failure of the barriers via sub-claim **IH CM SFC 5-7.2.2** (any effects from an internal missile event in one division e.g. concrete scabbing will not initiate a hazard event in a different division, and will not prevent SSCs in neighbouring divisions delivering FSFs). This sub claim is appropriate in so far that it addresses the conceded failure by scabbing of Class 1 barriers in a number of locations of the UK ABWR design.

468. As part of my assessment of the suitability of the claims, I concentrated on the level of coverage provided by the conventional missile claims and those areas where failure of the barriers had been conceded.

469. I sampled the failure of the HCU Nitrogen Tank in R/B room 103, which the RP acknowledged would result in scabbing of divisional barriers with R/B rooms 107, 108, 102, 123 and 207. The specific barriers that were conceded to fail by scabbing were documented in the Civil Structure Evaluation Report revision 1 (Ref 169). I sampled the Divisional Boundary Map revision 5 (Ref. 114) and Barrier Substantiation revision 5 and Civil Structure Evaluation Report revision 1 and I was satisfied that the RP documented all the potential barriers that could be perforated and scabbed (Table 5-2 in Ref. 170) and that the RP had adequately demonstrated that a design change had eliminated the potential for perforation whilst scabbing was conceded.

470. In cases where the barrier could be scabbed by the missile, the RP performed a check on SSCs in the adjacent division to the room housing the failed equipment, and this is presented in the Topic Report on Conventional Missiles revision 5 (Ref. 78). For the above R/B rooms the RP stated that:

- Rooms 102,108 and 123 do not contain safety related SSCs;
- Room 107 instrumentation: Core Flow and Suppression Pool S/P are stated to fail safe; and
- Room 207 containing reactor sampling PCV isolation valves (normally closed) are said to fail. The RP stated that the outcome is bounded by small Loss of Cooling Accident (LOCA).

471. I am generally satisfied that the rooms 102, 108 and 123 do not contain safety related SSCs, however, the potential for hazard initiation by scabbing and subsequent consequential effects e.g. fire or flooding from failure of supporting systems should be confirmed. Rooms 107 and 207 house SSCs and therefore the RC barrier scabbing places constraints on the location of those SSCs, which may be subject to optimisation during detailed design. Preventative measures to eliminate or reduce scabbing may be reasonable practicable and should be studied in line with ONR's SAPs EKP.1 and EKP.5. I have, therefore, raised an assessment finding **AF-ABWR-IH-11** for the future licensee to address this.

472. Similarly, the RP concluded that failure to a safe state ensures that there is no impact on the delivery of FSFs. I judged that the conclusion is acceptable, in GDA, if the failsafe status is confirmed, which requires detailed design information on the SSC characteristics.

AF-ABWR-IH-11- As a result of the predicted partial failure by scabbing and potentially cone cracking of a number of Class 1 barriers following conventional internal missile impact, the licensee shall implement measures to prevent these failure modes from affecting structures, systems and components in a separate safety division. These shall include so far as is reasonably practicable:

- **Consideration of measures to protect the barriers, or selection of pressurised / rotating equipment with design features or limits of operation that reduce the energy of missiles;**
- **Selecting the location and developing the design of structures, systems and components to prevent consequential hazards and/or structures, systems and components' unavailability.**
- **Providing a demonstration of how the assumed failsafe state of the structures, systems and components is delivered under the hazard conditions.**

473. Whilst the above finding is required for the future licensee to demonstrate that the risks associated with partial barrier failures have been reduced so far as is reasonably practicable, the RP has provided sufficient confidence that there is flexibility in the design to enable full substantiation. This may require minor design modifications such as installation of protective plates, avoiding placing SSCs on the affected barriers, or providing additional evidence on failsafe responses under hazard conditions. I therefore judge that there is sufficient flexibility in the design for the above changes not to challenge the generic layout of the UK ABWR post GDA.

474. I also sampled the hazard schedule, which follows the same layout as other internal hazard safety case topic reports. The hazard schedule entry for room 103 states that the missile is contained in division I by a safety divisional barrier, which is correctly Categorised and Classified as A-1. The mitigated consequences for this entry states that the consequences are limited to the division of origin as the SSCs on the other side of the Class 1 barrier (which undergoes scabbing) are “failsafe” and valves in the adjacent rooms are not impacted. The statement in the hazard schedule is consistent with the conclusions of the assessment and is, in my view, appropriate so far the above assessment finding is addressed.

475. My conclusion from the assessment of the claims is that they are suitable subject to additional evidence being provided during detailed design, given the conceded cases of scabbing.

476. My assessment of the analysis methodology, results and evidence of barrier substantiation is presented in sections 4.7.2.3 and 4.7.2.4 below.

4.7.2.3 Assessment of Analysis Methodology

477. The internal missile methodology follows, at a high level, the same 4 step approach as other internal hazards:

- Definition of the area considered;
- Identification of potential missiles sources, including High Energy systems and rotating equipment;
- Identification of SSCs and barriers potentially affected; and
- Assessment of internal missile consequences, including barrier responses.

478. Initially in Step 4 of the GDA, the RP included additional steps in the assessment methodology such as step 5: consideration of the frequency of impact for those cases where the consequences extended to multiple SSCs in multiple divisions and justification that the frequency is low enough for the event to be considered BDB. The RP removed this step in revision 1 of the Topic Report, as conventional missiles did not fall in the BDB category.

479. The RP identified missiles from rotating equipment and high pressure equipment as credible missile sources and calculated the missile energy using methods taken from the R3 Impact Assessment Procedure (Ref. 175) for both rotating equipment and pressure vessels.

480. The RP treated both rotating machine and pressuring machine fragments as hard missiles and set the prevention of scabbing and perforation as the target criteria.

481. A hard missile behaviour, application of the R3 Impact Assessment Procedure and the above target criteria is appropriate and in line with my expectations. The RP has nevertheless not studied target responses such as cone cracking, which places constraints on SSC positions in adjacent divisions and the barrier capacity to withstand combined hazards effects. My judgement is captured in section 4.7.2.2, and these shortfalls have been raised in assessment finding **AF-ABWR-IH-11.**

482. The RP assumed that all SSCs in the area affected by a missile (compartment) are unavailable and therefore the missile path / trajectory was not used to restrict the range of damage.

483. The RP modelled missiles from pressure vessels as a single large fragment. For rotating equipment, the RP assumed that a 1/3 of the impeller or disc mass would be ejected. Given the application of the bounding assumption (loss of all SSCs) consideration of a single fragment from a pressure vessel (ejection of the whole vessel) is appropriate. I also consider that a fragment with a third of the mass of the impeller is appropriately conservative for equipment designed according to RGP in nuclear plant.

484. I initially assessed the Topic Report on Conventional Missiles revision 0 and queried (Ref. 225) the assessment methodology and its application in RQ-ABWR-0844:

- The level of detail on the missile sources considered in the assessment of bounding rooms.
- Provision of design information (pressure, energy and trajectory of missiles) for the systems assessed as the analysis progressed beyond the R/B.
- Justification for exclusion of mechanical seals, valve stems or heat exchanger headers as credible missile sources.
- The potential for missiles to penetrate castings or component barriers and provision of information on missile impact protection measures.
- The methodology followed to assess missile impact on barrier wall/ floor or ceiling penetrations such as doors, pipes, ducts, cabling and floor gratings.
- Justification of the assumption that a single conventional missile would be generated from each source i.e. rationale for discounting multiple fragments generated upon failure of pressure vessels, and the mode of failure.
- Rationale for excluding not studying / bounding the RCIC steam turbine missiles by the RCIC pump.
- Lack of consideration of cone cracking as a barrier damage type in addition to scabbing and perforation.

485. The RP responded to the above queries in Ref. 226 as follows:

- Regarding the exclusion of potential missile sources, the RP confirmed that high energy pipework as credible missile sources had been excluded due to the high ductility of the design.
- The RP explained that it excluded bolts on high pressure pipework as sources on the basis that the design will be to ASME BPVC (Ref. 227) and the small mass resulted in low kinetic energies.
- The exclusion of valve stems and bonnets on high energy systems was supported by the design including a minimum of two retention mechanisms. The RP credited heat exchanger mountings and anchorage to eliminate the potential for missiles from such equipment.
- The RP acknowledged that the RCIC steam turbine wheel was a credible missile source with greater energy than the RCIC pump and changed the selected bounding source accordingly.

- The ejection of single fragments from missile sources presented the highest challenge on the barriers, given the bounding assessment strategy.
- The RP confirmed that axial failure of cylinders resulted in the highest missile energy and had been conservatively postulated as the failure type.

486. Based on these responses, I was broadly satisfied that the assumptions had been sufficiently justified according to specific design features that are subject to confirmation as part of detailed design. I also judged that the sources selected for assessment offered a representatively high challenge on the barriers and therefore provided a meaningful basis for the assessment in line with ONR's SAP EHA.14 and 19.

487. Section 4.7.2.4 below provides my assessment of the evidence on barrier substantiation against conventional missiles.

4.7.2.4 Assessment of Evidence on Barrier Substantiation Including Penetrations

488. The RP presented the consequence analysis evidence in Revisions 0 to 5 of the Conventional Missiles Topic Report (Refs. 73, 74, 75, 76, 77 and 78). In addition to the methodology queries raised in RQ-ABWR-0844 (Ref. 225) and, as part of RQ-ABWR-00991 (Ref. 228), I challenged a number of inconsistencies in the definition of bounding sources and areas impacted. Following my queries, the RP clarified that they had arisen as a result of misidentification of rooms and overlap with reports addressing areas with exceptions to segregation i.e. the MCR.

489. RQ-ABWR-0991 (Ref. 228) also challenged the selection of C/B room 101 as representative of room 104, as in my view the divisional boundary associated with room 101 offered a larger area for cross-divisional effects. The RP responded (in Ref. 229) by noting a design change which had resulted in further changes to divisional boundaries which supported the view of selecting room 104 as the representative room, in alignment with my challenge.

490. Following the initial assessment of conventional missiles in revisions 1 to 3 of the Conventional Missiles Hazards reports, the RP evaluated the response of the RC structures in the Civil Structure Evaluation Topic Report revision 0 (Ref. 169).

491. I sampled the calculations for rooms 113 and 603 in R/B, and I concluded that they correctly estimated the energy and barrier responses according to chosen failure criteria (perforation and scabbing). However, the results conceded that scabbing and perforation of Class 1 barriers would occur.

492. I consequently raised RQ-ABW-1302 (Ref. 130) and, subsequently in RQ-ABWR-1380 (Ref. 218). As the RP's response (Refs. 221) conceded that substantiation of the Class 1 barrier would not be fully confirmed within GDA, and given the shortfalls in barrier substantiation for other hazards, I raised RO-ABWR-0082 (Ref. 9) for the RP to substantiate the barriers against internal hazards including conventional missile impacts.

493. Appendix A4 of the Topic Report on Internal Missile revision 4 (Ref. 77) included numerous cases where, following the predicted perforation of Class 1 barriers, the RP considered that FSFs could still be delivered by SSCs on the other side of the damaged barrier. I judged this not to be adequate, as hazard progression would be credible following perforation of barriers (e.g. by impact on pipe/ flood sources, electrical switchgear, combustible inventories etc.). The RPs assessment was not aligned with ONR's SAPs EDR.1 and SC.4.

494. The RP subsequently clarified that partial failures of Class 1 barrier would only be accepted for scabbing damage, subject to confirmation that there was no impact on

SSCs. Whilst I am broadly satisfied that the check on SSCs confirmed the ability to deliver FSFs (to address ONR's SAP EHA.5), it is subject to substantiation of failsafe characteristics of SSCs and their position in the room, which are the matter of equipment specification and detailed design considerations. I have recorded the requirement in assessment finding **AF-ABWR-IH-11**.

495. The RP proposed a strategy for substantiation of missile cases which involved a revision of the assessment methodology to take into account energy reduction through the casing (for rotating missiles) as allowed for using some methods within the R3 Impact Assessment procedure.

496. For pressure missiles, the RP revised the design to implement changes that ensured the barriers would not fail (increase the concrete thickness and rebar size within the barrier). The RP recorded this requirement in AIRIS IH-IR-0005. The RP proposed that perforation would be eliminated and SSC checks (on the other side of the barriers) would be performed to confirm if any residual scabbing would impact delivery of FSFs.

497. The RP submitted the revised methods, barrier design changes and barrier response analysis in revision 5 of the Topic Report on Internal Conventional Missiles (Ref. 78), the Barrier Substantiation Report revision 5 (Ref. 90) and Civil Structure Evaluation Report revision 1. I judged that the revised approach was appropriate and in line with application of RGP i.e. the R3 Impact Assessment Procedure.

498. Tables 9 and 12 in the Topic Report on Barrier Substantiation revision 5 presented the design changes to substantiate the perforation cases previously conceded in the R/B and scabbing in the C/B. This involved an increase in concrete thickness and rebar size for 12 Class 1 barriers in the R/B and the scabbing cases in the C/B to no impact. I sampled the calculations for room 604 (R/B and R-W-3F-604) and the results aligned with a correct application of the methodology.

499. In the Topic Report on Internal Missiles revision 4 (Ref. 77), the RP had stated that engineering judgement would be used in the substantiation of non-Class 1 barriers (which were claimed but not assessed). This was stated as to be done by comparison with other barriers, which were substantiated in the Barrier Substantiation Report revision 5 (Ref. 90). I shared my expectation with the RP that the Internal Missiles Topic Report would explicitly link the representative case with the case that is considered to be bounded. The evidence provided for substantiation of divisional Class 1 barriers as part of the resolution of RO-ABWR-0082 (Ref. 9) did not explicitly address non-divisional Class 1 barriers, and therefore this remains to be addressed and is the subject of an assessment finding **AF-ABWR-IH-10** (see section 4.6). The RP indicated that the Class 1 non-divisional barriers are of the same construction as the divisional Class 1 barriers and therefore I am content to address this aspect post GDA.

500. In line with my conclusion from the assessment of Fire and Explosion and Pressure Part Failure impacts on penetrations, I judge that the RP has adequately demonstrated that internal missiles will be considered in the location of HVAC penetrations. The RP has also demonstrated how the design requirements for individual penetrations will be satisfied according to the penetration design guideline (Ref. 136) and design rules (Ref. 137). I therefore concluded that, during GDA, the RP has provided sufficient guidance on the design of all penetrations on Class 1 barriers for consideration during the detailed design, post GDA, subject to Assessment Finding **AF-ABWR-IH-03**.

501. Overall, based on the changes to Class 1 barriers through GDA as recorded in AIRIS (IH-IR-0005), I am broadly satisfied that the RP has adequately addressed the shortfalls highlighted in RO-ABWR-0082. Nevertheless satisfactory resolution of the assessment finding on acceptance of scabbing and substantiation of non-divisional Class 1 barriers is required post GDA. I am content that the analysis and

substantiation largely meets ONR's SAPS EHA.13, EHA.14 pending further substantiation as per assessment finding **AF-ABWR-IH-11**. .

4.7.3 Outstanding Issues

502. The RP has acknowledged that the internal missile analysis presented in GDA for the B/B, Fv/B, Rw/B, S/B, Yard and Service Tunnel was based on Piping and Instrumentation Diagrams (P&IDs) or Japanese ABWR (J-ABWR) data. The RP has therefore not presented an UK ABWR specific assessment for this hazard as part of GDA. The Rw/B design is also not complete.

503. Whilst I judge that that the RP has satisfactorily identified this in revision 5 of the Topic Report on Conventional Missiles as an outstanding issue to be resolved post GDA, the assessment of UK ABWR should be updated as the building design progresses through the detailed phase. The RP has recorded this need in their AIRIS database entry IH-IR-0016.

4.7.4 Assessment Findings

504. During my assessment of conventional internal missiles, one assessment finding was identified for a future licensee to take forward in their site-specific safety submissions. Details of this matter are contained in Annex 5.

505. This matter does not undermine the generic safety submission and is primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.7.5 Conclusions on Conventional Missile Assessment

506. During Step 4, the RP undertook a significant amount of work to identify and characterise conventional missile sources from rotating equipment and pressure vessels.

507. The RP provided an analysis methodology and applied the R3 procedure to determine the response of Class 1 barriers against impact. This initially resulted in the conceded failure of a number of barriers by perforation and scabbing.

508. Following a revised methodology which took account of rotating equipment casing and design changes to barriers in the R/B and C/B (increased thickness and rebar sizes), the RP substantiated the Class 1 barriers against conventional missiles against perforation, whilst scabbing was predicted in a number of locations.

509. The RP has provided assurances that consequential effects of scabbing on SSCs would be prevented by their location within the room or by failsafe characteristics. Given this, I judge it necessary for the requirements and locations to be substantiated during detailed design and I raised an assessment finding.

510. Also, whilst am satisfied from an internal hazards perspective that the design changes completed during the GDA process have resulted in the substantiation of Class 1 barriers, non-divisional Class 1 barriers have not been studied in GDA and I have raised assessment finding **AF-ABWR-IH-10** accordingly.

511. Notwithstanding the above, I judge that the RP has provided sufficient confidence that there is reasonable flexibility in the design to accommodate changes without major layout modifications. This work aided closure of RO-ABWR-0082 in this area.

4.8 Turbine Disintegration

512. This assessment section considers high energy missile hazards as a result of steam turbine disintegration. The assessment of conventional missiles is covered in section 4.7 of this report. As with the other sources of missiles, missile fragments ejected from the turbine could cause SSCs delivering FSFs to fail.

513. Key document submissions for turbine disintegration are:

- Pre-Construction Safety Report – Chapter 7 Internal Hazards (Ref.15)
- GA91-9201-0001-00260 - Topic Report on Turbine Disintegration Safety Case, Revisions 0 - 1 (Refs. 83-84).
- GA91-9201-0001-00278 – Topic Report on HP Turbine Casing Structural Integrity, Revisions 0 (Ref. 230).

514. There were two revisions of the above Topic Report on Turbine Disintegration Safety Case. The latter revision reflected the development of the safety case or reflected ONR's Regulatory Queries. My assessment is focused on the final versions of each of the document submissions.

4.8.1 Requesting Party's Safety Case

515. The RP's overarching safety claims are summarised in section 3.5 of this assessment report. The turbine disintegration safety case is primarily based on Claim **IH_SFC 5.7.1** "*Internal Hazards do not prevent the delivery of Fundamental Safety Functions*".

516. The RP's safety case concluded that in the event of a missile from turbine disintegration being realised, suitable and sufficient SSCs will remain available to maintain the plant in a safe state.

4.8.2 Scope of Assessment

517. The assessment strategy in section 2 was used to formulate the scope. My assessment scope is limited to the following:

- The turbine disintegration methodology;
- Sampling the suitability and sufficiency of the claims and arguments; and
- Substantiation of the claims made.

518. The areas chosen in my assessment of the turbine disintegration safety case followed the sampling strategy as discussed in section 2.4 and was limited to:

- Turbine Building (T/B); the key source of missile fragments from turbine disintegration; and
- Buildings surrounding the T/B for consideration of missile impact which contained Class 1 SSCs which deliver the Category A functions; in particular Hx/B.

4.8.3 Assessment of Turbine Disintegration Methodology

519. The RP's proposed safety case on turbine disintegration was based on combined deterministic and probabilistic aspects as given in the Topic Report on Internal Missile (Ref. 231). I initially reviewed the layout of buildings relative to the T/B. I was particularly concerned about the potential missile fragment impact on the Hx/B as it contains three divisions of Class 1 SSCs that are required to provide cooling in accident scenarios and I judged this was located in an unfavourable location within the missile strike zone. A potential impact on the Hx/B would result in loss of cooling from the Reactor Building Cooling Water System (RCW). The resultant impact of this would

be the unavailability of a number of Class 1 SSCs within the R/B which are cooled by the RCW.

520. I sought clarification under Regulatory Query RQ-ABWR-0769 (Ref. 232). The RP confirmed that the Hx/B was in an unfavourable location within the missile strike zone but argued that the initial proposed Design Basis (DB) safety case was based on a low probability event of a single missile hitting the Hx/B. The RP used US NRC guidance to determine missile strike zones but based on lessons learnt from previous GDAs, I considered the US NRC guidance should have been a starting point in the safety case. There was a lack of optioneering studies and justification of the Hx/B location, which was not optimised against turbine disintegration. Therefore, I did not consider that an adequate ALARP demonstration was made and the case was not in line with ONR SAPs EKP.1, EKP.3, ELO.4 and EHA.6.

521. I considered this to be a regulatory shortfall and therefore issued a Regulatory Observation RO-ABWR-0079 (Ref. 93). This required the RP to:

- Define and substantiate the number of missiles generated by a turbine disintegration event, and impact with buildings during DB and BDB events;
- Develop a robust deterministic safety case; and
- Provide an ALARP justification.

522. The RP developed a resolution plan detailing key deliverables and a programme of submissions (Ref. 233). In response to RO-ABWR-0079, the RP revised their methodology which led to the development of the Topic Report on Turbine Disintegration Safety Case (Refs. 83 and 84). There are two revisions of this report, with the latter revision including sensitivity studies. My assessment is based on the latter revision of the Topic Report. The RP's methodology included:

- Identification of turbine failure modes;
- Characterisation of missile numbers, mass of missile fragments, ejection velocities and angles;
- Allowance for missile energy reduction due to the energy required to perforate the casing;
- Categorisation of missiles into low trajectory and high trajectory. This determined the flight paths;
- Analysis of the barrier response to design basis turbine missile impacts; and
- Analysis of probabilistic assessment of beyond design basis turbine missiles.

523. The RP stated that the main steam turbine is operational only during power operation; and therefore argued that the hazard of a turbine only exists during this mode of operation (Ref. 84). However, I sampled the Topic Report on Turbine Disintegration Safety Case to check for whether the main steam turbine would be operational during maintenance testing. The RP notes that the schedule of the over-speed protection systems occur at six to twelve monthly intervals for mechanical over-speed tests and for twelve to twenty four monthly intervals for the back-up over-speed tests. Therefore the summary is incorrect and the safety case should reflect all operational modes when turbine missiles are credible. However, the bounding case occurs when the main steam turbine is operational during the power operation and therefore I judged that the turbine failure mode bounding case was adequately identified.

524. The RP considered the disintegration of a disc into a different number of fragments. The safety case is now based on one disc disintegrating into four quadrants, with each adjacent disc assumed to fail in a similar fashion. This resulted in 12 turbine missile fragments being ejected from the turbine. Bounding masses and ejection velocities were estimated and sensitivity studies were performed for fragmentation into 2, 3 and 5, 6, 7 pieces.

525. The RP's approach using the R3 Impact Assessment Procedure (Ref. 175) demonstrated that Low Trajectory missiles (LT) would be retained in the T/B. Two sets of RC walls (0.9 and 1.2 m thick) had been identified and these would be relied upon to retain LT missiles within the T/B.

526. In summary, as part of Regulatory Observation RO-ABWR-0079 the RP was required to define and substantiate the number of missiles generated by a turbine disintegration event, and the impact with structures during DB and BDB events; develop a robust deterministic safety case and provide an ALARP justification. The remedial work carried out is broadly in line with my expectations and I consider it to be in line with the IAEA Safety Guides NS-G-1.11 and SSG-2 (Refs. 171 and 190) and with ONR's SAP EHA.1.

4.8.4 Assessment of Claims and Arguments

527. The turbine disintegration safety case had additional sub-claims which were:

- Claim **IH_TB_SFC_5-7.2**. The frequency of turbine missile generation is minimised through good practice in plant design and operation. This is achieved via design, manufacture, inspections, testing, and maintenance, and via the provision of a high reliability over-speed protection system.
- Claim **IH_TB_SFC_5.7.3**. Design basis missiles resulting from turbine disintegration do not perforate the outer structures of safety classified buildings. This is achieved by missile fragment retention in the casing / stator or has insufficient energy.

528. The RP argued that equipment is designed and manufactured according to appropriate international design and operational health and safety standards. The High Pressure (HP) turbine casing will be designed in accordance to the Japanese standard JIS B 8201 (Ref. 234) which the RP advised is the equivalent of ASME Section VIII (Ref. 235). The comparison of standards was sampled by the structural integrity assessor who advised that the parameters were similar and followed a design approach (Ref. 215) in line with SAP. ECS.3.

529. The risk of turbine failure is minimised through the adoption of a high reliability design, high quality manufacturing process, rigorous inspection and factory testing. Figure 4 and Table 4 of the Topic Report on Turbine Disintegration Safety Case gave an overview of the inspection and testing during the turbine manufacturing stages; and summarised the turbine manufacturing inspections and tests respectively (Ref. 84). This included rotor overspeed testing, at 120% of its nominal speed. I considered that the RP's arguments were reasonable. I consulted the structural integrity assessor who also agreed with the above arguments (Ref. 215).

530. I also sampled the argument for the Low Pressure (LP) turbine shaft. The RP argued that monobloc LP forgings instead of discs shrunk into a central shaft gave an improvement in integrity and reduction in bore stress. The structural integrity assessor considered that mono-block reduces stress concentrations/ singularities (Ref. 215) and that the use of monobloc is considered in line with RGP. Therefore, I consider that the RP's arguments take cognisance of SAP ERL.2 and satisfy claim **IH_TB_SFC_5-7.2**.

531. Two turbine failure modes with the potential to result in the generation and ejection of high energy missiles were identified:

- Normal over-speed failure as a result of rotor brittle failure or stress corrosion cracking; and
- Runaway over-speed failure resulting from a loss of load to the turbo-generator and the main steam supply failing to trip.

532. Turbine overspeed protection is provided by three systems. These are the speed control during normal operation by an Electro-Hydraulic Control (EHC) system and two additional systems; a mechanical overspeed protection system and an electrical backup overspeed protection system.

533. The mechanical system relies on an emergency governor adopting the principle of an unbalanced ring. If the turbine reaches 110 – 111% of its nominal speed, the centrifugal force forces the ring to snap to an eccentric position. In doing so, it activates the trip system. The electrical backup system operates when the turbine reaches 112% of its nominal speed. The electrical trip de-energises the master trip solenoid valves. There are diverse systems for turbine overspeed protection, which I consider to be in line with SAP EDR.2. Therefore, this also satisfies sub-claim **IH_TB_SFC_5-7.2.**

534. The rotor is surrounded by the stator and the turbine casing and any high energy missile fragments produced would impact these components. The RP argued that worst credible missiles due to the fragmentation of the HP rotor would retained by the casing of the HP turbine. For normal over-speed of the LP turbine, the RP analysed the perforation energies of the diaphragm, inner cylinder and outer cylinder. The RP conceded that perforation of the T/B may occur. Within the T/B, the RP has assumed that all systems will be lost following a disruptive turbine failure. However, there are no Class 1 SSCs inside the T/B apart from some A-1 instrumentation.

535. External to the T/B, the RP confirmed that the Nuclear Island buildings were located along the axis of the turbine and away from the LP rotor ejection planes. However, I was still concerned with the location of the Hx/B as this was within the missile strike zone. I identified this earlier as part of the Regulatory Observation RO-ABWR-0079.

536. The RP facilitated a workshop in March 2017 which considered a range of options to reduce risk of turbine missiles impacting on the Hx/B. These included plant layout and separation / segregation measures. Potential options to reduce the risk were identified and summarised in Table 16 of the Topic Report on Turbine Disintegration Safety Case (Ref. 84).

537. The RP used a Multi-Attribute Decision Analysis (MADA) procedure to score the different options. The RP identified potential options to take forward but did not implement any risk reduction measures. The RP concluded there was "*no obvious alternative option that will result in a significant reduction in the risk to the Hx/B associated with turbine disintegration*." Therefore, the RP did not confirm the location of Hx/B would be moved as a result of the workshop review and argued that "*moving the Hx/B to a more favourable location scored approximately the same as the current layout*." However, scores were derived by a multi-discipline team based on qualitative subjective arguments (Ref. 84).

538. The current location of the Hx/B is not in an inherently safe location as the Hx/B contains Class 1 SSCs and remains in an unfavourable location in the path of potential turbine missiles. The RP has acknowledged that there is a potential for turbine missiles to perforate the T/B and be ejected into the path of the Hx/B. A key mitigating factor is that the RP's analysis confirmed that perforation of the Hx/B does not occur. However, there were additional mitigation measures identified in the RP's workshop. These risk reduction measures were not implemented and so this does not provide adequate defence in depth. Therefore, I consider that the design is not in line with ONR's SAPs EKP.1 and EKP.3.

539. In addition, the RP argued that the total loss of the Hx/B due to the damage by multiple LT missile impacts was bounded by the loss of all RCW at power fault. I sought clarification in Regulatory Query RQ-ABWR-1440 (Ref. 236). The RP response stated that the RCW system provides A1 functions for fuel cooling (FSF2) and long-term heat

removal (FSF3). Loss of RCW is a DB infrequent fault, for which mitigation is provided by diverse A2 systems (Ref. 237).

540. I was satisfied the loss of the Hx/B was bounded in the short term i.e. 8 hours or less. However, I am not satisfied that the long term loss of the Hx/B has been considered adequately. That is, if the Hx/B was damaged, it is highly likely that it would take greater than 8 hours for damage resolution. Therefore, I am raising an assessment finding:

AF-ABWR-IH-12 - The Requesting Party's assumed location for the Heat Exchanger Building in the Generic Design Assessment plot plan is not optimised against low trajectory turbine missile strikes following a disintegration event. Consequently, the licensee shall demonstrate that the risk to this building has been reduced to As Low As Reasonably Practicable.

541. I consider that an assessment finding is adequate and does not require escalation to a GDA issue as the RP determined penetration depths on barriers, and carried out sensitivity analysis using different numbers of turbine disc fragments and different numbers of structural barriers. From the analysis, the RP concluded that perforation of the Hx/B does not occur. My assessment of the consequence analysis is addressed in section 4.8.5 below. My expectation is that the risk reduction measures that were identified during the RP's March 2017 workshop will be implemented. It is also my understanding that the position of the Hx/B is likely to change during the site licensing process.

4.8.5 Substantiation of the Claims

542. For the HP turbine, the penetration depth of the casing was evaluated to be 37mm (Ref. 84). I sought further clarification on derivation of the substantiation of the turbine casing as part of RQ-ABWR-1440. The RP responded that detailed calculations could not be provided due to the commercial sensitivity of information but were expected to be consistent with other nuclear power plant turbines.

543. I discussed the substantiation with the structural integrity assessor and sought confirmation that the internal hazards analysis was within the bounds of the structural integrity assessment. The depth of penetration before full perforation would occur was calculated to be 58mm. The calculation was detailed in the Topic Report on HP Turbine Casing Structural Integrity (Ref. 230). I am satisfied that the penetration depth of 37mm is adequately less than the target of 58mm. This satisfies sub-claim **IH_TB SFC_5-7.3.**

544. The RP performed damage calculations using the R3 Impact Assessment Procedure for LP rotor missiles. Table B-1 in the Topic Report on Turbine Disintegration Safety Case (Ref. 84) shows that there is enough energy for the missiles to perforate five walls and exit the T/B at floor 4F and impact on the Hx/B. The initial velocity of the missile is at 105m/s and is progressively reduced at each wall perforation. The impact energy required to perforate the Hx/B is articulated as 57.5MJ and the impact energy of the missile entering the Hx/B was reduced to 10.7MJ. This would suggest that there is an adequate safety margin. Although there is some scabbing, perforation of the Hx/B does not occur.

545. The RP also carried out a sensitivity analysis which allowed for the perforation of the rotor casing, but removed the T/B structures in the analysis. Table B-2 in the Topic Report on Turbine Disintegration Safety Case (Ref. 84) summarised that the Hx/B would suffer an impact but the missile fragments would not perforate the building.

546. As a further sensitivity study, the T/B structures and the turbine casing were removed from the analysis. Table B-3 of the above Topic Report (Ref. 84) concluded that further

scabbing would occur on the outer wall of the Hx/B but no perforation would occur. I consider that the damage calculations also satisfy the sub-claim **IH _TB_SFC_5-7.3**.

547. I sampled the Barrier Substantiation Report (Ref. 90) to check the consistency of the safety case but information on turbine disintegration was not incorporated. I also liaised with the civil engineering assessor to check that the turbine missile impacts had been incorporated, but I was advised it was not clear in the civil engineering safety case and an assessment finding was raised in ONR-NR-AR-17-013 (Ref. 238).

548. In other Topic Reports, the RP summarised the safety case within a hazard schedule. The Topic Report on Turbine Disintegration Safety Case (Ref. 84) instead had a "Summary of Protection Measures against Turbine Missiles for GDA Buildings and Structures." (Ref. 84). The tables provided an overview of each building and the following details:

- The type of FSF (i.e. control of reactivity, fuel cooling, long term heat removal, containment or other FSF);
- Unmitigated consequences; and
- Protection and mitigation against missile impact.

549. The SSCs providing the key FSF are not described. Hazard safety systems and mitigated consequences are also not summarised. For most of the buildings, it states that turbine low trajectory missiles are retained in the T/B. For high trajectory turbine missiles, it states that the protection is due to the low impact frequency. The table presents best estimate arguments and does not align with the safety case.

550. I cross-checked against the Topic Report on Internal Missile – Conventional Internal Missiles (Ref. 76). The hazard schedule in this report contained an entry for the T/B (TB-MI-01) but this pertained to conventional missiles.

551. I sampled the PCSR to review the summary of the turbine disintegration safety case (Ref. 15). It was summarised that design basis missiles have insufficient kinetic energy to perforate the civil structure of the Hx/B. It concedes that scabbing may occur but this would result in only one of the three divisions of the Reactor Building Cooling Water System (RCW) and Reactor Building Service Water System (RSW) being lost.

552. The turbine disintegration hazard is linked to a bounding fault in the fault schedule (Fault ID 17.6). Therefore, I also sampled the Topic Report on Fault Assessment. This report notes a turbine missile striking the Hx/B as a BDB fault with two divisional trains being affected (Ref. 99). This is contradictory to the PCSR summary above. I noted a misalignment in the safety case in that the Topic Report on Fault Assessment also articulates that turbine missiles are described in a now out-of-date Topic Report on Internal Missiles (Ref. 231).

553. The consideration of turbine disintegration represents a clear example of where the internal hazards safety case is not auditable and not aligned in different disciplines. The linking of hazards, fault sequences and safety measures cannot easily be followed and is not in line with SAPs. FA.7 and FA.8, nor paragraph 408 of the SAPs. There are two overarching assessment findings which capture the key actions for the licensee to ensure that the hazard schedule is alignment with the safety case (**AF-ABWR-IH-14**); and that the safety case is coherent and demonstrably complete (**AF-ABWR-IH-19**). Therefore no additional assessment finding is required.

4.8.6 Assessment Findings

554. During my assessment one assessment finding was identified for a future licensee to take forward in their site-specific safety submissions. Detail of this is contained in Annex 5.

555. This assessment finding does not undermine the generic safety submission and is primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages, particularly as the site layout is developed.

4.8.7 Turbine Disintegration Assessment Conclusion

556. In response to RO-ABWR-0079, the RP provided a revised safety case. This detailed information relating to the identification of missile impact from turbine disintegration, consequences analysis and the identification of safety measures. The RP demonstrated that in the event of turbine disintegration, perforation of the Hx/B does not occur.

557. There is the outstanding issue of the Hx/B being located in an unfavourable location within the missile strike zone. The RP identified potential risk reduction measures which require further development. I expect the licensee to implement risk reduction measures in this area and adequately demonstrate that risks have been reduced to ALARP in line with SAPs. EKP.1 and EKP.3 and I raised an assessment finding **AF-ABWR-IH-12** to address this shortfall.

558. Notwithstanding the above, I judge that the approach is appropriate within GDA. I am satisfied with the level of turbine disintegration analysis to close Regulatory Observation RO-ABWR-0079. The RP has provided confidence with the analysis outputs and that risk reduction measures will be developed during detail design as the site layout plan is optimised.

4.9 Dropped and Collapsed Loads

560. Loss of control of loads during lifting operations can lead to impacts on to SSCs of nuclear safety significance and as a result, impair delivery of FSFs.

561. The energy of the impact from a dropped load is directly proportional to the mass and height of the drop. The severity of the impact on SSCs depends on the energy of the impact, the geometry/ shape of the dropped item and the characteristics of the target.

562. The RP presented the assessment of dropped loads for the GDA buildings in a number of Step 4 submissions:

- The Pre-construction Safety Report (PCSR) revision C (Ref. 15);
- Topic Report on Dropped and Collapsed Loads (LE-GD-0082) Revs. 2 to 4 (Refs. 45, 46 and 47);
- Topic Report on Dropped Loads Assessments of Nuclear Special Cranes (NSCs) (LE-GD-0249) Revs 0 and 1 (Refs. 239 and 240, respectively);
- The Topic Report on Internal Hazards Barrier Substantiation (BKE-GD-0019) Revisions 2 to 5 (Refs. 87, 88, 89 and 90);
- The Civil Structure Evaluation Report for Barrier Substantiation (LE-GD-0322) Revisions 0 and 1 (Refs. 169 and 170); and
- Concrete Structure Assessment against Heavy Drop for Reactor Building Operating Deck revision 0. (LE-GD-0248), Ref. 241.

563. In addition to the above documentation, the RP provided further analysis as part of the resolution of RO-ABWR-0056 and RO-ABWR-0082 and associated RQs. The additional reports assessed, relevant to RO-ABWR-0056 were as follows:

- Spent Fuel Interim Storage Optioneering for Spent Fuel Removal from Spent Fuel Pool (FRE-GD-0080) to Outside of Reactor Building, Revisions 0 to 3 (Ref. 242, 243, 244 and 245); and
- Fuel Route Layout and Fuel Pool Cooling (FPC) System ALARP workshop reports (UE-GD-0414) Revisions 0 and 1 (Ref. 246 and 247).

564. My assessment of the above submissions is presented in the section below, which covers the following:

- The RP’s safety case for dropped load hazards;
- My assessment of the claims and arguments;
- Assessment of the RP’s analysis methodology;
- Assessment of the evidence provided for the substantiation of Class 1 barriers and availability of FSFs; and
- Outstanding issues, conclusions and assessment findings.

565. Similar to other internal hazards, the analysis of dropped load consequences for areas where there are exceptions to physical segregation such as inside the PCV, the MSTR and MCR are covered in separate sections, i.e. 4.11, 4.12 and 4.13, respectively.

4.9.1 The RP’s Dropped Load Safety Case

566. The RP’s internal hazards safety case claims are given in section 3.2 of this report. The safety case for dropped loads is principally based on claim **IH_D_SFC_5-7**, which is in turn supported by claim **IH_D_SFC_5-7.1**.

567. Claim **IH_D_SFC_5-7.1** is supported by dedicated dropped load sub-claims **IH_D_SFC_5-7.1.1** and **IH_D_SFC_5-7.1.2** (as per Ref. 47), which cover the effect of design basis dropped load events on neighbouring SSCs and divisional slabs. The PCSR does not include sub-claims but two sets of arguments H_D_SFC_5-7.1.A1 &

IH_D_SFC_5-7.1.A2, and IH_D_SFC_5-7.1.A3 capturing the same aspects of the case. The latter is also the approach followed in the Claim-Argument-Evidence Map of Internal Hazards revision 0 (Ref. 100).

568. Specifically, the RP claimed that any design basis dropped load event would not result in the loss of SSCs from different safety divisions and that the resistance of safety divisional slabs would be maintained following the drop.

569. The topic reports included assessment of all GDA buildings (R/B, C/B, Hx/B, T/B, S/B, Fv/B, Rw/B, EDG/Bs and service tunnels) and all operational modes.

570. Revision C of the PCSR (Ref. 15) summarises the case made and largely refers to revision 4 of the Dropped and Collapsed Loads Topic Report (for conventional loads) and revision 1 of the Topic Report on Dropped Loads Assessments of Nuclear Special Cranes (NSCs), which captures the assessment of drops from the R/B crane and the Fuel Handling Machine.

571. The RP's safety case for design basis dropped loads concluded that in the event of a dropped or collapsed load event, suitable and sufficient SSCs would remain available to maintain the plant in a safe state.

4.9.2 Assessment of the RP's Case

572. The assessment strategy in section 2 was used to formulate my assessment.

4.9.2.1 Scope of assessment

573. My assessment covers all RP's internal hazards submissions in the area of dropped loads provided during Step 4 of GDA, the PCSR and the associated internal hazards and civil engineering reports to ensure that substantiation of the claims has been achieved in line with the expectations set out in ONR SAPs (Ref.6) and TAGs (Ref.7 and 8).

574. From the safety case submissions listed above, I focused my assessment on the following areas:

- Suitability and sufficiency of safety case, and the claims and arguments made and in this area;
- Analysis methodology and assumptions;
- Substantiation of the claims made, including the dropped load consequence analysis and response of target SSCs and divisional boundaries to dropped loads; and
- Margins of safety.

575. My assessment has covered conventional loads and nuclear special cranes separately in line with the structure of the RP's submissions. The assessment sections below present the outcome of my assessment.

4.9.2.2 Assessment of Claims and Arguments

576. Delivery of the safety claims relating to dropped loads, specifically **IH_D_SFC_5-7.1**, **IH_D_SFC_5-7.1.1** and **IH_D_SFC_5-7.1.2** is principally achieved via RC slabs and walls.

577. The RP's claim on Class 1 divisional barriers for the R/B and C/B is in line with ONR's SAPS EDR.2, EKP.5 and EHA.5, and IAEA guidance (Ref.171).

578. The barriers claimed against dropped loads are listed in revision 5 of the Topic Report on Internal Hazards Barrier Substantiation (Ref. 90). This included design changes to

sling lengths, thickness and rebar size changes to substantiate the barriers against dropped loads.

579. A hazard schedule for conventional loads is not available in the Topic Report on Dropped and Collapsed Loads revision 4 (Ref. 47). Therefore, this topic report is not aligned with the rest of the internal hazards safety cases and my expectations.

580. A hazard schedule is available for drops from NSCs in the revision 1 of the Topic Report (Ref. 240). This hazard schedule is generic (as in the case of other internal hazards e.g. internal blast). The schedule lists drop loads on to locations such as the Reactor Core, the Spent Fuel Storage Pool (SFP), the Operating Deck, the Dryer Separator Pool (DSP) and the SSCs required for safety. It also includes a general claim on Class 1 barriers, but it does not state the specific load or the barrier impacted that is supporting the delivery of the FSFs. My assessment of the suitability and sufficiency of the context and evidence provided in the dropped load submissions and the Barrier Substantiation Report is presented in the assessment sections below. The information should, however, be incorporated into the hazard schedule to provide the context to support that Class 1 barriers are delivering the claim.

581. Section 4.9.4 below presents my assessment of the RP's internal hazards case for dropped loads hazards. The assessment of the generic design of cranes, lifting schedules etc. is addressed by the mechanical engineering discipline report in ONR-NR-AR-17-022 (Ref. 248).

4.9.2.3 Assessment of the Dropped Load Analysis Methodology

582. The RP presented the initial analysis methodology in the Topic Report on Dropped and Collapsed loads (LE-GD-0122) revision 1, and consisted of the following steps:

- Step 1 - Identification of lifting equipment;
- Step 2 - Identification of potential lifts;
- Step 3 - Identification of bounding lifts;
- Step 4 - Identification of SSCs which may be damaged; and
- Step 5 - Mitigating features.

583. Subsequently, the RP revised the assessment methodology to align it with the approach followed in other internal hazards. The revised steps were as follows:

- Step 1 - Systems and components assessment. This involved identification of all lifting equipment and rooms, and performing checks on whether there are SSCs within the room which belong to other divisions and could be affected. If the SSCs in the room belong to the same division, or no SSCs from other divisions could be affected in that room, the RP progressed to Step 2, which is a check on the withstand on the room floor slab.
- Step 2 - As part of this step, the RP selected an impact energy threshold (0.2MJ) below which substantiation against scabbing and perforation had been provided for the weakest slab in the ABWR and, therefore, detailed structural analysis was not considered necessary for any cases bounded by it. Where the energy of the impact was predicted to be above 0.2MJ (or marginally below, to check for cliff edge effects), the RP checked whether there would be potential for impact on a separate divisions e.g. the floor slab below is a divisional barrier. Where the room floor is a divisional barrier, the RP calculated the response of the structure using the R3 Impact Assessment Procedure (Ref. 175).
- Step 3 – Mitigation features. This step specifically dealt with predicted failures of divisional slabs when the R3 Impact Assessment Procedure was applied. The RP aimed to develop the design to eliminate or reduce the extent of

damage, or to provide protection measures to mitigate the consequences of the damage.

584. If the energy of an impact is below 0.2MJ, the RP generally considered that the slab would withstand the impact and no SSCs within different rooms or Safety Divisions would be lost. I requested the requisite substantiation as part of RQ-ABWR-1272 (Ref. 249) and the RP responded satisfactorily in Reference 250.

585. As part of RQ-ABWR-1445 (Ref. 251), I challenged the following aspects of the assessment methodology:

- The RP initially applied the above methodology to lifts in rooms where the floors represented divisional boundaries. This did not meet my expectations, as secondary drops (following failure of a non-divisional floor) could credibly result in impacts on different divisions two floors down, based on the UK ABWR layouts in the Divisional Boundary Maps (Ref. 114). Revision 3 of the Topic Report did not include information on those lifts.
- The assessment of dropped loads was based on the mass of the lifted item, and does not appear to include the mass of the lifting attachment or the lifting device should the lifting arrangements collapse whilst in operation.
- The RP did not include the geometry, dimensions etc. of the dropped loads assessed. Some dimensions had been provided during GDA Step 3 but the values had not been carried forward to the Step 4 or were different.
- The methodology did not refer to the specific R3 Impact Assessment Procedure equations or provided a justification for all relevant parameters.
- The RP's statement that, where reasonable practicable, the lifts would take place in the R/B and would remain within the Safety division of origin. However, cross divisional lifts appeared to take place through Class 1 hatches.

586. I judged that the RP responded satisfactorily to the above points in Reference 252:

- The RP provided evidence to support that there were no cases in the R/B where perforation of non-divisional slabs resulted in secondary drops on to a divisional slab. There were nevertheless cases in the C/B and R/B where perforation or scabbing of the non-divisional slab was predicted and therefore secondary drops on divisional slabs were credible. The RP resolved these cases via design change: the reinforcement size has been increased from 20 mm to 25 mm in C/B room 450, and from 25 to 32 mm to prevent scabbing in Hx/B room 551 (Ref. 252).
- The RP revised the lift tables to include the use of the combined mass of lifted item, lifting device and lifting attachment in the evaluation, as shown in revision 4 of the Topic Report on Dropped Loads (Ref. 47). The RP also provided the effective diameter and mass of the lifted object.
- The Civil Structure Evaluation Report revision and Dropped Load Topic Report revision 4 were updated to provide worked examples of application of R3 Impact Assessment Procedure, ACI318 (Ref. 253) and ACI349 (Ref. 196). An example calculation was also provided in the RQ response (Ref. 252).
- The RP identified the hatches on divisional barriers that are part of lift paths, and considered the effects on slabs following dropped loads in the R/B and the Hx/B. Further assessment of the evidence on this specific topic is provided in section 4.9.4.4 below.

587. Following the methodology changes implemented by the RP, I am satisfied that the level of analysis is sufficient and is aligned with ONR's SAPs EKP.1, EKP.2, EHA.7 and EHA.14.

4.9.2.4 Assessment of Evidence and Barrier Substantiation

588. The UK ABWR slabs forming hazard compartments are made of RC. These slabs were identified by the RP as providing a Category A safety function and are classified as Class 1. This is in line with my expectations and ONR's SAP ECS.2.

589. The RP presented the assessment of dropped loads from Nuclear Special Cranes (NSCs) revision 0 in Ref. 239. This report included the analysis of heavy lifts in the R/B during outages, which have the potential to impact the RPV and the SFP and would therefore result in very significant radiological consequences. Following my review of the submission, I raised RQ-ABWR-0994 (Ref. 254) as it fell short of my expectations in a number of areas, including:

- It was not clear the extent to which SSCs on the Operating Deck had been identified as affected by the dropped loads. SSCs such as the Dryer Separator Pool (DSP) and SFP had been excluded from lists of SSCs.
- The RP used the energy of the drop as the parameter to determine whether the consequences would be bounding, and appeared to disregard the effect that the impact area and shape of the object could have on the severity of the consequences.
- It did not provide evidence on the effect of swinging loads impacting on structures. This was a concern given the height of the lifts and mass of the lifted items.
- The level of assessment for drops during Spent Fuel Export activities.
- The base information used to select a bounding lifts was incomplete e.g. the lift heights had not been provided for any bounded lifts.
- The lack of appropriate referencing to the interlocks credited to prevent transfer over specific areas, e.g. the Transfer Cask being transported over the SFP or RPV.
- The prediction that cone cracking and scabbing of the operating deck would occur without justification to support how delivery of the FSFs was maintained.
- The quality of the lifting route representations provided, which did not allow the identification of key SSCs.
- The effect of vibrations as a result of cask drop impacts on the concrete slab of the Truck Bay.
- The routes showing lifts over the reactor well showed that there could be impacts on the RPV shield plugs.
- The high severity of the consequences following a drop on the Operating Deck and SFP.
- The absence of evidence to support that loss of SFP water inventory could be made up by the RHR trains.

590. The RP responded to RQ-ABWR-0994 in Reference 255. I considered that this response addressed the above points satisfactorily. The RP's response included a commitment to develop a swinging load analysis methodology (which was subsequently applied and queried in RQ-ABWR-1445). It also included improved lift plans and the acknowledgement that the Operating Deck had not been fully substantiated. The predicted damage to the SFP was calculated by reference to a quantitative Finite Element Analysis performed in the report 'PSA Supporting Information Regarding SFP Structural Analysis' revision 0 (Ref. 256) and supported the conclusion that damage to the SFP would result in leakage not exceeding 30 m^3/h. This was later refined to 6 m^3/h in the Topic Report on Fault Assessment for SFP and Fuel Route (Ref. 257), which is well below the makeup rate capacity of the FLSS.

591. The RP presented the response of the Civil Engineering Structure to dropped loads in the revision 3 of the Topic Report on Dropped Loads (Ref. 46) and revision 3 of the Barrier Substantiation Report. The RP conceded that application of the R3 Impact Assessment Procedure predicted the failure of Class 1 barriers in a number of

locations, including the R/B Operating Deck. I raised this initially in RQ-ABWR-1445 (Ref. 251), and also as part of RO-ABWR-0082 (Ref. 9), due to lack of substantiation of Class 1 barriers against a number of internal hazards (pipe whip, conventional missiles, dropped loads and combined hazards).

592. As part of RQ-ABWR-1445, I challenged the following analysis results:

- The assumption that only one Skimmer Surge tank could be damaged following a drop of the SFP Slot Plug (A), as the pipework connecting both tanks could be within the damage range and lifting route of the SFP plug (A) or could be disrupted by secondary effects such as vibrations.
- The results of dropped load assessments in C/B rooms 203 and 205, which had impact energies marginally below 0.2MJ, but had not been studied in detail.
- The conceded failure of the C/B floor slab in the C/B room 450, which would result in scabbing of the slab. The RP had noted that changes to the layout or design or further analysis would be required but would not be provided within GDA.
- The swing load assessments assumed a target divisional barrier thickness of 0.5m. I recognised that there are Class 1 walls in the ABWR that are thinner than the assumed value.

593. In relation to the above points, I was satisfied that the RP’s response in Reference 252 demonstrated that the potential for simultaneous damage of Skimmer Surge tank piping and the FPC cooling function was very remote, subject to confirmation of pipework layouts during detailed design. The RP also provided the assessment of C/B rooms 203 and 205, which demonstrated that perforation or scabbing could not occur.

594. As part of my assessment, I also sampled the analysis of C/B room 450 in the Barrier Substantiation Report revision 5 (Ref. 90) and the Civil Structure Evaluation Report revision 1 (Ref. 170) and found no errors. The analysis conceded the failure of the Class 1 slab by scabbing, which is not appropriate unless it is confirmed that there is no potential to impact delivery of the FSFs. This should be either by implementation of additional protection measures, selecting appropriate locations for SSCs or SSC qualification. I therefore, refer to an assessment finding on this topic raised elsewhere in this report (**AF-ABWR-IH-11**).

595. The response to RQ-ABWR-1445 (Ref. 252) included a swing load assessment for the R/B crane as a typical lifting device, carrying the Reactor Well Shield Plug E (146 tons) and assumed a barrier thickness of 0.25 m for the load travelling at 0.332 m/s and behaving as a sharp missile upon impact. I judged that the above example is a more realistic representation of swing loads on divisional walls than the one originally used, and was satisfied that neither perforation nor scabbing would occur.

596. I also assessed, from an internal hazards perspective, the RP’s submissions associated with the resolution of RO-ABWR-0056 (“*Demonstration that adequate optioneering has been carried out for the removal of Spent Fuel from the Reactor Building*”). As part of this RO, the RP was requested to demonstrate that the risks associated with the following activities had been reduced to ALARP:

- The import of equipment into the R/B for the removal of spent fuel;
- Removal of the spent fuel out of the SFP;
- Loading of spent fuel into the transfer container; and
- The export of the spent fuel from the R/B.

597. The above activities involve a number of heavy lifts over Class 1 SSCs, divisional boundaries and the SFP, and it was therefore relevant to the internal hazards assessment. RO-ABWR-0056 Action A.2 (for the RP to provide a robust demonstration

to show that adequate optioneering has been undertaken for the loading of spent fuel into the transfer container) had a particular focus on internal hazards.

598. The assessment of the optioneering performed on the transfer of spent fuel is primarily presented in the spent fuel interim storage, fault studies and C&I assessments (Refs. 258, 259 and 260), respectively. This includes the assessment of key submissions in this area:

- Spent Fuel Interim Storage Optioneering for Spent Fuel Removal from Spent Fuel Pool (FRE-GD-0080) to Outside of Reactor Building, revision 3 (Ref. 245);
- Fuel Route Layout and Fuel Pool Cooling (FPC) System ALARP workshop reports (UE-GD-0414) revision 1 (Ref. 247); and
- Reactor Building Truck Bay Cask Drop Impact Evaluation Report (LE-GD-0251) revision 0 (Ref. 261).

599. From an internal hazards perspective, I sampled the following:

- The optioneering performed by the RP to demonstrate that the transfer of spent fuel over the SFP reduced the risks to ALARP; and
- The capacity of the transfer cask and cask bay to withstand a drop during export activities, which involve a 21m lift.

600. The lifts associated with the transfer of spent fuel from the SFP to the Truck Bay are presented in the Topic Report on Dropped Loads of NSCs revision 1. This report included the key input information e.g. mass and height, and the predicted consequences. The assessment of the Cask drop on to the Truck Bay performed during Step 4 of GDA had concluded that the structure would not withstand the impact and would be perforated.

601. The RP subsequently performed a Finite Element Structural analysis for the drop (as presented in the Reactor Building Truck Bay Cask Drop Impact Evaluation Report (LE-GD-0251) revision 0. (Ref. 261). This assessment concluded that an increase in the thickness of the slab by 300mm (from 1500mm to the full depth of the beam support 1800 mm) was required to prevent perforation and would be implemented. An impact limiter was also incorporated to the design (although this is not credited in the above consequence assessment). I am satisfied that the Class 1 structure was substantiated following the above design changes. In addition, I consider the RP's assessment that vibration hazards following a Cask dropped load would not prevent delivery of the FSFs as a reasonable conclusion.

602. With the RP having substantiated the structure against the unmitigated drop, I was satisfied that the internal hazard aspects had been addressed appropriately. However, the RP's safety claims for the fuel export route rely on the R/B crane having a probability of failure on demand of 10^{-4} per year. This represents a key assumption in the Spent Fuel Export case and is subject to confirmation during detailed design. To prevent difficulties in substantiation of the crane with the required level of reliability impacting the extant case, the Civil Engineering assessor sought confirmation that the hoist well could be made larger to prevent foreclosure of design modifications. This was raised in RO-ABWR-0080 (Ref. 262) and the assessment is presented in ONR-NR-AR-17-013 – Step 4 Assessment of Civil Engineering for the UK ABWR (Ref.131).

603. In relation to hazards associated with drops on to the SFP, which were to be addressed as part of RO-ABWR-0056, Action 2, the RP carried out optioneering to determine whether the layout of the R/B could be improved to reduce the risk from the extant design. During Step 4 of GDA, the RP provided the Fuel Route Layout and Fuel Pool Cooling (FPC) System ALARP workshop reports (UE-GD-0414) revision 1 (Ref. 247).

604. I considered that some aspects from the IAEA Safety Guide Safety Guide NS-G-1.4 (Ref. 263) were not clearly reflected in the extant design. Specifically, that the design would minimise the number of lifts and transfer operations over the SFP. The RP had presented three options aimed at reducing the number of transfers but these were described at a high level only:

- Option 1 involved the use of transfer baskets. The RP discounted this option because it deemed it to result in higher risk than the baseline design (due to the handling of a higher number of fuel assemblies per lift).
- Option 2 (relocation of the cask pit to reduce the fuel handling distance within the SFP) was discounted using a qualitative description i.e. "*these options would tend to increase the handling of the cask around or over the SFP*". The various cask pit and preparation pit locations were not presented.
- Option 3 (to bring the storage racks next to the SFP gates, which was clearly undesirable.

605. I therefore requested the RP to provide the following:

- The alternative Cask Pit locations for cask preparation as per Option 2 and the movements/ transfers over the spent fuel racks associated with them.
- The list of handling/ lifting operations (involving spent fuel or else) that are carried above the SFP racks after incorporating the options proposed in the optioneering studies.
- A justification as to why transfers over spent fuel racks are considered unavoidable, and the storage layout modifications, transfer paths and zonal restrictions etc. related to the case.

606. The RP responded in Ref. 264. This provided an improved description of the transfer path and the options considered as part of the optioneering studies. It also considered additional options to move the Cask Pit from the SFP, including to locations outside the SFP. Based on the evidence provided, I was satisfied that the additional options would result in higher risks to the spent fuel due to the potential handling of the Cask Pit gate over the spent fuel racks and rejection was appropriate.

607. The RP also confirmed that the extant design offered sufficient space for an impact limiter to be fitted in the Cask Pit (in a similar approach to that fitted in the Cask Bay following resolution of RO-ABWR-56). The RP also provided a reference to support that a suitable interlock would prevent cask drop into SFP ("Basis of Safety Cases on Fuel Handling Systems and Overhead Crane Systems" (M1D-UK-0006) revision 4 (Ref. 265).

608. Considering the above evidence, I was satisfied that RQ-ABWR-1196 had been responded appropriately and I closed RO-ABWR-56 Action 2.

609. The RP's reply to RQ-ABWR-1445 (Ref. 252) provided a simplified assessment of the response of the Operating Deck (Floor 4F) slab in the R/B against the 146.5t lift load, which is heaviest segment of Reactor Well Shield Plug (RWSP). The calculation was based on a 2.5m lift height. The results showed that the impact shear force exceeded the beam shear capacity at the mid-span by 6% and subsequently at the supports.

610. I discussed the calculation with the Civil Engineering assessor (Ref. 266), who considered it to be simplistic but also that it had used conservative assumptions in both the design of the structure and the analysis. The Civil Engineering assessor also judged that the calculations showed that the RP would need to implement design changes (strengthen the structure) or restrict the lifting operations unless further analysis was conducted. It was nevertheless pointed out that there was scope for more sophisticated analysis, e.g. Finite Element Analysis (FEA), to substantiate the barrier.

611. As the analysis was not performed and the Class 1 barrier had not been substantiated to meet the expectations of ONR SAPs, I raised the issue as part of a Regulatory Observation on the substantiation of Class 1 barriers (RO-ABWR-0082). Following this RO, the RP proposed changes to the Operating Deck design, and performed additional calculations according to the following base assumptions:

- The thickness of the slab was increased to provide the required capacity;
- The RP considered the drop as close to the supports as physically possible (these supports had been previously been found to fail in shear);
- The RP considered a fairly average concrete strength (C35/45); and
- The slab being impacted was assumed as one-way spanning.

612. The RP presented the results in the Internal Hazards Barrier Substantiation Report revision 5 (Ref. 90) and the Civil Structure Evaluation Report for Barrier Substantiation, revision 1 (Ref. 170). I discussed the approach with the Civil Engineering assessor, who considered it to be sufficiently conservative, particularly given the one-way spanning assumption and the concrete strength used in the assessment (likely to be of a higher strength for the R/B). He also concluded that, although the shear utilisation for an impact close to the supports was 0.97, the majority of utilisation factors showed a good degree of safety margin. In his view, more sophisticated analysis e.g. a global FEA model would show far greater safety margins (Ref. 266).

613. The Civil Engineer also noted that the Civil Structure Evaluation Report (Ref. 170) had stated that the input parameters for barrier assessment were based on an earlier version of the General Arrangement drawings for the Design Reference Point, October 2015 (Ref. 267). He considered that there would be multiple changes to the Design Reference Point based on ongoing work from the civil engineering and internal hazards teams during GDA and, as a result, there was a need to ensure the barrier design would not be compromised. On that basis, Civil Engineering has raised an assessment finding to address the gap (Ref. 131).

614. Based on the conservative approach used to define the dropped load and the civil engineering assessor's judgement on the RP's target response analysis, I am satisfied that the expectations of the RO-ABWR-0082 on barrier substantiation were met.

615. In the UK ABWR there are hatches across divisional slabs to transfer equipment during maintenance operations, e.g. in the R/B: R-F-3F-615C, R-F-2F-520, R-F-3F-654A and R-F-1F-459. There is also a case where a divisional boundary is located below the hatch opening (R-F-2F-520 below R-F-3F-615C). The RP substantiated the divisional slab against this lift over several floors in revision 4 of the Topic Report on Dropped Loads (Ref. 47).

616. In the Hx/B, the RP identified barriers H-F-1F-409A and H-F-1F-409B required additional reinforcement (from 25mm to 32mm) for substantiating them against dropped loads.

617. The RP's case for cross divisional effects during the lifts across divisional hatches relies on the short duration of the task, which is performed where there are limited demands on SSCs. As part of RO-ABWR-0012, the RP undertook an exercise to reduce the number of doors through Class 1 barriers. During GDA, the RP also undertook an exercise to remove HVAC penetrations through Class 1 barriers as far as is reasonably practicable (Ref. 82). However, given the design of the UK ABWR, I consider that there is virtually no scope for eliminating the hatches without grossly disproportionate changes to the generic design. Although, I am reassured by the short duration of the task, the state of the reactor during maintenance and the level of barrier substantiation provided as a result of RO-ABWR-0082, I have raised an assessment finding to ensure that the future licensee develops the specification of the hatches

during detailed design, to prevent damage to SSCs during lifting operations in the R/B. This is captured in the **AF-ABWR-IH-03**.

4.9.3 Outstanding issues

618. All outstanding issues identified by the RP in revision 3 of the Topic Report on Dropped Loads and revision 0 of the Topic Report on Dropped Load Assessment of NSCs (revision 0) were resolved as part of RO-ABWR-0082 (Ref. 9).

4.9.4 Assessment Findings

619. No additional assessment findings have been raised as part of the assessment of the RP's dropped loads safety case.

4.9.5 Conclusions on the Dropped Load Assessment

620. During Step 4, the RP undertook a significant amount of work to identify and characterise the response of the UK ABWR structures to dropped load impacts.

621. The methodology was based on the R3 Impact Assessment Procedure to determine the response of Class 1 barriers against impacts and conservatively assumed sharp bullet behaviour of the dropped item. This initially resulted in the conceded failure of a number of barriers by perforation and scabbing including the R/B Operating Deck and the Cask Bay during the 21m lift of cask loaded with spent fuel.

622. Following design changes to reinforce the concrete slabs in the R/B, the C/B and Hx/B, the RP substantiated the Class 1 barriers against perforation, whilst scabbing was still predicted in a number of locations. I am satisfied that the design changes have prevented failure by perforation. However, during detailed design, it is necessary to substantiate SSCs in locations where scabbing is predicted. This is not restricted to dropped loads as highlighted in **AF-ABWR-IH-11**.

623. Based on the above and subject to resolution of the assessment finding raised elsewhere in this report, I judge that the RP has provided a suitable level of substantiation of the generic design of the UK ABWR against dropped loads. This work has aided closure of the dropped loads aspects in RO-ABWR-0082.

4.10 Exceptions to Segregation by Divisional Barriers

624. The primary means to prevent common cause failure from internal hazards is by segregation of the safety systems into divisions using robust RC barriers (divisional and non-divisional). This is reflected in RP claim **IH_SFS 5.7.2**. In the sections 4.1 to 4.9 of this report I assessed the suitability and sufficiency of this claim against the internal hazards considered in UK ABWR.

625. In the UK ABWR design there are a number of rooms that contain SSCs from more than one division, including SSCs of the same category and class supporting the same safety function. These areas and SSCs referred to as "exceptions to segregation". The most significant exceptions to segregation areas are inside the PCV, MSTR and MCR and these are assessed in sections 4.11 to 4.13 of this assessment report. All areas outside the PCV, MSTR and MCR are captured in the Topic Report on exceptions to segregation which is assessed here.

626. During Step 4 of the GDA, the RP submitted the following key documentation in the area of exceptions to segregation:

- The Pre-construction Safety Report (PCSR) (SE-GD-0127) revision C (Ref. 15); and
- Topic Report on Exceptions to Segregation revisions 2 and 3 (Ref. 24 and 25).

627. I subjected all the above submissions to assessment as discussed below.

628. In the following sub-sections I will cover the following:

- The RP's safety case on exceptions to segregation;
- My assessment of exceptions to segregation safety case; and
- My conclusions and assessment findings.

4.10.1 RP's Exception to Segregation Safety Case

629. The RP's internal hazards safety case claims are given in section 3.2 of this assessment report. The safety case on exception to segregation is principally based on claim **IH-SFC 5.7.3** – "*Where there are exceptions to physical segregation, sufficient A-1 or A-2 signals and equipment are available, during and after an Internal Hazard, to fulfil the Fundamental Safety Functions*".

630. Revision 3 of the Topic Report on Exceptions to Segregation focuses on all SSC falling within the exception to segregation principle. This included control and instrumentation, isolation valves, and SSC that relate to reactivity control. This included both A-1 and A-2 SSCs.

631. The Topic Report indicated that the assessment covered all GDA buildings (R/B, C/B, Hx/B, T/B, S/B, Fv/B, Rw/B, EDG/Bs and service tunnels) and all operational modes. The Topic Report concluded that for all exception to segregation of SSCs the internal hazard will not prevent the delivery of the FSFs. A number of engineering changes have also been identified.

632. Revision C of the PCSR (Ref. 15) covers this aspect at high level and largely referred to revision 3 of the Topic Report on exceptions to segregation.

4.10.2 ONR's Assessment of Exceptions to Segregation Safety Case Submissions

633. The assessment strategy in section 2 was used to formulate my assessment.

4.10.2.1 Scope of Assessment

634. My assessment covers all RP's submissions in this area. I assessed the PCSR and all revisions of the Topic Report on exceptions to segregation to obtain confidence on the requisite evidence and substantiation of the claim **IH-SFC 5.7.3**.

635. The areas chosen to assess the exceptions to segregation safety case were limited to the following:

- Overall assessment of exceptions to segregation safety case including analysis methodology; and
- Substantiation of claim **IH-SFC 5.7.3**.

4.10.2.2 Assessment of Exceptions to Segregation Claims, Arguments and Evidence

636. The scope of Topic Report on Exceptions to Segregation is to provide arguments and evidence to support claim **IH-SFC 5.7.3**.

637. Initially the RP submitted revision 2 of the Topic Report on Exceptions to Segregation (Ref. 24). I subjected this document into a detailed assessment and identified a number of shortfalls which I captured then in RQ-ABWR-1060 (Ref. 268). These can be summarised as follows:

- The majority of the exceptions to segregation involve control and instrumentation (C&I) components. Categorisation and classification of the C&I systems is key to adequate application of the principle of segregation, however, this is not explicitly addressed in the Topic Report. There was a lack of a high level design philosophy and methodology on the design approach for the exception to segregation and management of segregation of C&I systems between different C&I systems and between different divisions. There is also a need to consider the segregation of those electrical power supplies which support the SSCs.
- The specific internal hazards events causing loss of SSCs subject to exceptions to segregation were not discussed. The internal hazards safety case should systematically identify all internal hazards events, identify all SSCs affected by the event, assess the potential consequences and identify SSCs to deliver the FSFs, in line with ONR expectations in SAPs EHA.14 and ECS.2. In this context, appropriate claims, arguments and evidence should be provided (ONR SAPs para. 86). Appropriate defence-in-depth arguments and demonstration of ALARP should also be provided (SAP EKP.3). Furthermore, the Topic Report should explicitly address:

  - Single failure assumption and equipment unavailability due to maintenance in line with ONR SAPs EDR.1 and EDR.4.
  - Common Cause Failures in line with ONR SAP EDR.3.
  - Suitability and sufficiency of identified SSCs.

638. Given the significance of the above shortfalls, I raised RO-ABWR-0078 which captured the shortfalls and my regulatory expectations (Ref. 92). I included the following regulatory actions:

- RO-ABWR-0078.A1.1 - Provide a document with the design philosophy and rule sets which ensure that a systematic process is followed in the determination of segregation requirements for all C&I, electrical and mechanical SSCs.
- RO-ABWR-0078.A1.2 - Provide an internal hazards assessment in the exceptions to segregation report.

- RO-ABWR-0078.A1.3 - Provide the claims, arguments and evidence in support of the suitability and sufficiency of segregation, redundancy and diversity for SSCs identified and studied according to A1.1 and A1.2.
- RO-ABWR-0078.A1.4 - Provide an ALARP justification.

639. The RP responded positively and developed a resolution plan which detailed the work to be undertaken, the documents affected, and included a programme of submissions. All the above actions were responded in revision 3 of the Topic Report on Exception to Segregation, which also included the responses to RQ-ABWR-1060 (Ref. 269). Revision 3 of the Topic Report on Exceptions to Segregation presented the following:

- High level design requirements for all SSCs that support FSFs;
- A methodology for assessment of all SSCs falling into this category;
- Assessment of all C&I, isolation valves and reactivity control SSCs falling within the exception to segregation principle.

640. The RP's design requirements are in the form of Mechanical Engineering Safety Property Claims (SPC) for all SSCs. The application of the SPC depends on categorisation and classification of the SSCs, the type of SSC (e.g. mitigated systems) and the nature of the events to which the SSC is expected to respond (e.g. frequent, infrequent, Beyond Design Basis). The RP also defined reliability requirements for each SSC type and listed those relevant to exception to segregation: measures against single failure, measures against common cause failure, interfaces between safety classes, and internal hazards protection. Specific to protection against the internal hazards (Mechanical Engineering SPC 4), the RP listed the design requirements for each SSC type which included:

- Class 1 systems that mitigate the effects of frequent faults or infrequent faults and that prevent the occurrence of events that lead to exposures above the BSL, are designed with physical separation between the redundant divisions.
- Class 2 systems that mitigate the effects of frequent faults are designed with physical separation against hazard sources.
- Class 2 systems, relatively to the equivalent Class 1 systems that mitigate the effects of frequent faults are physically separated from their equivalent alternative systems.

641. The GDA ALARP methodology has been applied in the assessment of exception to segregation SSCs which included the following parts :

- Part 1: Identification of all exceptions to segregation:

    - Identification of all A-1 and A-2 SSCs that do not comply with the above design requirements for internal hazards.
    - Undertaking risk assessment which includes identification of internal hazards and SSCs affected, determination of the overall importance to safety of each exception to segregation SSCs and identification of alternative systems that can support the functions of SSCs when lost due to an internal hazard.

- Part 2: Identification of risk reduction measures. This included definition of relevant good practice, identification of risk reduction measures, consideration of whether measures are reasonably practicable, implementation, further measures and proposed ALARP solution.
- Part 3: Summary.

642. The Topic Report on Exceptions to Segregation applied the above methodology for the following systems:

- Leak Detection System (LDS);
- Main Steam Line low piping pressure monitors;
- Safety Process Radiation Monitoring (SPRM) system;
- Fuel Pool Cooling (FPC) system;
- Turbine electro-hydraulic system (EHC);
- Extraction Steam (ES) system;
- High Pressure Core Flooder (HPCF) system;
- Safety System Logic and Control (SSLC) system;
- PCV Boundary valve;
- Primary Containment Isolation System (PCIS);
- Suppression Pool Clean-up (SPCU) system;
- Residual Heat Removal (RHR) system;
- Fuel Pool Cooling and Clean-Up (FPC) system;
- Control Rod Drive (CRD), Alternative Rod Insertion (ARI) and Stand-by Liquid Control (SLC) systems; and
- Flooder System of Specific Safety Facility system (FLSS).

643. The RP concluded that for each exception to segregation sufficient systems remain available to deliver the FSF. The RP also identified a number of design changes. Those relevant to valves (Engineering Change 1, 2, 3 and 5) were captured in AIRIS as IH-IR-0011- “Reflection of Design Changes Raised in Topic Report on Exceptions to Segregation (BKE-GD-0021 revision 3)”.

644. I subjected revision 3 of the Topic Report on Exceptions to Segregation to an assessment and I am overall content that the RP applied in a systematic manner the assessment methodology for all identified systems against internal hazards. I sampled the CUW flow transmitters and the PCIS CUW valves, and I satisfied myself that the conclusions reached by the RP are reasonable.

645. Regarding the CUW flow transmitters, outlet and blow down monitors from all four electric divisions are in the R/B hazard compartment RB2001 as shown in Reference 25. The RP identified that an internal hazard affecting this compartment can result in the loss of all 4 outlet flow transmitters. This will result in a differential flow reading with the inlet flow monitors which are segregated (3 of them are in separate hazard compartments) and then will trigger PCIS isolation. The RP has also provided segregated diverse systems (the Low Reactor Water level monitors in segregated hazard compartments RB1001, RB3001 and RB4002) as a defence-in-depth measure to detect LOCA from the CUW. On this basis, I am satisfied that the logic and defence-in-depth measure supports the RP’s conclusion, subject to confirmation of failsafe mechanisms during detailed design.

646. Regarding the PCIS CUW valves, the RP also identified an engineering change (EC2) which involves changes to the inboard and outboard valve power supply to eliminate the exception to segregation in this area. I noted, however, that the document did not include a hazard schedule. Therefore, the links between the claimed SSCs for each exception to segregation case and the fault assessment and design basis analysis (Refs. 99 and 270) are not transparent. I judge this as not in line with ONR’s SAP FA.8 and ESS.11 (para. 407) (see **AF-ABWR-IH-14**). I also noted that combined internal hazards were not considered in this Topic Report, but this aspect requires further consideration during the detailed design and I raised **AF-ABWR-IH-18** in section 4.14 below.

647. Overall, revision 3 of the Topic Report provides sufficient evidence to substantiate claim **IH-SFC 5.7.3**, and to support closure to RO-ABWR-0078.

648. I also liaised with the C&I assessor who broadly concurred with my conclusions above, but who also raised a number of observations which are summarised below (Ref. 271).

- The options considered and the level of justification in the optioneering studies is not always sufficient.
- The hierarchy of measures has not always been applied. For example wrapping of cables is a poor alternative to routing a cable to avoid a hazard.
- A number of exceptions to segregation were judged as adequate but the justification was inadequate; e.g. the CST level transmitters being wired down the same tunnel.
- The impact of the changes made, if any, was not explicitly considered.
- Where claims are made, these need to be carried forward to requirements for detailed design. For example, sensors are failsafe. Where failsafe behaviour of sensors is claimed, there must be a defined mechanism by which failsafe behaviour is achieved.

649. Whilst I am overall content with the work undertaken and the documents submitted within GDA in this area, I raised **AF-ABWR-IH-13** to capture the above points.

AF-ABWR-IH-13 - As the Requesting Party's case for exceptions to segregation relies on assumptions, design choices and failsafe considerations not fully developed in the Generic Design Assessment phase, the licensee shall provide evidence to justify that the risk presented by each exception to segregation structure, system and component is reduced to As Low As Reasonably Practicable. Appropriate consideration and justification shall be given to the options available, including consideration of the hierarchy of safety measures.

650. Based on the evidence available in the GDA submissions, I am content that resolution of the above gap is achievable by further analysis and consideration of SSC design options during detailed design (when vendor specific information on qualification and fail safe mechanisms will be available). I also judge that although minor design changes may be needed (selection of alternative SSCs or protection against internal hazards), these will not challenge the generic layout of the UK ABWR.

4.10.3 Assessment Findings

651. During my assessment one assessment finding was identified for a future licensee to take forward in their site-specific safety submissions. Details of these are contained in Annex 5.

652. These matters do not undermine the generic safety submission and are primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.10.4 Conclusions on Exceptions to Segregation Safety Case

653. I am broadly satisfied with the level of analysis undertaken and documents submitted in the area of exceptions to segregation during GDA. In response to RO-ABWR-0078, the RP developed an analysis methodology and considered, in a systematic fashion, all SSCs falling within the exception to segregation principle and demonstrated that sufficient systems remain available to deliver the FSFs. This forms the basis of my judgement that appropriate principles have been followed, from a generic design perspective, to identify and avoid exceptions to segregation so far as is reasonably practicable.

654. The design options discussed, however, have not been fully justified and their selection is based on high level qualitative arguments, which, for example, credit

failsafe behaviours subject to confirmation during detailed design to ensure that appropriate outcomes are achieved under the hazard conditions. Whilst I raised **AF-ABWR-IH-13** to address shortfalls, I judge that the RP has provided sufficient evidence to demonstrate that resolution will not require significant changes to the UK ABWR layout.

4.11 Internal Hazards Inside Primary Containment Vessel (PCV)

655. The PCV is a cylindrical Reinforced Concrete Containment Vessel (RCCV) in the UK ABWR Reactor Building (R/B).

656. The PCV is the primary containment boundary and encloses the Reactor Pressure Vessel (RPV), the Dry Well (D/W), Suppression Chamber (S/C) and Suppression Pool (S/P).

657. Nuclear safety against internal hazards inside the PCV is not delivered via segregation by barriers as all safety divisions come together in a relatively small space.

658. As in the case of other exceptions to divisional segregation, the RP has presented a dedicated safety case for this area. This case is discussed, together with my assessment of the Claims, Arguments and Evidence, in the sections below.

4.11.1 The RP's Internal Hazards Safety Case inside the Primary Containment Vessel (PCV)

659. The overarching Internal Hazard claim (**IH_SFC_5-7.1** "*Internal hazards will not affect the delivery of the Fundamental Safety Functions*") presented in section 3.3 is formally delivered, inside containment via **IH_SFC_5-7.2-4** "*Prevention, protection or mitigation arrangements ensure suitable and sufficient SSCs are available to deliver the Fundamental Safety Functions (FSFs) for the PCV*".

660. The claim is not delivered by barriers therefore layout, separation by distance, SSC design considerations, control and mitigative measures support the delivery of the claim for each internal hazard.

661. The RP considered that the **IH_SFC_5-7.2-4** claim is delivered if the following conditions are met:

- As a minimum, two lines of protection are provided (and remain available) to deliver the FSFs in the event of a Design Basis Fault. The principal means of delivery of the FSFs are claimed as Class 1, with supporting diverse means being Class 2. At least one line of protection is claimed for infrequent reactor faults.
- The RP applied the single failure criterion to Category A Class 1 systems when one of the redundant divisions is undergoing maintenance.

662. Specifically, demonstration that suitable and sufficient SSCs are available means demonstrating that, for any postulated internal hazard event, the above availability criteria is fulfilled by any (or all) of the following strategies:

- The extent and severity of the hazard consequences do not preclude the availability of lines of protection;
- Sufficient SSCs are qualified against the hazard loading and available to deliver their expected functionality under hazard conditions; and
- Sufficient SSCs are protected by other means (other than qualification) against the internal hazards so that their ability to deliver the FSFs remains unaffected.

663. The RP proposed that in the design of SSCs, the following measures are considered (in decreasing order of priority):

- Passive measures;
- Automatic engineered safety measures;
- Manual engineered safety measures;
- Administrative safety measures; and
- Risk reduction measures.

4.11.2 ONR's Assessment of Submissions of the Internal Hazards Inside the PCV

4.11.2.1 Scope of Assessment

664. The RP's assessment is presented in the Internal Hazards inside the Primary Containment Vessel (PCV) Topic Report. The Topic Report provides a hazard-by-hazard assessment including fire and explosion, flooding, internal blast, steam release, internal missiles, pipe whip and jet impact and electromagnetic interference.

665. During Step 4 of GDA, the RP submitted the following key documentation to support the Internal Hazards case inside the PCV:

- The Pre-Construction Safety Report (PCSR) revision C (Ref. 15);
- Topic Report on Internal Hazards inside the PCV, revision 2 and 3 (Refs. 71 and 72);
- Pipe Whip and Impact Evaluation Evidence Document revision 0 to 2 (Refs. 272, 214 and 273); and
- Multiple Piping Break Evaluation of Reactor and Containment for Structural Integrity Classification revision 0 (Ref. 274)

666. As part of my assessment, I assessed the Topic Reports and the PCSR sub-chapter. I also sampled the supporting documents to gain confidence that sufficient evidence was available to substantiate the applicable claim **IH_SFC_5-7.2-4**. Effectively this meant forming a view on the evidence provided by the RP to support that:

- The extent and severity of the internal hazard does not preclude the availability of the claimed lines of protection.
- There is evidence that the SSCs (either by qualification or protection) are able to operate as intended under the conditions of the internal hazard scenarios.

667. In order to gain confidence in the case, I focused my sampling on the following key points:

- The input data, underpinning assumptions and hazard characterisation methodologies;
- The predicted extent and severity of the consequences for each internal hazard in turn;
- The impact criteria used to judge availability and performance of claimed SSCs under the conditions of the hazard; and
- The potential for event combination and escalation given the separation distance between hazard sources / lack of segregation inside the PCV.

668. The sections below cover the areas of my assessment.

4.11.2.2 Assessment of Claims

669. I assessed the RP's claims and arguments relating to internal hazards inside the PCV and I observed the following points.

670. The claim made inside containment is a high level claim and applies generically to each internal hazard. The means of delivering the claim vary depending on the internal hazard. Thus the overall substantiation involves a balance between provision of sufficient separation distance, qualification and/ or protection of SSCs to ensure that suitable lines of Category A Class 1 and 2 SSCs remain available in accordance with the frequency of the originating event.

671. A hazard schedule for the PCV is provided in the Topic Report on Internal Hazards inside the PCV revision 2 and 3 (Refs. 71 and 72). This hazard schedule summarises the hazard reference, frequency, unmitigated consequences, hazard safety function,

the categorisation and classification of the safety function in light of its nuclear safety significance, and the mitigated consequence. It is broadly aligned with my expectations.

672. I sampled the level of alignment of the claims with the evidence provided to form a view as to whether the categorisation and classification of the claimed hazard safety function were in line with ONR's SAPs specifically ECS.2 and FA.9.

673. In the event of fire, the claim is supported by consequence analysis and the limited combustible inventory within the PCV, which is claimed to prevent challenge to A-1 functions. Given the limited inventory, the RP considered that, in this case, the hazard function does not require categorisation and classification at the A-1 level. I am satisfied that the above provision is suitable, providing that suitable and sufficient consequence analysis supported the limited extent of effect from a fire event inside containment. My assessment of the fire analysis evidence is provided in the section below.

674. I also sampled the level of alignment between the overarching claim and the hazard safety functions claimed in relation to internal flooding and pipe whip. Generally, the RP has claimed all SSCs (including penetrations) requiring availability and performance in LOCA conditions as a Category A Class 1 function. Further defence-in-depth is claimed by means of venting between the D/W and S/C, which act as drains with a nuclear safety categorisation and classification of C-3.

675. Regarding pipe whip, the RP has claimed that suitable and sufficient safeguard systems remain available to maintain the reactor in a safe state and the protection of Class 1 safeguard systems according to incredibility of failure claims (Very High Integrity claims on the Main Steam Line between the reactor shield and the Reinforced Concrete Containment Vessel, RCCV) and Pipe Whip restraints in the Reactor Pressure Vessel (RPV) nozzles as an A-1 function.

676. The above approach is reasonable, in principle, providing qualification of SSCs in the harsh conditions of a LOCA is achievable and substantiated (for the flooding hazard scenarios), and internal hazards including pipe whip cannot credibly fail VHI components.

677. My assessment of the arguments and evidence related to these claims are again provided for each internal hazard in turn in the sections below.

678. Overall, the RP has acknowledged that the hazard schedule presented is not complete and that it had only included representative cases. Specifically, in my sampling of the claimed hazard safety functions, I could not locate a LOCA below Top of Active Fuel for example, which had been included in the Topic Report on Design Basis Analysis revision 10 (Ref. 275) and were further sampled during Step 4. As a result, it is appropriate to raise an assessment finding for the future licensee to address the gaps in the hazard schedules:

AF-ABWR-IH-14- As the Requesting Party has not fully developed the hazard schedules for each internal hazard during Generic Design Assessment the licensee shall complete them to ensure the following:

- **Appropriate reference is provided to all internal hazard events in the UK ABWR design basis;**
- **The specific location and extent of the hazards is appropriately documented;**
- **All claimed safety measures and remaining systems to deliver the Fundamental Safety Functions are explicitly documented.**

679. Notwithstanding the above, I consider that the claims and arguments presented in the latest revision of the Topic Report of Internal Hazards inside the PCV (Ref. 71) are generally adequate and aligned with ONR SAPs.

4.11.2.3 Assessment of Arguments and Evidence

Fire & Explosion

680. The RP's case for fire inside containment as presented in revision 3 of the Topic Report (Ref. 72) was developed using the lubricant and cable inventories collated in the Room Data Sheets for the R/B (Ref. 174).

681. The hazard range includes fires associated with pool fires and cable fires. These were characterised according to the source and the potential Category A functions affected. The results presented included the assessment of a single scenario: a Reactor Internal Pump (RIP) upper hoist gearbox leak (16 l) into either the PCV sump or pits, with ignition, and potentially impacting the following SSCs: Fine Motion Control Rod Drive (FMCRD) Handling Equipment, RIP motor elevator above the lower drywell (D/W) and PCV Sump delivering Category A criticality control (at around 8m above the fire) or Neutron monitor cabling and RIP cabling (10-11m above the sump). The RP used the US National Fire Protection Association's guidance document for pool fire calculations and US NRC's NUREG 1805 Fire Dynamics Tools (Ref. 132) to predict flame heights and plume centreline temperatures.

682. Whilst fire spread as a result of flame impingement on cabling was also considered, the RP stated that most types of cables to be used on UK ABWR would be rated up to 230º C before they short-circuit; they would also be high above the fire to prevent direct impingement and would therefore remain unaffected. I queried this assumption in RQ-ABWR-1400 (Ref. 276) as the cables would lose functionality (e.g. as a result of cabling insulators melting/ failing locally). The RP provided an assessment of the consequences to safety systems from failure of FMCRD cabling and a simultaneous neutron monitoring cabling failure. It also provided bounding arguments which documented the means to ensure reactor scram, and this did not credit any degree of protection to cabling from its encasement in metal conduits or from the inert atmosphere in the PCV during power operations. I am also content that there are further levels of defence-in-depth available e.g. the PCV spray mode of the RHR (a Class 2 system), which is not formally claimed and can be manually initiated to supress fires when the inert nitrogen blanket is not deployed (outages). In my view, the representative scenario chosen has been substantiated in line with expectations in ONR's SAPs EHA.1 and EHA.16.

683. The R/B Room Data Sheets (Ref. 174) contains evidence of the generally very small quantities of additional combustible inventories inside the PCV. The RP then studied the potential for pool fire escalation by impingement on cables or SSCs and this is presented the Topic Report on Internal Hazards inside the PCV revision 2 (Ref. 71). However, the topic report does not discuss the relative position and local impact on SSCs from fires involving other marginally smaller combustible inventories in the PCV e.g. the Control Rod Drive (CRD) Handling Equipment gear lubricants (separate inventories of 8.8 and 14.5 litres, amongst other small quantities) or the RIP motor elevator (guide screw lubricant 3 kg, and smaller 1 and 2 litre inventories). It also did not provide evidence relating to potential fire spread between lubricant inventories. I therefore consider appropriate to include this as an assessment finding for the future licensee to address this shortfall (see **AF-ABWR-IH-01**).

684. Regarding cable fires, the RP applied the distances between raceways defined in IEEE-384 (Ref. 277). In revision 2 of the Topic Report (Ref. 71), the RP stated that a minimum of 300mm horizontal distance and 500mm vertical distance for crossing

raceways and 1500mm vertical distance for parallel raceways would be used. I concur with the RP assessment that these distances are considerably larger than the minimum of 25mm stated in IEEE-384 when the source of ignition is a fault in electrical equipment. However, in the event of a developed fire, fire spread could not be discounted on these distances alone. This is captured in **AF-ABWR-IH-01**.

685. Overall, I am satisfied with the fire and explosion assessment set out in the Topic Report, which I considered meets the expectation of ONR's SAPs EHA.1, EHA.6 and EHA.14 with the exception of those items highlighted in the Internal Fire assessment finding regarding combustible inventories (**AF-ABWR-IH-02**) and the specific points regarding the analysis inside containment raised in **AF-ABWR-IH-01**. Whilst the assessment findings highlight shortfalls in the current fire analysis inside containment, given the small lubricant inventories involved inside the PCV, I judge that full substantiation is achievable by further analysis and/or minor changes such as SSC qualification or protection without significant changes to the containment layout.

Internal Flooding

686. The Topic Report on Internal Hazards inside the PCV revision 2 (Ref. 71) documented the analysis methodology and key findings for internal flooding. The identification of flooding sources included pipes or vessels containing water or steam within the PCV, with the exception of VHI components. It subsequently postulated flood scenarios, and concluded that, during power operations the most severe immersion consequences are bounded by the postulated Loss of Cooling Accident submitted by the RP as part of submissions in the Fault Analysis area (Ref. 259).

687. The withstand of the Reinforced Concrete Containment Vessel (RCCV) against the LOCA loads was documented in an Structural Integrity submission "Internal Structures of Reinforced Concrete Containment Vessel" (Ref. 278). Within the Internal Hazards discipline, my assessment targeted the internal loads assumed for Structural Integrity and Civil Engineering substantiation of SSCs. The RP provided tables with LOCA loads on the RCCV and followed ASME B&PVC Sec. III Division 2 (Ref. 227) and NUREG-0800, Concrete Containment revision 4 (Ref. 212).

688. Regarding the Civil Engineering aspects, the Engineering Supporting Report Reactor Building Hydrodynamic Vibration Analysis Report (JE-GD-0117) revision 2 (Ref. 279) used the time histories from internal hazards loads corresponding to Annulus Pressurisation (AP) Condensation Oscillation (CO), Chugging (CH), Horizontal Vent and Safety Relief Valve (SRV) loads as an input to the vibration analysis. As part of my sampling, I checked the jet impingement force against the values predicted by the R3 Impact Assessment Procedure (Ref. 175) assuming an unexpanded jet and I was satisfied that the values used were suitably conservative. I also sampled the peak SRV load against bounding calculations using R3 and was satisfied the values presented were suitably conservative on that specific parameter.

689. The report did not provide the derivation of the time histories and I therefore raised RQ-ABWR-1357 (Ref. 280). In response, the RP provided a submission (ASE-GD-0059) revision 0 (Ref. 281), which provided linkage to the Mark III confirmatory test program and the additional test performed to address the differences with the ABWR (Ref. 281). I judged that the document presents a reasonable appreciation of condensation oscillation, chugging and SRV actuation and I am therefore satisfied that the analysis provided by the RP is reasonable within the scope of GDA.

690. The Topic Report on Design Basis Analysis (DBA) (UE-GD-0219) revision 10 - Attachment J (Ref. 275) identified a fault [LOCA (mechanical) below Top of Active Fuel (TAF)] which was considered to result in flooding of the lower Drywell (D/W) and the

R/B during shutdown modes unless the access hatch to division III via R/B room 216 was closed and sealed.

691. Following fault identification, mobilisation of resources, closure of airlocks, the RP considered that it would take an additional 2 hours to close the access hatch. Given the lower D/W capacity and the total time to successfully isolate the tunnel, I judged that water may flow out of the lower D/W, through the tunnel and into the R/B (via room 216) before closure and sealing of the access hatch is achieved. Following the break, water injection via trains of RHR, HPCF or LPFL is required to prevent uncovering of active fuel in the core.

692. I judged that, if the hatch could not be closed, large inventories of water would eventually accumulate within the R/B leading to levels exceeding the hydrostatic load rating of divisional barriers on the B3F level. Although the Topic Report on DBA revision 10 (Ref. 275) clearly identified the potential for flooding of the R/B as a result of the above fault, it stated that the consequences to the R/B would not extend beyond loss of safety division III. This is not compatible with the extent of flooding if the barriers fail.

693. I raised RQ-ABWR-1165 (Ref. 282) for the RP to demonstrate how the claims in the internal flooding case in the R/B could be met, including demonstration that the hatch design and operations required reduced the risk to ALARP. In its response (Ref. 283), the RP acknowledged that all divisions of RHR could be eventually lost and assumed that A-2 SSCs would then be available. It also stated that changes to the design of the hatch or PCV would introduce significant risks.

694. Revision 3 of the Topic Report on Internal Hazards Inside the PCV (Ref. 72) noted that the access hatch would only be open when maintenance activities are taking place, the flood would be recognized quickly and an action to close the hatch would be promptly instigated. It also stated that the human error aspects of the task would be addressed in the site specific safety case, and the flooding hazards and consequences were confined within the PCV. I subsequently raised RQ-ABWR-1400 (Ref. 276) and extended my query for the RP to consider flooding from LOCA above TAF as well as below TAF, as the Topic Report on DBA revision 11 (Ref. 284) acknowledged that flow rates and maximum volumes for LOCA above TAF exceeded the capacity of the lower D/W and would flow through the tunnel.

695. The RP’s response to RQ-ABWR-1400 (Ref. 285) concluded that the risks were considered to be ALARP because the pressure boundary is at low pressure during outages, the access tunnels are normally closed unless maintenance activities are taking place and the flooding event would be identified locally by personnel. It also stated that other measures described in the response to RQ-ABWR-1305 (Ref. 286) would be considered such as: tools to improve the hatch closure process/ task duration times and introduction of additional drainage systems to the lower drywell. Analysis and implementation were deferred to post GDA.

696. As the above related to a generic design matter, I raised RQ-ABWR-1485 (Ref. 189) and requested that the RP described the options and provided evidence that they would not be foreclosed by the generic design.

697. The RP responded that the Design Basis Assessment Topic Report revision 14 (Ref. 270) would consider a slit break and leak from the Bottom Drain Line (BDL), not a guillotine failure (as the line would not be energised during shutdown). This was a late development in the RP’s case, which had so far considered a double ended guillotine failure of the line to be within the design basis. In the RP’s submission SE-GD-0645 (revision 2; Ref. 200), the RP stated that the frequency of small leaks from this Class 1 ASME III pipe would be of less than $1x10^{-5}$ per year and a major leak or guillotine break was considered to be less than $1x10^{-8}$ per year). Given that this revised

assessment discounted gross failure, I discussed with the structural integrity assessor who supported the view that a highest reliability claim could not be countenanced if the provision of engineered protection is reasonably practicable (SAP Paragraph 293 under EMC.2). Structural integrity have also raised an assessment finding to ensure that the scope of the structural integrity classification which may have been limited to power operation includes shutdown conditions and other plant states to be considered post GDA as given in ONR-NR-AR-17-037 (Ref. 215).

698. The RP's submission described a number of options including (Ref. 200):

- Temporary flood barrier systems within the equipment access tunnels;
- Mobile pumps to limit water level rise in the lower drywell and allow closure of the hatch; and
- Use of the LCW drainage sumps in the B3F corridor or submersible drainage pumps to discharge water into the S/P.

699. Furthermore, other options, including alternative means of isolating the flood path, have not been presented, may be reasonably practicable and should also be explored during detailed design. I have documented this in assessment finding **AF-ABWR-IH-15** below.

AF-ABWR-IH-15 - Flooding as a result of a Loss of Cooling Accident during outages has the potential to spread to the Reactor Building and exceed the design capacity of key Class 1 barriers. The licensee shall therefore develop and implement all reasonably practicable design options, including engineered measures, to prevent the spread of flooding from the Lower Dry Well to the Reactor Building.

700. I judge that the additional design options identified in GDA, which are subject to licensee choices and detailed design considerations, will be able to provide additional time for closure and should be adopted subject to reasonable practicability. During site licensing, additional engineering means of isolation e.g. valves or flood barriers should be explored in line with **AF-ABWR-IH-15** and implemented if reasonably practicable. It is on the basis that these options are available to the future licensee that I judge that satisfactory close out is achievable without significant changes to the generic layout and the shortfall does not merit a GDA issue to be raised.

701. Substantiation of the Internal Flooding claims inside the PCV relies on qualification of SSCs to deliver the expected functionality in a LOCA environment, including when subject to immersion / hydrostatic loads. The RP has not provided SSC substantiation, however, I am satisfied that this is a matter of detailed design which requires vendor information and is subject to licensee choices. It has also been adequately captured by the RP as an outstanding issue in revision 3 of the report and associated AIRIS entry (IH-IR-0010) to be addressed as part of normal business during licensing.

702. Based on the above, I am satisfied that the RP's internal flooding analysis for floods within the PCV is supportive of the claims made.

Internal Blast

703. The Topic Report on Internal Hazards inside the PCV revision 3 (Ref. 72) presented the assessment of blast overpressure from condensing chambers, SRV accumulators, Automatic Depressurisation System (ADS) accumulators and High Energy lines inside the PCV.

704. As part of RQ-ABWR-1400 (Ref. 276), I challenged the following aspects of the assessment presented by the RP:

- The calculations underestimated the overpressure values as the velocity of sound in air (as opposed to the velocity of sound in the high pressure gas i.e. steam) had been used.
- Criteria used to define SSC damage thresholds stated that sensitive equipment would not be seriously damaged when subjected to pressure below 50 kPa, which is much higher than those listed in the Gas Explosion Handbook (Ref. 180): serious damage to equipment including C&I components can occur at much lower thresholds (0.07-0.10barg for instrumentation, 0.20barg for C&I cabinets, C&I cabinets are overturned or destroyed at as low as 0.41barg and pipe supports / frames collapse at around 0.41barg).
- The RP did not explicitly identify the SSCs, systems and FSFs that could be affected and how the systems are protected against failure in the event of an internal blast. This effectively meant producing an equipment qualification schedule by the RP.
- To provide substantiation for the assumption that failure of the FDW lines, would not result in blast overpressures unless the superheat limit was reached at the time of rupture. The predicted peak overpressures were high (75-137kPa at 4m distance from the source). However, the RP had concluded that only the reactor safeguard systems in one half of the upper D/W could be affected.

705. The RP responded in Reference 285 by recalculating the blast overpressure for all high energy lines including steam systems where failure is postulated (excluding the MSLs where VHI claims apply). It also explained that it had assumed the most onerous conditions (design pressure and temperature). However, in practice, high energy lines inside the PCV would be operated below the superheat limit at all times, with the exception of the feed water lines, which could theoretically exceed the limit during start up. The RP also adopted a damage threshold of 7kPa and documented the blast effects on PCV instrument systems. As there are residual locations where the operating conditions may exceed the superheat limit, I judge that the following assessment finding is appropriate for the future licensee to support the ALARP justification:

AF-ABWR-IH-16 - As the peak pressures associated with Boiling Liquid Expanding Vapour Explosions (BLEVEs) or blasts following high energy line breaks inside containment could exceed the damage threshold for claimed structures, systems and components, the licensee shall develop plans, procedures and limits of operation to ensure that they are operated below the superheat limit with a suitable safety margin.

706. As part of my assessment, I also sampled the potential for multiple blast from high energy lines to affect other high energy systems, i.e. a single blast event causing a cascaded failure of accumulators, given the geometry and space constraints inside containment. Specifically, I challenged the relatively close proximity of 7 A-1 ADS accumulators condensing chambers, and the 7 additional A-2 accumulators introduced in the Reactor Depressurisation Control Facility (RDCF) system.

707. Considering that the specific location of these accumulators has not been fully defined within GDA, and the blast assessment did not identify the potential domino effect, I consider appropriate to raise an assessment finding so that the licensee selects their location in a way that consequential failures are prevented so far as is reasonably practicable. This should also include the potential for missiles in relation to the assessment below.

AF-ABWR-IH-17 - During the Generic Design Assessment phase, additional A-2 accumulators have been introduced in the Primary Containment Vessel to ensure Safety Relief Valve actuation during a station blackout. As the Requesting Party's internal hazard case inside the Primary Containment Vessel (PCV) discounts the potential for consequential blasts following a single blast

event, the licensee shall ensure so far as is reasonably practicable that single failure of an accumulator does not result in domino effects or unacceptable consequences to structures, systems and components.

708. Whilst the above assessment finding is a shortfall in the blast modelling conducted inside containment by the RP, I judge that further analysis (considering the accumulator locations) and minor changes to design (e.g. insertion of protection plates) will be able to achieve full substantiation without challenging the generic layout of the UK ABWR and therefore a GDA issue is not merited.

Internal missiles

709. Substantiation of the RP's Claim **IH_SFC_5-7.2-4** for the PCV against missile impacts requires substantiation that source locations and separation distances between redundant and diverse SSCs ensure that delivery of FSFs remains unaffected following an internal missile.

710. The Topic Report on Internal Hazards inside the PCV, Ref. 72, identified the following missile sources:

- the Drywell Cooling (DWC) system fans (in all operating modes);
- Instrumentation condensing chambers (during power operations); and
- SRV and ADS accumulators (which remain pressurised throughout all operating modes).

711. In RQ-ABWR-1400 (Ref. 276), I sought clarification on consequential effects from missile impact as the RP had considered that there would be no further damage to SSCs other than that from the initial impact. The RP had assumed that no deflections or secondary impacts in the congested PCV would cause damage to SSCs.

712. The RP acknowledged that following a condensing chamber failure, there would be multiple deflections from the RPV or the reactor shield wall. Although the impacts were not studied quantitatively, the limited space between the RPV and the reactor shield wall, and the location and vertical separation between the two types of condensing chambers (7m), reduced the potential for multiple condensing chamber failures.

713. Although I am content with the above justification for the condensing chambers, I judge that an assessment finding is appropriate to confirm that the potential for domino effects associated with the close proximity between blast / missile sources in the PCV including the additional accumulators. This is reflected in **AF-ABWR-IH-17** above.

Pipe Whip and Jet Impact

714. The RP's pipe whip impact case was presented in revisions 2 and 3 of the Topic Report as it evolved during Step 4 of GDA. The case was supported by additional submissions including:

- Pipe Whip and Impact Evaluation Evidence Document revisions 0 to 2 (Refs. 272, 214 and 273);
- Multiple Piping Break Evaluation of Reactor and Containment for Structural Integrity Classification revision 0 (Ref. 274);
- Associated RQs in internal hazards (RQ-ABWR-948, 1380, 1400; Refs. 287, 218, 276) and structural integrity (RQs-ABWR-1382, 1403, 1501; Refs. 220, 288, 289, respectively).

715. Following revision 2 of the Topic Report, I questioned the RP's conclusion that damage associated with pipe whip within containment would be restricted to one half of the PCV (RQ-ABWR-0948) as I did not consider this had been supported by evidence.

716. In RQ-ABWR-1400 (Ref. 276), I further challenged the RP to support the conclusion that consequential pipe breaks inside containment were BDB events, given that single High Energy Line Breaks (HELB) were conceded as infrequent events within the Design Basis (DB) and, in my view, the following points conflicted with the RP's conclusion:

- High energy pipes are in close proximity and not protected by barriers therefore pipe to pipe interactions leading to consequential failure could not be precluded on probabilistic grounds without analysis.
- There was not a clear indication of pipe behaviours following double guillotine break failure.
- The RP postulated pipe breaks at weld locations exclusively, however, failure at other locations e.g. intermediate points including locations of high stress or giving rise to bounding consequences (as a result of impact on SSCs) should also be considered.
- Without the presence of restraints, pipe whipping lengths could be seen to credibly impact several other pipes including smaller diameter pipes that, according to the assessment methodology should be conceded as consequential breaks.

717. In response to the above points, the RP reconsidered the pipe whip analysis in revision 3 of the Topic Report of Internal Hazards Inside the PCV (Ref. 72) and noted that, whilst not wishing to place a formal claim, the Drywell Equipment and Pipe Support Structures (DEPSS) would restrict the damage potential from pipe whip and prevent or limit the likelihood of consequential breaks.

718. In its response to RQ-ABWR-1400 (Ref. 285), the RP presented a detailed analysis for a high energy line break and whip case which, without consideration of the DEPSS, would result in up to 5 consequential line breaks. It also provided a list of high energy lines where consequential breaks could occur upon initial failure. The RP also substantiated a DEPSS column member against a single pipe impact.

719. Following the above analysis, and given the list of high energy lines within the PCV, I challenged the RP to demonstrate that DEPSS prevented all consequential breaks following impact by the initial pipe whip as the BDB assumption implied. This effectively meant providing evidence that the geometry and location of DEPSS members resulted in impact by the initial pipe whip before impact on smaller diameter pipes.

720. The RP acknowledged that there were areas of the PCV where protection by DEPSS was not available, and proposed revised pipe-to-pipe interaction criteria and a defined energy threshold below which breaks would not be conceded following impact. The energy threshold was derived from NUREG/CR3231 (Ref. 290) and was presented in revision 2 of the Pipe Whip and Impact Evaluation Evidence Report (Ref. 291). The RP also noted the perceived conservatism of application of NUREG/CR3231 to the UK ABWR design:

- Reactor pressures in the ABWR (8.62 MPa) are lower than the PWR conditions (15.90MPa) used in the tests;
- The narrower impact angles as a result of ABWR pipe layout than the 90 degrees used in the tests;
- No credit is taken for insulation or supports which would absorb a proportion of the impact energy;
- The assumed failure end point of the NUREG tests was detection of a through wall crack, not guillotine failure.

721. Following discussions with the structural integrity assessor, I judged that the derived impact energy criteria provided a level of assurance and link with experimental

observations, but there was sufficient uncertainty on its applicability to the UK ABWR design to preclude reliance on it for DBA. There was also evidence of NUREG/CR3231 guidelines being applied non-conservatively, as highlighted in the Structural Integrity Assessment Report (TRIM Ref. 215). I therefore requested that the RP presented the following:

- The consequences of conceding consequential breaks;
- The design features that could be credited or implemented to mitigate impact including additional supports or restraints; and
- Implementation of all reasonably practicable measures.

722. The RP provided further revisions of the Pipe Whip and Impact Evaluation Evidence Document (revision 2) and Multiple Piping Break Evaluation of Reactor and Containment for Structural Integrity Classification (revision. 1) to support that, given the postulated break locations (welds), whipping lengths and pipe behaviours, sufficient lines of injection remain available. The RP also clarified pipe behaviours and impact velocities as part of their response to RQ-ABWR-1501 (Ref. 290) which I considered adequate from an internal hazards perspective.

723. I also welcomed the RP’s assessment of the five multiple pipe impact cases studied in the Pipe Whip and Impact Evaluation Evidence Document revision 2 (Ref. 273). Feedback from my fault studies colleagues considered that the predicted consequences were bounded by existing LOCA analysis in their field: in 2 cases (where the Reactor Water Clean-up System, CUW, is impacted), a LOCA below TAF occurs with minor consequences as it occurs during power operations. In the other three cases, the fault studies specialist concluded that there would be no challenge for core cooling.

724. Given the level of demonstration provided for the postulated breaks, I am satisfied that the assessment is appropriate and an adequate demonstration has been provided for these selected cases. However, in line with the assessment presented in the Pipe Whip section 4.6, I judged that consideration of alternative failure locations including intermediate break locations may give raise to bounding consequences on SSCs which should be studied. I therefore consider that an assessment finding in this area is appropriate. This is covered by the broader assessment finding presented in the Pipe Whip and Jet impact section (**AF-ABWR-IH-10**). Whilst this is a shortfall of the RP’s analysis, the RP has demonstrated in the Fault Studies submissions (Ref. 259) that the plant is resilient to multiple pipe breaks. Minor design modifications such as improvements to structural properties or provision of the DEPPS, installation of pipe whip restraints and steel plate reinforcement could also be achievable in specific locations. On this basis, I judge that the shortfall can be addressed without significant challenges to the generic UK ABWR generic layout and does not merit a GDA issue to be raised.

725. In addition to the above points on the pipe whip analysis, there were a number of points raised during Step 4 that require substantiation and analysis during detailed design including:

- Substantiation of the whip restraints provided near nozzle areas of the MS/ FDW/ RHR, as the design specification has not been provided; and
- Confirmation that jet impact consequences are bounded by pipe whip.

726. The RP captured the above outstanding issues in AIRIS entries (IH-IR-0010).

727. With regards to jet impact modelling, the RP proposed the use of the ANSI Jet Model (Ref. 292) and provided an indicative calculation of the damage range for a 700mm with fluid pressure at 7MPa to justify that the effects will be bounded by pipe whip (revision 3 of the Internal Hazards Inside PCV Topic Report). A description of the jet

impact range associated with an alternative example (failure at weld W16MY impacting HPCF, FDW and RHR lines) was provided as a response to RQ-ABWR-1403 revision 1 (Ref. 293). Whilst I consider that there is a reasonable prospect that jet impact challenges to FSFs are bounded by the current assessment, I judge that it is appropriate to ensure that this gap is addressed as part of assessment finding **AF-ABWR-IH-10**.

Steam release

728. The RP steam release case inside containment is considered to be bounded by the assessment of LOCA scenarios and was provided as part of the fault studies submissions and therefore assessed by this discipline.

729. In the Internal Hazards Topic Report revision 3 (Ref. 72), the RP stated that there were no potential steam, pipe whip and jet impact sources during outages. Whilst I considered that this assertion reflects the overall position since the majority of the systems are depressurised during outages, the RHR will be operating at around 180ºC for around 20 hours and could therefore pose a steam release hazard albeit for a relatively short period of time. Submissions in the fault studies area (Ref. 270) also identified that, in the event of loss of decay heat removal, the steam generated could be released to outside of the R/B. However, depending on the condition of RPV and PCV, steam could also be released into the R/B. As my expectation is that all DBA faults that lead to steam generation would be considered in the internal hazards assessment, I raised the point in RQ-ABWR-1400 (Ref. 276).

730. The RP responded that, for the steam sources in the R/B, the RCIC and MS will not contain steam and the water temperature of CUW and FDW will be below 100^{o} C and therefore not posing a credible steam challenge. The RP then considered steam generated from the reactor well and SFP water on loss of decay heat removal during outages and pointed out that it would spread to the operating deck and areas of safety division I. It also acknowledged that, if hatches on barriers are open, it would spread to either division II or division III. Steam release paths through these divisions and to the atmosphere via the provided routes and blowout panels are assessed elsewhere in this report (section 4.5).

731. However, in a loss of decay heat removal fault or loss of an operating RHR train, the RP's case credits that injection via the FLSS is available (Ref. 270). I sampled the P&IDs relating to the FLSS route through the R/B for SFP injection (Ref. 294) and did not find active components in the steam release path other than check valves. Therefore, from an internal hazards perspective, I am satisfied that the RP has provided an adequate demonstration of the steam release case in that area to support injection via the FLSS. However, there are electrically driven valves in the RHR system upstream from the FLSS injection tie in to the Reactor Well (R/W) which may be affected by steam unless suitably qualified for the steam environment. This will be particularly the case if the loss of the operating train of RHR is as a result of a pipe break or leak. For injection to the R/W to be possible following the fault, the RHR system valves need to be in a closed position following the fault. The operability of the valves in the steam environment has not been discussed in the internal hazards case. The RP did not include the RHR as a steam release source (see section 4.5). Also, the steam release assessment in section 4.5 assumes that any SSCs in a steam release path would be affected and therefore not operable. Design, qualification and specification of the above components are matters for detailed design, however, as the requirement has not been identified, I consider that it is appropriate to include it in the assessment finding on steam releases (**AF-ABWR-IH-09**). Whilst this is a shortfall in the RP's assessment, I judge that protection and/or qualification of the above valves to operate in a steam environment is achievable without significant changes to the generic UK ABWR layout.

Dropped and Collapsed Loads

732. The topic report on Internal Hazards inside the PCV documented credible load sources inside the PCV which may impact Class 1 SSC components:

- Lifting of MSIVs and SRVs for maintenance operations outside the PCV using a pneumatic jack and trolley system;
- Lifting operations for the maintenance of DWC fans; and
- Handling of Fine Motion Control Rod Drive (FMCRD) and Reactor Internal Pump (RIP) components.

733. Revision 2 of the Topic Report on Internal Hazards Inside the PCV (Ref. 71) concluded that the FMCRD and RIPs were not considered sources of dropped loads. Consequently, I queried whether the RP had considered toppled loads (from the transport cart e.g. following incorrect attachment of the handling device). I was satisfied that the RP provided a description of the design including the handling cart, attachment and lowering operations, which confirmed that the load remains supported during lowering. The RP also confirmed that there is no Class 1 equipment in the area that could potentially be affected by the toppled/dropped load scenario.

734. Revision 3 of the Topic Report on Internal Hazards inside the PCV (Ref. 72) described the arrangements for lifting of MSIVs and SRVs with reference to the design changes (to provide a pneumatic jack and trolley system). I am satisfied that the proposed change reduces manual operations (the lifting of MSIV internals with several manual hoists) and therefore the complexity of the load transfer. The RP also considered that, given the trajectory of the MSIV and SRV loads, the area of damage associated with a drop from the DWC fan component handling in the upper D/W is bounded by the MSIV and SRV drop. The RP also acknowledged that the loss of control of the load could result into impacts on Class 1 systems and pessimistically assumed loss of all SSCs on either side of the PCV, which is bounded by LOCA events, and concluded that delivery of the FSFs would still achieved.

735. Although assessment of individual drops and impact on SSCs has not been performed inside the PCV within GDA, I am satisfied that the design changes implemented and the qualitative consequence analysis presented predicts bounding consequences which do not call into question the claims made in the internal hazards case.

Electro Magnetic Interference

736. The RP's assessment of EMI inside the PCV presented in revision 3 of the Topic Report (Ref. 72) concluded that there would be no fixed sources of EMI within the PCV, and transient sources introduced during outages would be assessed in the site-specific safety case. This was not in line with my expectations:

- Sources such as high voltage cables, electric motors, or sources of EMI from outside the PCV (running through cables / penetrations) etc. could affect equipment in the PCV and had not been studied.
- The assessment did not identify vulnerable receptors or their locations. These could be fixed by the generic design and foreclose preventative, control and mitigative measures of EMI in the future detailed design, for example, at the time when the strategy for transient sources is developed.

737. I also referred to regulatory queries on EMI hazard assessment outside the PCV (RQ-ABWR-1315 and RQ-ABWR-1368; Refs. 295 and 296, respectively) and liaised with the Electrical Engineering and C&I assessors who supported the view that the assessment did not recognise all potential sources or provided demonstration that the risks of EMI have been reduced to ALARP.

738. The assessment of the RP's responses to the above RQs and control of EMI hazards are assessed in section 4.16 of this report. Although the RP did not revisit the analysis of EMI hazards inside the PCV, I have reasonable confidence that the methodology issues have been resolved as discussed in section 4.16 and the RP has recorded the need to revisit the assessment post-GDA in AIRIS ref. IH-IR-0010.

4.11.3 Outstanding issues

739. The assessment of the submissions covering the internal hazards inside the PCV has highlighted that a number of issues of particular relevance to internal hazards have been recognised as outstanding at the end of GDA, including:

- Confirmation that combustible fluids inside containment e.g. lubricants are not explosive at their operating temperatures;
- Consideration of transient combustible or flammable or explosive materials and EMI hazards and specification of administrative controls;
- Specification of cables, electric equipment for substantiation against fire propagation, EMI and harsh environmental conditions inside the PCV;
- Evidence that Class 1 PCV equipment is qualified and certified according to the PCV conditions and their nuclear safety significance;
- Assessment of jet impingement inside the PCV;
- Specification of pipe insulation materials;
- Substantiation of pipe whip restraints;
- Confirmation that maintenance operations on MSIV, SRV and DWC are performed using monorails and manuals hoists or the risks of such operations are bounded by these assumed arrangements;
- Confirmation of Operating Rules governing lifting operations of MSIVs and SRVs in the PCV so that due account is taken of the potential impact on RHR/LPFL availability (so that these operations are not performed when the systems are claimed to be operable);
- Confirmation that loss of 1 of the 2 SSLC divisions does not lead to common cause failure of the system during POS A, B and C periods.

740. I am satisfied, that in line with ONR's guidance on Generic Design Assessment to the RPs (Ref.1), the above outstanding issues are subject to licensee choices (e.g. selection of materials, operating rules), or are the matter of detailed design / require vendor specific input or consideration (e.g. selection of cabling, equipment or substantiation of environmental qualification for specific SCCs). Regarding the outstanding issue to address jet hazards, I am satisfied that jet impact assessment provided by the RP for the weakest part of the outboard MSIVs within the MSTR Topic Report, instigated as part of Regulatory Observation RO-ABWR-0020 (Ref. 91), is supportive that the pipe whip assessment generally bounds the effect of jet impact inside containment.

741. I have also gained confidence from the layout of core cooling injection lines in the two halves of the PCV, and the congested geometry which restricts the potential for the jet's cone of influence to credibly disable the available lines of protection beyond that sampled in the pipe whip area.

742. I am also satisfied that the RP have documented the outstanding issues for closure following GDA and recorded in the Assumption Issue Register Information System (AIRIS) with reference to revision 3 of the Topic Report on Internal Hazards inside the PCV (IH-IR-0010).

4.11.4 Assessment Findings

743. During my assessment, five assessment findings were identified for a future licensee to take forward in their site-specific safety submissions. Details of these matters are contained in Annex 5.

744. These matters do not undermine the generic safety submission and are primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.11.5 Conclusions on Assessment of Internal Hazards Case Inside Containment

745. The RP has demonstrated that it has made significant amount of effort during GDA to support the claims made on the internal hazards case inside containment, and to address the identified shortfall, specifically in the area of pressure part failure analysis.

746. Whilst I am satisfied with the evidence provided to demonstrate that delivery of FSFs would be sustained following an internal hazard, I have identified a number of areas where the claims have not been fully substantiated. These relate to:

- Pressure part failure and, specifically pipe whip including further consideration of break locations giving rise to bounding consequences on SSCs, as documented in section 4.6.
- Outstanding issues identified by the RP, when assumptions or bounding arguments were made to support that the loads will not challenge the extant case.
- Findings from my assessment, which largely cover pressure part failure, flood prevention measures, equipment qualification and validation of the assessment once vendor specific and detailed design considerations are available.

747. Overall, I am satisfied that there is sufficient evidence to support that, during detailed design, the outstanding issues and assessment findings can be resolved without major modifications to the generic design.

4.12 Main Steam Tunnel Room (MSTR)

748. The MSTR is one of the areas in the UK ABWR design where segregation of A-1 instruments from different safety divisions is not provided. The MSTR connects the R/B to the T/B via the C/B. Divisional walls segregate the MSTR from all rooms in the R/B, C/B and T/B with blowout panels within the boundary wall between the R/B and C/B portion of the MSTR and between the T/B portion of the MSTR and T/B.

749. The MSTR contains four Main Steam (MS) lines between the PCV and the main steam turbine, as well as the two return Feedwater (FDW) lines from the main condenser. Each of the four MS lines has a Main Steam Isolation Valve (MSIV) within the PCV (i.e. inboard) and within the MSTR (i.e. outboard) that can isolate the MS lines at the PCV boundary. The outboard MSIVs are Class 1 valves that ensure confinement/ containment of radioactive materials following a Main Steam Line Break Accident (MSLBA). The four inboard MSIVs are Very High Integrity (VHI) components which also isolate the reactor during some internal hazard events.

750. Each of the FDW lines has two check valves, a cooling injection point and the main FDW isolation valve; all located within the MSTR. Additional check valves are within the PCV. The FDW lines have connections to division “A” of the RHR, RCIC system, LPFL, CUW and FLSS all within the MSTR.

751. The inboard and outboard MSIVs are also designed to be ‘fail safe’ and, as such, during a steam release both will either close due to provision of a ‘close’ signal or will fail safe in the closed position on loss of signal.

752. During Step 4 of the GDA, the RP submitted the following key documentation in the area of MSTR.

- The Pre-Construction Safety Report (PCSR) revision C (Ref. 15); and
- Topic Report on internal hazards in Main Steam Tunnel Room revision 2 and 3 (Ref. 63 and 64).

753. I subjected all the above submissions to assessment as discussed below.

754. In the following sub-sections I will cover the following:

- The RP’s safety case;
- My assessment of the MSTR safety case; and
- My conclusions and assessment findings.

4.12.1 RP’s MSTR Safety Case

755. The RP’s internal hazards safety case claims are given in section 3.2 of this assessment report. Claim **IH-SFC 5-7.3** is applicable to MSTR - “*Where there are exceptions to physical segregation, sufficient A-1 or A-2 signals and equipment are available, during and after an Internal Hazard, to fulfil the Fundamental Safety Functions*”. Note that the revision 3 of the Topic Report on MSTR identified claims specific to IH-SFC 5-7.1, for example **IH SFC 5-7 FE-MSTR.1**- “*any design basis internal hazard fire or explosion event originating within the MSTR will not prevent delivery of the FSFs*”. This discrepancy in the documents submitted was clarified in the Claim-Argument-Evidence Map of Internal Hazards Documents (Ref. 100) where it confirmed that claim **IH-SFC 5-7.3** is applicable to MSTR.

756. Revision 1 of the Topic Report on Internal Hazards in Main Steam Tunnel Room considered fire and explosions, flooding, pipe whip and jet impact, dropped and collapsed loads, blast, missiles and hazard combinations. It concluded that although internal hazards have the potential to result in SSCs from multiple Class 1 divisions of

instruments to fail, the failure modes of these SSCs are such that the FSFs are not compromised by equipment failure. In addition, internal hazards do not propagate beyond the MSTR such that could affect SSCs delivering any necessary FSFs in any adjacent areas, rooms or buildings. Although flood and steam hazards propagate beyond the MSTR (to the T/B) by design, this is demonstrated to be acceptable.

4.12.2 ONR's Assessment of MSTR Safety case Submissions

757. The assessment strategy in section 2 was used to formulate my assessment.

4.12.2.1 Scope of Assessment

758. My assessment covers all RP's submissions in this area. I assessed the PCSR and all revisions of the Topic Report on MSTR to obtain confidence on the requisite evidence and substantiation of the claim **IH-SFC 5.7.3**.

759. The areas chosen to assess the exceptions to segregation safety case were limited to the following:

- Overall assessment of MSTR safety case; and
- Substantiation of claim **IH-SFC 5-7.3**.

4.12.2.2 Assessment of MSTR Safety Case

760. Early in GDA I raised RO-ABWR-0020 (Ref. 91) based on my concern from the absence of segregation of the main steam lines and feed water lines within the MSTR. This RO included action RO-ABWR-0020.A1: "Review the Main Steam Tunnel Room plant layout and provide a robust ALARP justification of the internal hazards safety case in this area", which included the following sub-actions:

- Review the MSTR plant layout and give consideration to different options from the existing design;
- Provide detail arguments and evidence to underpin the claims made; and
- Provide an internal hazards ALARP justification for the MSTR.

761. The RP developed a resolution plan detailing the key deliverables and a programme of submissions (Ref. 297).

762. The Topic Report on Internal Hazards in Main Steam Tunnel Room captures the response to RO-ABWR-0020, where the RP undertook an assessment of all relevant internal hazards. Initially, and in response to RO-ABWR-0020, the RP submitted revision 2 of the Topic Report on Internal Hazards in the Main Steam Tunnel Room (Ref. 63). I assessed this document and raised RQ-ABWR-1244 specific to failure of MS and FDW lines in the MSTR (Ref. 298) and RQ-ABWR-1272 specific to dropped load analysis (Ref. 249). The responses to these RQs (Refs. 178 and 250) were captured in the revision 3 of the Topic Report on Internal Hazards in Main Steam Tunnel Room (Ref. 64), which I subjected to a further assessment and I noted the following:

- The RP identified all relevant internal hazards in the MSTR, all A-1 and A-2 systems and all exceptions to segregations within the MSTR.
- Fire and Explosions: The RP identified all fire loads within the MSTR and concluded that a fire originating in the MSTR will not propagate to other Class 1 divisions (within the R/B or C/B).
- Flooding: The RP identified all flooding sources with a FDW line break, after the connection of the RCIC to the FDW, being the most onerous resulting in a release of water from both FDW and RCIC. This source is sufficient to lead to flooding of all three sections of the MSTR (R/B, C/B and T/B), affecting rooms

406, 407 and 428. A hydrostatic load of 10.3 metres was estimated. The RP claimed that the MSTR structure will prevent the flood from affecting other divisions.

- Steam release: The RP identified a guillotine break of the MS line as the bounding steam release sources and undertook an assessment based on 5 seconds steam release prior to inboard MSIV closure. The blowout panels which segregate the R/B section of the MSTR from the C/B section and the blowout panel between the T/B section and T/B operations deck provide an engineered route to steam release. The RP claimed that the MSTR structure will be able to withstand the over-pressure generated by the steam release.
- Pipe whip and jet impact: The RP identified the MS and FDW lines as potential pipe whip and jet impact sources and undertook significant amount of analysis in response to RO-ABWR-0020 and to the queries raised in RQ-ABWR-1244. The RP claimed that the MSTR barriers would be able to withstand the bounding design basis pipe whip and jet impingement loads. The analysis is summarised below:

  - The pipe to pipe interaction inside the MSTR firstly involved development criteria based on NUREG/ CR-3231 experimental data (Ref. 290) followed by numerical analysis using the LS DYNA model and finally validation of the analysis undertaken against the experimental data. Based on the failure criteria developed from the experimental data and using the LS DYNA model the RP concluded that the impacted line will not break as a result of MS pipe whip. Therefore only one pipe break needed considering for the design basis analysis. This assertion was the subject of the structural integrity assessment as captured in Reference 215 and in sections 4.6 and 4.11 of this report. See assessment finding **AF-ABWR-IH-10**.
  - Using LS DYNA the RP showed that the MS line will not hit the FDW and vice versa.
  - In order to ensure 10-5/yr reliability of an outboard MSIV, it was necessary to demonstrate that the outboard MSIV has sufficient strength to withstand a jet impingement resulting from a pipe break at the Class 1 to Class 3 boundary. The RP undertook analysis and indicated that the MSIV is of sufficient structural integrity that they can withstand the force (of 257,118N) of an MS line jet impact from a distance of 10 diameters (L/D=10) .
  - The MSTR barriers can withstand the jet impingement force of 257,118N.
  - Availability of the ECCS boundary was also evaluated. The RP initially identified a worst case scenario (involving a FDW(B) line break impacting FDW(A) line) and qualitatively argued that the functional requirement of check valve (F070A) on the target pipe would remain available which in turn enables isolation of FDW(A), making available the downstream ECCS injection points. The RP also argued qualitatively that, due to design changes of the piping route and valve design, when a FDW pipe breaks, the ECCS system pipe connected to the other FDW line is maintained via RCIC and RHR tie line connected to FDW(B) on failure of FDW(A), and RHR connected to FDW(A) on FDW(B) line failure.
  - Jet impact evaluation on FDW (A) side of the ECCS boundary was also analysed to ensure that at least one side of the ECCS boundary is available and two cases were evaluated; 550A FDW(A), and the branch pipe 150A-FDW(A). It was concluded that the ECCS boundary on FDW (B) would fail but ECCS boundary on FDW(A) integrity can be maintained.

- Dropped and collapsed loads: The RP identified the MSIV lift (3.2t over 8.3m height) as the bounding lift within the MSTR. The RP indicated that the consequences of such a dropped load scenario would not result in perforation or scabbing of the floor slab within room 406 and therefore the consequences are limited to room 406. In response to RQ-ABWR-1272 (Ref. 249), the RP clarified the lift route plan of the MSIV in MSTR and the consequences during the various plant stages of the refuelling outage, and concluded that although it is not possible to avoid lifting over the RHR (A) line (division I) within the MSTR, a dropped load onto this line may lead to a loss of RHR (A). Sufficient redundancy exists within the RHR to ensure that long term heat removal will continue to be delivered in the event of a loss of RHR (A).
- Blast: A number of blast sources were identified within the MSTR but the RP bounded the consequences of the blast from all pressurised sources by those of the steam release discussed above.
- Missile: the RP identified the outboard MSIV accumulators as a potential source of missile inside MSTR. These however were judged to be insignificant due to the low operating pressure and are bounded by the consequences of a pipe whip.
- Combined hazards: The RP undertook a qualitative discussion of the various potential consequential, correlated and independent combined hazards and concluded that either a seismic event or a pressure part failure event have the potential to cause multiple hazards simultaneously. It concluded however that the consequences would be no worse than the single hazards. It also concluded that consequential pipe failure is not a credible combination. I raised a number of concerns with both the combined internal hazards assessment and the consequential pipe failures and these are captured in assessment findings **AF-ABWR-IH-10** and **AF-ABWR-IH-18**.

763. The RP has developed a hazard schedule capturing the internal hazards considered, consequences, the barriers claimed and the available SSCs to deliver the FSFs.

764. The Topic Report on Internal Hazards inside MSTR identified a number of barriers that require substantiation. These were in the section of the MSTR in R/B (room 406) and in the section of the MSTR in C/B (room 407) against flooding (flood height of 10.3 metres), steam release (of 177 kPa overpressure) and dropped load (energy of 0.23MJ). Whilst the Topic Report on Internal Hazards inside the MSTR did not identify any specific barriers needed substantiation against pipe whip and jet impact, which is in contradiction with the hazard schedule, the Barrier Substantiation Report (Ref. 90) indicated that substantiation against these hazards was achieved. This discrepancy with the hazard schedule has been captured as a generic issue in this assessment report in **AF-ABWR-IH-14**. I also sampled the Civil Structure Evaluation Report for Barrier Substantiation (Ref. 170) and was satisfied that substantiation against all relevant hazards has been achieved (Ref. 299).

765. As the thickness of MSTR boundary barriers is not uniform, I queried the suitability of the blowout panels in protecting the thinnest barrier. The RP undertook a review and explained that based on commercially available blowout panels the release limit can be specified with a failure range of ±15%. For the case of the MSTR the rupture limit is provided as 9.8kPa so the expected rupture range would be between 8kPa and 12kPa. In order to put this into context, the CUW steam release study assessment against a 300mm wall with a large opening found that the wall could resist 30kPa gauge pressure. For the MSTR further margin is available as the thinnest wall is 500mm (not a Class 1 barrier). The thinnest Class 1 barrier is 1400mm in the MSTR.

766. The RP has also undertaken an optioneering study, as part of demonstrating that the current design reduces risks from internal hazards to ALARP. The RP considered a number of options including segregation of pipework, MSTR plant layout re-evaluation,

pipe whip restraints and pipework classification level. The RP identified the following design changes:

- Enhancement of piping support. This modification was confirmed in the "design freeze" document (Ref. 300).
- Improvements to pipe routing to ensure availability of ECCS injection after FDW line break. This enhancement will be captured in the detailed design.
- Re-classification of MS pipework from the PCV, through the penetration into the MSTR and up to the inboard MSIVs as VHI. The MSIV valve itself would be Standard Class 1 and designed to be 'fail safe'. The pipework after the inboard MSIVs would also be standard Class 1 up to a limit of L/D = 10, or 4.9m in this case, where the pipe would change to standard Class 3. These design modifications were already captured in the design.

767. The RP raised AIRIS IH-IR-0014 "*Design of piping support and piping route in Main Steam Tunnel Room derived by Internal Hazards assessment*" to capture the above design changes.

4.12.3 Assessment Findings

768. No additional findings identified in this area.

4.12.4 Conclusions on MSTR Safety Case

769. Overall, I am satisfied with the level of analysis undertaken in the area of internal hazards inside MSTR during GDA. The RP in response to RO-ABWR-0020 developed an analysis methodology and considered in a systematic fashion all internal hazards inside the MSTR and provided sufficient substantiation of the claims made. I have identified some discrepancies in the Topic Report and captured them as part of a generic assessment finding (**AF-ABWR-IH-14**). The work aided the closure of RO-ABWR-0020. A number of design changes were also identified and captured in the AIRIS for implementation during the detailed design.

4.13 Main Control Room (MCR)

770. The MCR in the C/B is one of the areas considered where segregation of safety divisions is not provided in the UK ABWR design. The MCR consists of room on floor levels 1F, 2F and 3F in C/B. The C/B is located adjacent to R/B, S/B, T/B and Rw/B.

771. The MCR is an area important to the safety of the UK ABWR due to its involvement in the monitoring and control of SSC delivering the FSFs. The MCR contains Human Machine Interfaces (HMI) for A-1 and A-2 SSCs.

772. The MCR contains equipment associated with all four A-1 C&I divisions and the three A-1 electrical divisions required to support them. The HMI within the MCR include the Main Control Console (MCC), the Wide Display Panel (WDP) and the Safety Auxiliary Panel (SAuxP) for A-1 SSCs and Hardwired Backup Panels (HWBP). For functional reasons it is not possible to fully segregate SSCs from different divisions within the MCR.

773. During Step 4 of the GDA, the RP submitted the following key documentation in the technical area of the MCR:

- The Pre-Construction Safety Report (PCSR) revision C (Ref. 15); and
- Topic Report on Internal Hazards Inside the Main Control Room revisions 0 and 1 (Ref. 79 and 80).

774. I subjected all the above submissions to assessment as discussed below.

775. In the following sub-sections I will cover the following:

- The RP's MCR safety case;
- My assessment of the MCR safety case; and
- My conclusions and assessment findings.

4.13.1 RP's MCR Safety Case

776. The RP's internal hazards safety case claims are given in section 3.2 of this assessment report. Claim **IH-SFC 5.7.3** is applicable to MCR - "*Where there are exceptions to physical segregation, sufficient A-1 or A-2 signals and equipment are available, during and after an Internal Hazard, to fulfil the Fundamental Safety Functions*".

777. Revision 1 of the Topic Report focused on the demonstration that a least one safety division of the relevant A-1 safety systems is capable of fulfilling the FSFs following an internal hazard event. If safety classified A-1 safety systems are not available during a hazard event, safety classified A-2 systems are available. This is ensured by either the 3-hour fire barriers which confine the hazard within the MCR or by the following diverse back-up systems outside of the MCR should the MCR becomes uninhabitable:

- Four divisions (divisions I, II, III, IV) of SSLC Panels (A-1) located on Floor 1F of the CB. SSLC panels perform automatic control.
- Two divisions (divisions I and II) of the RSS (A-1) located in the RB. The RSS panels (RSPs) provide manual controls and monitoring functionality to deliver parts of safety functions assigned to the MCR.
- Two divisions (divisions I and II) of the Class 2 Control Panel for automatic actuation of SLC, ARI, ATWS-RPT and Feedwater Stops are located in the C/B outside the MCR and separated from the MCR by Class 1 Barriers. Class 2 control panels for FLSS, RDCF, and containment venting are located in the B/B. Additionally, Class 2 HMIs for manual operations of SA C&I (B-2) and part

of HWBS (A-2) for the SSCs which is shared with SA C&I are located in the B/B.

778. Using the above systems, the RP also stated which systems would be available during the various plant states and concluded that internal hazards within the MCR would not prevent the delivery of the FSFs.

4.13.2 ONR's Assessment of MCR Safety Case Submissions

779. The assessment strategy in section 2 was used to formulate my assessment

4.13.2.1 Scope of Assessment

780. My assessment covers all RP's submissions in this area. I assessed the PCSR and all revisions of the Topic Report on MCR to obtain confidence on the requisite evidence and substantiation of the claim **IH-SFC 5.7.3**.

781. The areas chosen to assess the exceptions to segregation safety case were limited to the following:

- Overall assessment of MCR safety case; and
- Substantiation of claim **IH-SFC 5-7.3**.

4.13.2.2 Assessment of MCR Safety Case

782. The RP initially submitted revision 0 of the Topic Report on internal hazards inside MCR (Ref. 79) which I assessed and provided detailed comments via RQ-ABWR-942 (Ref. 301). The RP incorporated the responses to RQ-ABWR-0942 (Ref. 302) in Revision 1 of the Topic Report on internal hazards inside MCR which is discussed below.

783. Revision 1 of the Topic Report on internal hazards inside MCR presented the internal hazards analysis methodology inside the MCR which follows the generic analysis adopted by the RP for the UK ABWR. This included

- Identification of all A-1 and A-2 SSCs inside MCR;
- Identification of internal hazards- namely fire and explosions, flooding, dropped and collapsed loads and internal missile; and
- Internal hazards characterisation and identification of safety measures.

784. I subjected revision 1 of the Topic Report on internal hazard inside the MCR into an assessment and noted the following:

- The RP undertook a conservative fire analysis where it is assumed that a fire event in in room 502, on floor level 2F, with the highest fire load, could spread to all other rooms that are not separated by the divisional barriers. All SSCs in the affected hazard compartment are conservatively assumed to fail. The RP claimed that the safety Class 1 RSS (divisions I and II), the Class 1 SSLC panels (divisions I, II, III, and IV) and the Class 1 non-divisional barriers will ensure delivery of the FSFs.
- The RP considered that flooding from HECW (A) systems involving rooms 401, 402 and 456 would result in 0.123m flooding height, but this flood height would not result in loss of the HECW (B) as the two systems are segregated by 50m distance and a 500mm concrete floor slab. However, during Plant Operation State B-1 to B-2 flooding will result in loss of all MCR HVAC systems and consequently loss of MCC and WDP, as the MCR HVAC (B) system is not available due to maintenance. In this case the associated FSFs will be delivered by the redundant Class 1 RSS and SSLC panels located outside the MCR.

- The RP identified that the monorails in room 401 and 503 associated with lifting operations of the MCR HVAC supply fans, and therefore any dropped load from these lifting operations would be contained within rooms 401 and 503 as the floors form parts of the Class 1 barriers and only one division of the MCR HVAC system would be affected. The RP identified the following safety measures specific to outage operations: Class 1 RSS (division I and II) and Class 1 SSLC panels (divisions I, II, III and IV).
- The RP conservatively assumed that missiles generated in room 401 or 503 associated with the MCR HVAC systems could render all SSCs as unavailable. The RP identified that the Class 1 barriers would contain the missiles. The Class 1 RSS (division I and II) and Class 1 SSLC panels (divisions I, II, III and IV) would be available.
- The RP did not consider combined internal hazards in the assessment of the MCR. This area is covered in section 4.14 of this report where I raised **AF-ABWR-IH-18.**
- The RP recognised that penetrations through Class 1 barriers represent potential weak points and referred to the Barrier Substantiation Report (Ref. 90). I considered the impact of penetrations on the Class 1 barriers and raised **AF-ABWR-IH-03**, which is applicable to all internal hazards.
- The RP included a hazard schedule which concisely provided the route map for each internal hazard considered. This included the fire detection and alarm system (Class 3 system) as a claimed system against frequent fires in the MCR. This system was identified as a defence in depth system within the report. Whilst there is a discrepancy on the claims made within the report, I am content that the facility includes a fire detection and alarm system for the MCR.
- The hazard schedule also lists the 3 hours fire barriers claimed against internal fires and the divisional barriers claimed against dropped load and missile hazards inside MCR. It also refers to future revisions of the Barrier Substantiation Report for the substantiation of the non-divisional barriers claimed in the Topic Report on internal hazards inside MCR. I sampled room 401 which is claimed against dropped load and internal missile against the revision 5 of the Barrier Substantiation Report (Ref. 90) and noted that the slab for room 401 was included against dropped load but the walls were not included against missile hazard. I queried this with the RP which explained that this is due to impact taking into consideration the withstand of the casing. This was not included in the early revisions of the Topic Report on internal Conventional Missiles.

785. Overall, I am satisfied with the level of consideration of the internal hazards inside the MCR given by the RP and the redundancy available by the design to ensure delivery of the FSFs. This is in line with IAEA SSR.2/1 requirements 65 and 66 (Ref. 303).

786. The UK ABWR plant includes a number of nitrogen systems which imply the need for storage of large quantities of nitrogen within the site. My expectation is that the RP would have considered nitrogen releases as having the potential to compromise delivery of SFSs by affecting the MCR habitable environment and or plant (e.g. HVAC) and this should have been captured in the revision 1 of the Topic Report. I raised RQ-ABWR-1436 (Ref. 304) to seek clarity on the sources of nitrogen stored within the site and the potential consequences. In response to RQ-ABWR-1436, the RP listed all sources of nitrogen (mainly within the yard and R/B) (Ref. 301). The RP explained that if MCR habitability is lost, then the FSFs would be provided by operators from the RSS (rooms 504 and 526) in the R/B. The MCR has a dedicated MCR HVAC system with its inlet located on the C/B roof (FL+16.5m). The C/B is also at least 60m away from the atmospheric control system and the cylinder storage house.

787. I also liaised with the C&I inspector on the transfer switches between various locations and in particular on how internal hazards considerations were included in the design

and location of the MCR/ RSS and MCR/ BBCR transfer switches and jointly with C&I raised RQ-ABWR-1470 (Ref. 306). The RP in the response (Ref. 307) provided the failure mode of the transfer switches and its consequences. This was assessed by the C&I inspector and an assessment finding raised in ONR-NR-AR-17-017 (Ref. 260).

4.13.3 Assessment Findings

788. No assessment findings were identified in this area.

4.13.4 Conclusions on MCR Safety Case

789. I am satisfied that the RP gave an appropriate level of consideration to internal hazards inside MCR and has demonstrated that sufficient level of redundancy is available in the design to ensure delivery of the FSFs.

4.14 Combined Internal Hazards Safety Case

790. The RP has developed a combined internal hazards safety case where it considered a number of credible internal combined hazards and their impact on Class 1 divisional barriers.

791. The combined internal hazards Topic Report presents the methodology for screening out combinations of internal hazards events and the identification of credible combined internal hazards. It focused on the response of divisional barriers to internal hazards combinations to support claim **IH_SFC_5-7.2**. Combined internal hazards in areas where segregation of SSCs by barriers is not available, such as inside PCV, MSTR and MCR, were considered in their own topic reports.

792. During Step 4, the RP submitted the following key documents in the area of combined internal hazards:

- The Pre-Construction Safety Report (PCSR) revision C (Ref. 15); and
- Topic Report on Combined Internal Hazards revisions 2 to 4 (Refs. 55, 56 and 57).

793. I subjected the above submissions to an assessment which is discussed in the following sub-sections:

- The RP's safety case on combined internal hazards;
- My assessment of combined internal hazards safety case;
- My assessment of the methodology used in screening out combination of internal hazards;
- My assessment of the analysis undertaken and substantiation of the Class 1 barriers; and
- My conclusions and assessment findings.

4.14.1 RP's Combined Internal Hazards Safety case

794. The RP's internal hazards safety case claims are given in section 3.2 of this assessment report. The safety case on combined internal hazards for all areas where segregation by divisional barriers exists is principally based on claim **IH_SFC 5.7.2** – "*the consequences of any internal hazard are limited to one division by the provision of class1 barriers"*. The Topic Report on Combined Internal Hazards focuses primarily on R/B.

795. The following categories of combined internal hazards were considered:

- Consequential hazards – An event causing a primary internal hazard may give rise to one or more consequential internal hazards due to direct causal relationship.
- Correlated hazards – Multiple hazards could occur as a consequence of a single underlying cause.
- Independent hazards – Those hazards which could only be expected to occur together by random coincidence.

796. The Topic Report on Combined Internal Hazards concluded that the combined internal hazards either do not cause combined loads on the Class 1 barriers due to hazard effects not occurring at the same time, or that the margins available for single hazards are sufficient that the Class1 barriers can accommodate all credible combined internal hazards. The Topic Report on combined internal hazards also concluded that should a Class 1 barrier become damaged causing loss of two A-1 divisions delivering the same FSF (i.e. divisions I and II) and with a single failure of the remaining A-1 division (due

to failure of Class 1 switchboard) there would still be sufficient A-1 and A-2 SSCs to deliver the FSF.

797. The Topic Report indicated that the results apply to the R/B, C/B, Hx/B, T/B and S/Ts. For the B/B, EDG/Bs, Fv/B and yard, no assessment was undertaken as the buildings are single divisions or the divisions are separated by distance such as the EDG/Bs.

798. A number of outstanding issues were identified in the Topic Report, to be completed post GDA.

4.14.2 ONR's Assessment of the Combined Internal Hazards Safety Case Submissions

799. The assessment strategy in section 2 was used to formulate my assessment.

4.14.2.1 Scope of Assessment

800. My assessment covers all RP's submissions in this area. I assessed the PCSR and all revisions of the Topic Report on Combined Internal Hazards to obtain confidence on the requisite evidence and substantiation of the claims made.

801. The areas chosen to assess the combined internal hazards safety case were limited to the following:

- Assessment of combined internal hazards safety case;
- Assessment of combined hazards screening methodology; and
- Assessment of Class 1 barriers substantiation against combined internal hazards.

4.14.2.2 Assessment of Combined Internal Hazards Safety Case

802. The combined internal hazards safety case is given in the Topic Report on Combined Internal Hazards which aim to support claim **IH_SFC 5.7.2**. I am satisfied that the RP recognised the significance of the combined internal hazards on the Class 1 barriers and the work undertaken in this area.

803. I sampled the hazard schedule presented in the Combined Internal Hazards Topic Report and concluded that the hazard schedule is not detailed enough, it is not plant specific or combined internal hazards specific, as it groups internal hazards and buildings, and finally I could not decipher which barriers are claimed against combined internal hazards. I therefore captured this shortfall in **AF-ABWR-IH-14**.

804. I am content with the qualitative deterministic arguments put forward that should a Class 1 barrier damaged causing loss of two A-1 divisions delivering the same FSF (i.e. divisions I and II) and with a single failure of the remaining A-1 division (due to failure of Class 1 switchboard), there would still be sufficient A-1 and A-2 SSCs to deliver the FSF. This provides further confidence on the resilience of the plant.

4.14.2.3 Assessment of Combined Hazards Screening Methodology

805. The Topic Report on Combined Internal Hazards presented the screening methodology applied in the identification of credible combined internal hazards. This included the following steps (Ref. 55):

- Generic Assessment, which included;
    - Definition of combination types (e.g. consequential, correlated and independent) and assessment criteria;
    - Identification of hazards requiring assessment; and
    - Assessment of structural response of barriers.

- Specific assessment of all Class 1 divisional barriers within the UK ABWR plant. This includes determination of suitability and sufficiency of safety measures.

806. In order to derive a credible list of combined internal hazards, the RP has developed a number of screening criteria to deal with the large number of internal and external hazards. This included the following screening criteria:

- Combined hazards do not adversely affect barrier confinement / integrity;
- There is a time delay or different impact zone by the combined hazards;
- Initiating internal hazard will not cause a credible consequential hazard;
- Frequency of combined hazard is Beyond Design Basis;
- Combined hazard are bounded by another combination;
- The combination of hazards already assessed under single hazards assessment; and
- Combinations excluded due to low impact hazard.

807. I am largely content with the screening criteria developed for the identification of credible combined internal hazards and this is in line with ONR's SAP EHA.1 and EHA.19. However, I was not satisfied with the overall application of the screening criteria and the derivation of credible internal hazards identified in the revision 2 of the Topic Report for the following reasons:

- The RP excluded all miscellaneous hazards due to low impact. The RP claimed that miscellaneous hazards do not have an effect on the Class 1 barriers and therefore can be excluded. I have assessed the miscellaneous hazards safety case in section 4.15 of this report and I have raised assessment finding **AF-ABWR-IH-19** on the safety case presented.
- The RP excluded EMI on the basis of low impact as this hazard does not present a challenge to Class 1 barriers. However, EMI is a credible internal hazard which could affect a redundant SSC delivering a FSF, which in combination with another internal hazard may compromise 2 divisions of an SSC delivering the same function. Therefore EMI in combination with other internal or external hazards should have been considered.
- Independent combined hazards have been screened out based on the frequency alone i.e. less than 10^{-7} per year. In line with ONR's SAP EHA.19, the screening criteria should also consider the potential consequences. I noted also that the qualitative discussions presented on independent combined internal hazards was generic rather than specific to UK ABWR plant status. This is not in line with ONR's SAP EHA.1. However, I noted that utilising the argument presented in Appendix G of the Topic Report revision 3, the RP was able to assert that, even with 2 A-1 divisions affected by the combined internal hazards and even whilst applying the single failure criterion to an additional A-1 division, the key FSFs could be still delivered.
- The identification of correlated hazards was focused on pressure part failure only and for the R/B.
- Tertiary hazards (a primary hazard causing secondary hazards which in turn causing tertiary hazard) were dismissed due to conditional probability, but no assessed probability was stated.
- The screening outcome detailed in Appendix 1 of the Topic Report on Combined Internal Hazards was not based on a room-by-room identification process of potential credible scenarios. In addition, screening out of a number of consequential hazards was based on qualitative discussions. As an example, I noted that high pressure pipework failure (PW4) causing pipe whip, internal blast, spray, steam release, pipe jet, flooding, (immersion) and internal missile was considered as a Beyond Design Basis event and was not taken further for consideration. This was not in line with my expectations and the

relevant good practice established in the UK. My expectation is to treat a number of these effects holistically such as pipe whip and steam pressurisation, or pipe whip and jet impact and flooding. I noted, however, the RP has undertaken some analysis in this area as documented in Appendices F and G of the Topic Report on Combined Internal Hazards. Therefore the document is not fully consistent.

808. I challenged the RP on the selection of credible internal hazards combinations and raised RQ-ABWR-1484 (Ref. 308). This RQ follows and builds on the RP's response to RQ-ABWR-1380, RQ-ABWR-1302 and RQ-ABWR-1231. The key themes of this RQ focused on:

- Identification and justification of plant specific credible combined internal hazards; and
- Justification of events dismissed as Beyond Design Basis events such as due to pressure part failure and independent events.

809. The Topic Report on Combined Internal Hazards built on the work undertaken on single internal hazards and therefore the submissions were late in Step 4 programme. I had to adopt a pragmatic approach, within the timescales available, and focus my attention in the area of pressurised components failure causing a number of correlated internal hazards. This was based partly on the fact that a number of credible consequential events have been dismissed as BDB events in revision 2 of the Topic Report, and partly because a number of potential credible combined hazards require further consideration at site specific stage such as miscellaneous and external hazards. I needed to obtain confidence that combined correlated / consequential events will not compromise the Class 1 barriers claimed for internal hazards. My challenge was subsequently captured in RO-ABWR-0082 actions RO-ABWR-0082.A1, RO-ABWR-0082.A2, RO-ABWR-0082.A3 (Ref. 9). It should be stated here that RO-ABWR-0082 was much broader as, in addition to combined internal hazard barrier substantiation, the RO was seeking confidence that all claimed barriers could be substantiated against all single hazards.

810. The RP responded to RQ-ABWR-1484 in Reference 309 and submitted revision 3 (progress revision only) and revision 4 of the Topic Report on Combined Internal Hazards (Refs. 56 and 57). In revision 4 the RP presented a supplementary identification process specific to pressure part failure for the R/B. The screening process included the following steps:

- Identify all Class 1 barriers which could be affected by pressure part failure;
- Screen out barriers where the only effect of pressure part failure is a conventional missile or insignificant blast;
- Screen out barriers which cannot be affected by flooding or steam;
- Covert the identified barrier to a list of rooms;
- Establish margins and severity of each case;
- Identify rooms which contain the same set of potential hazards;
- Identify bounding case rooms;
- Create appropriate groups for remaining rooms to establish bounding cases; and
- Undertake detailed checks on identified rooms taking into account the as-designed pipe runs within the rooms, the room geometry and of event timing on combined hazard loads.

811. The above screening process resulted into two groups of rooms: group 1 with steam hazards - rooms 110, 113, 253, 313 and 327 and group 2 with rooms 103, 118, 121, 152, 751. The difference between the two groups was that one group contained steam release hazards. From these two groups the following bounding two rooms were selected:

- Room 113 - presenting a pipe whip, jet impact, steam release, missile and flooding. This room was selected as it has most internal hazards and presents a bounding case for steam release from RCIC.
- Room 118 – presenting a pipe whip, jet impact, blast, missile and flooding. This room was selected because has the thinnest barrier of all rooms in group 2.

812. I am content that the RP has considered holistically the pressure part failure consequential effects, but I am not fully convinced that the process resulted in the most bounding case. This is because the Topic Report on Combined Internal Hazards builds on the cases presented for single hazards. Specifically to pipe whip and jet impact, I raised **AF-ABWR-IH-10** in section 4.6 above, which requires significant work to be undertaken post GDA including confirmation of bounding scenarios. I also noted that for room 113 the pipe whip and jet impact did not result in an impact on the Class 1 barrier and therefore it did not provide the worst combined load condition on the Class 1 barriers. I have further challenged the RP on the selection of room 113 as a bounding example and suggested that room 327 may present a more challenging scenario. Room 327 contain FLSS piping which could potentially lead to pipe whip, jet impact, steam release, blast and flooding. The RP undertook additional analysis and confirmed that the pipe whip impact of either the FLSS line (250A-FLSS-022) or the RHR line (150A-RHR-023) on barrier R-W-BM1-327 results in utilisation factors less than 1 for scabbing and perforation (see also **AF-ABWR-IH-11**relevant here). Similarly, the RP assess that the blast, flooding or steam release would not damage the associated Class 1 barriers.

813. Overall the RP has developed a screening methodology and applied it to a number of Class 1 barriers derived from single hazards. Whilst in principle the approach is reasonable, the overall assessment is incomplete partly because it requires detailed design input during the site licensing for the single hazard and partly because of the outstanding issues identified by the RP in the Topic Report on Pipe Whip and Jet Impact (Ref. 42). In addition, I have identified a number of areas where the screening criteria either dismissed scenarios without appropriate justification or the bounding scenarios appeared not to be truly bounded. ONR's SAP SC.4 and IAEA NS-G-1.11 and SSR-2/1 (Refs. 6, 171 and 303) call for systematic and thorough approach to identification of a comprehensive set of postulated events. Therefore I raise **AF-ABWR-IH-18** to address these shortfalls.

814. The Topic Report on Combined Internal Hazards also identified two external hazards (seismic and aircraft impact) which could cause internal hazard but these were considered at very high level. Such combinations required addressing during the site specific stage (see **AF-ABWR-IH-18**).

AF-ABWR-IH-18 - As the Requesting Party's evidence for substantiation of barriers claimed against combined hazards is based on a representative set of rooms, scenarios and consequential effects, the licensee shall perform the following as part of the development of a site specific safety case:

- **Complete the screening assessment of combined internal and external hazard combinations as appropriate, and provide justification for those screened out.**
- **Analyse all credible external and internal hazards combinations and quantitatively justify the adequacy of Class 1 barriers.**

4.14.2.4 Assessment of Class 1 Barriers Substantiation Against Combined Hazards

815. In the above sub-section, I sampled the substantiation work undertaken for room 113 and 327 and concluded that although the analysis is suitable the bounding rooms selected may not be truly bounding. This was based on the fact that for room 113 no

impact to the barrier has been identified whereas the overall analysis for both rooms depends on the break location. In addition, I sampled the analysis presented on the substantiation of a set of scenarios identified in Appendix A of the Topic Report summarised in Table 5-2 and presented in section 6 of the Topic Report on Combined Internal Hazards for the following scenarios:

- Internal fire followed by blast and missile;
- Internal blast combined with explosion;
- Internal blast followed by internal fire and secondary blast;
- Internal explosion followed by internal fire; and
- Internal fire followed by impact load.

816. Specific to the analysis presented, I noted the following:

- The analysis is based largely on qualitative analysis building on the work undertaken on single hazards. This includes results, assumptions and judgement which lack quantification and justification.
- No rooms containing potential sources of internal blast combined with internal explosions were identified. This indicates that the generic non-plant specific screening process did not identify all potential true scenarios or identified scenarios which are not existent. As stated above the selection or dismissal of scenarios was based on qualitative non plant specific consideration.
- Steam release causing internal fire or explosion (scenario 'ST1') was not considered.

817. In Table D-1 of revision 4 of the Topic Report the RP listed all barriers affected by either a single or combined internal hazards. This table attempts to take into account the plant specific aspects of the analysis as it includes all relevant Class1 barriers. I noted however that Table D-1 is incomplete as the substantiation of some single hazards was still ongoing, whereas the combined internal hazards scenario IE1 given in Table 5-2 (internal explosion causing internal fire and internal blast) was not listed in Table D-1. In addition, as I explained earlier, the approach adopted is not a systematic room-by-room identification of all credible combined internal hazards as it resulted in derivation of some generic credible combined internal hazards, in Table 5-2, but when applied, no rooms have been identified for the R/B; e.g. internal blast combined with explosions. Furthermore, it is not clear where the evidence that the barriers have been substantiated was given.

818. I liaised with the civil engineering inspector who undertook an assessment of the civil engineering aspects of the Topic Report on Combined Internal Hazards focusing on methodologies applied, assumptions and overall results and, in particular, on the analysis presented in Appendix H of the Topic Report for barriers R-W-B3-113 and R-W-B3-118 (in rooms 113 and 118) subjected to combined loading after 3 hours fire. It concluded that the document presented a reasonable appreciation of the effects of likely combinations of loads on typical RC walls and pointed out that no floor or slab or other structural member had been considered (Ref. 238). Reference 238 further discusses the link between the internal hazards and civil engineering and the latter have raised an assessment finding to take account of the final internal hazards loads in the structural designs of the civil engineering structures that provide Class 1 barriers and ensure that all elements of civil engineering structure (including walls, slabs and roofs) are appropriately assessed and detailed. This applies to all internal hazard areas assessed in this assessment report.

819. Overall, I concluded that the substantiation of Class 1 barriers presented in the Topic Report on Combined Internal Hazards is not in line with my expectations. The RP, however, within the timescales available, undertook sufficient work in this area to give me enough confidence that the RP would be able to substantiate all relevant Class 1 barriers post GDA reflecting site specific requirements including detailed design

development. This conclusion is further supported by the RP’s demonstration of flexibility in the design to incorporate minor design changes. The work in this area also aided closure of RO-ABWR-IH-0082.

4.14.3 Assessment Findings

820. During my assessment one assessment finding was identified for a future licensee to take forward in their site-specific safety submissions. Details of this are contained in Annex 5.

821. This matter does not undermine the generic safety submission and is primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.14.4 Conclusions on Combined Internal Hazards

822. I am satisfied that the RP commenced its study to identify credible combined internal hazard events and to substantiate the Class 1 barriers. My assessment has identified a number of shortfalls in the screening methodology applied, the substantiation of the barriers undertaken and in the overall consistency of the Topic Report. There is a need to complete this work post GDA for all relevant buildings and to include the detailed design aspects including site specific requirements. Based on the work presented in the Barrier Substantiation Report, the RP is confident that they would be able to substantiate the Class 1 barriers against the combined internal hazards without the need to implement major design modifications.

4.15 Miscellaneous Hazards Safety Case

823. The RP provided an additional topic report to cover miscellaneous hazards that were not already considered within other individual internal hazard Topic Reports. The key document submission was:

- Topic Report on Miscellaneous Internal Hazards (SE-GD-0218) revision 2 (Ref. 60).

4.15.1 Requesting Party's Miscellaneous Hazards Safety Case

824. The objective of the Topic Report states that a, "*Miscellaneous Internal Hazard is considered to be a hazard identified by the Topic Report on Internal Hazard Identification and not considered within other IH TRs*." (Ref. 60). The PCSR summarised these hazards as "*less significant hazards*" in comparison with the hazards which are described in detail within separate Topic Reports (Ref. 5).

825. One of the miscellaneous hazards was identified as pipeline accidents. However, the narrative for the pipeline accidents refers out to other available Topic Reports, such fire / explosion, internal flooding and pipe whip / jet impingement (Refs. 31, 36 and 42).

826. Neither the above Topic Reports or the PCSR (Ref. 15) provided clear narrative on pipeline accidents. I consider that this not in line with paragraph 86 of the SAPs, which states that a, "*safety case is a logical and hierarchical set of documents*". Therefore I am raising assessment finding **AF-ABWR-IH-19.**

The overarching safety claims are summarised in section 3.5. The safety case for miscellaneous internal hazards is principally based on Claims **IH_SFC 5.7.1** and **IH_SFC 5.7.2**. These are achieved by limiting the inventory or area of occurrence and implementation of Class 1 structural barriers.

827. The RP's safety case concluded that in the event of a miscellaneous hazard being realised, suitable and sufficient SSCs will remain available to maintain the plant in a safe state.

4.15.2 Scope of my Assessment

828. The assessment strategy in section 2 was used to formulate the scope. My assessment scope is limited to:

- The identification of miscellaneous hazards;
- The miscellaneous hazards methodology;
- Sampling the suitability and sufficiency of the claims and arguments; and
- Substantiation of the claims made.

829. The RP covered the consideration of miscellaneous hazards using an area / building approach. These included the R/B, Hx/B, C/B, T/B, B/B, EDG/Bs, ST, Rw/B, S/B, Fv/B and the Yard. The RP also considered a number of service tunnels.

830. The areas chosen to review the miscellaneous internal hazards included all buildings or areas mentioned in the Topic Report on Miscellaneous Hazards (Ref. 60); except for the following areas considered as exceptions to segregation including inside PCV, MSTR and MCR. These are covered under sections 4.11 – 4.13 respectively.

4.15.3 Assessment of Identification of Miscellaneous Hazards

831. Four miscellaneous hazards were identified. These were on-site materials, transport accidents, pipeline accidents and methane hazards. I did not consider methane or any natural gas hazards originating from organic material in the ground as part of my

assessment as these are categorised as external hazards in accordance with ONR's SAPs paragraph 228. I discussed this item with the external hazards assessor, who confirmed that the assessment of methane hazards will be considered as part of site-specific activities.

832. It was unclear to me from the safety case how the four miscellaneous hazards were derived. In order to provide context to my assessment and to clarify the hazard derivation process, the RP identified a number of internal hazards using regulatory guidance, publically available documents and UK nuclear power plant experience. Twenty internal hazards were considered (Topic Report on Internal Hazard Identification, Ref. 310).

833. From the twenty hazards listed, 11 internal hazards are considered in separate Topic Reports; internal fire, internal flooding, pipe whip, jet effects, spray, steam release, pipe failure effects, internal explosion, internal missiles, dropped and collapsed loads and electromagnetic interference (EMI).

834. Five internal hazards were screened out; vibration, static electricity, biological agents, wildlife and snow melt. I did not consider wildlife and snow melt as part of my assessment as these are categorised as external hazards in accordance to SAPs paragraph 228. The RP provided qualitative arguments for screening out the first three hazards. I considered each of these in turn.

835. The RP argued that low levels of vibration would be addressed by qualifications of the components and that high levels of vibration were bounded by seismic vibrations for seismically qualified equipment.

836. The RP also argued that static electricity would be bounded by equipment designed to meet electrical and EMI. EMI is addressed in section 4.16 of this assessment report. I sampled the Topic Report of Electro Magnetic Interference to check for the consistency of the safety case (Ref. 21). Electrostatic discharge was identified as a natural source but not identified as a man-made source. Electrostatic discharge can potentially result in a fire and explosion. The Topic Report on Fire and Explosion covered the assessment of fire and explosion regardless of the ignition source and therefore I am satisfied that the consideration of an electrostatic discharge hazard is bounded by the current fire and explosion safety case (Ref. 31).

837. The RP finally argued that consequences from biological agents would be bounded by internal flooding hazards. The RP considered biological agents as biological intrusions, biological growth, organic matter and microbiological corrosion. Depending on the plant location, biological agents can be an external hazard as well as an internal hazard. Biological agents are outside of the scope of my assessment and are for external hazards to consider.

838. I consider that the qualitative arguments for screening out the above three hazards as being reasonable. However my expectation is that these hazards will be reviewed as part of detailed design to ensure those hazards are still bounded by other hazard scenarios or adequately characterised.

839. Out of the original twenty hazards, the remaining four hazards formed the consideration of the Topic Report on Miscellaneous Internal Hazards (Ref. 60). I consider the review of twenty internal hazards is proportionate for GDA and that the identification process is in line with SAPs EHA.1 and EHA.19. Therefore I am satisfied with the miscellaneous hazard identification.

4.15.4 Assessment of On-site Hazardous Materials Methodology

840. The RP identified potential sources of on-site hazardous materials and quantities held. The RP then defined the release scenario, categorising the releases as a liquid or gas and then determined the consequences of release. On-site hazardous materials were grouped as:

- Hazardous materials not within safety classified buildings;
- Nitrogen within the R/B; and
- Transient or permanent hazardous materials of a low quantity within safety classified buildings.

841. The above approach is broadly in line with my expectations and I consider in line with IAEA Safety Guides NS-G-1.11 and SSG-2 (Refs. 171 and 190).

4.15.5 Assessment of Transportation Accidents Methodology

842. The RP identified potential sources of transportation accidents from a range of medium to large vehicles. Vehicle movements are not required for normal operation and therefore the RP's analysis only covered outage periods. The vehicles considered were summarised in the Topic Report on Miscellaneous Hazards (Ref. 59).

843. The RP also confirmed that access points are limited to the R/B, T/B, Rw/B and Hx/B. Vehicle access to the T/B, Rw/B and Hx/B is only during outage and the only large component entrance within the R/B is accessed during power operation. During outage only a single safety division is out for maintenance and vehicle access is only to that division. The designated routes avoid SSCs important to safety with additional defence-in-depth measures in place, such as crash barriers (Ref. 309).

844. I sampled the hazard schedule (Ref. 59), which summarises that safety divisional barriers are claimed to limit the transport accident hazard to one division. The RP explained in response to RQ-ABWR-1460 that vehicles enter the R/B via a large component entrance. An airlock system is in place to prevent the two doors being opened at the same time and therefore reduces the likelihood of the vehicle travelling at high speed (Ref. 312). The RP has used qualitative arguments to demonstrate that vehicle impact is not significant. I am satisfied with this approach for GDA. The RP acknowledges that more detailed assessment is required post GDA and that "*a full list of vehicle movements will be developed to support the site specific PCSR*" (Ref. 15).

845. There is an overarching assessment finding **AF-ABWR-IH-19** which captures the key action for the licensee to ensure that the safety case is coherent and demonstrably complete. It is my expectation that the full list of vehicle movements will be captured.

4.15.6 Assessment of Pipeline Accidents

846. A methodology for pipeline accidents was not described in the Topic Report for Miscellaneous Hazards (Ref. 58). Instead, the RP stated that "*pipeline accidents are contained within the respective topic reports for each of the potential hazards and are not discussed further within this document*". Therefore there were no additional claims, arguments or evidence presented in this Topic Report. Pipeline accidents which could result in one or more consequential hazards e.g. fire, explosion, pipe whip etc. are covered in other Topic Reports. These are:

- Topic Report on Fire and Explosion (Ref. 31);
- Topic Report on Internal Flooding (Ref. 36); and
- Topic Report on Pipe Whip and Jet Impact (Ref. 42).

847. However, the Topic Report on Pipe Whip and Jet Impact appeared to only discuss high pressure pipe mainly in the R/B and C/B (Ref. 42). I already identified earlier in my assessment under section 4.4 that the Topic Report on Internal Flooding (Ref. 36) did not address Fire Water or inexhaustible Towns Water. It is also not clear where other pipelines containing gas/liquid systems or chemicals are covered nor areas where pipes are routed outside of buildings. The assessment for pipelines therefore appeared to be incomplete and therefore I raised RQ-ABWR-1460 (Ref. 311) seeking further clarification.

848. The RP stated that a "*pipeline accident is considered to be any pressurised pipework that can fail disruptively and release the contents of the pipe."* The RP also confirmed that the potential consequences identified were jet impact, pipe whip, fire, explosion, flooding and release of hazardous / corrosive materials. Apart from the release of hazardous/corrosive materials, the RP articulated that the consequences have been assessed in other internal hazard topic areas (Ref. 312).

849. As I was still concerned with gaps in the pipeline accident safety case. I requested a generic site layout showing relevant pipelines as part of RQ-ABWR-1460 (Ref. 311), but the RP argued that they considered this to be a site specific detailed design consideration. In addition, the RP stated that room data sheets would identify all hazard sources relating to pipeline accidents and that pipeline accidents occurring outside / between buildings would be captured in the Yard section of the individual Topic Reports.

850. To seek consistency of the safety case on the Yard, I sampled the Topic Report on Pipe Whip and Jet Impact. The RP acknowledged that a pipe whip or jet impact taking place within the yard "*has the potential to damage SSCs within the yard*" (Ref. 42). However, the RP argued that due to a lack of information, the assessment will be completed post-GDA. I also sampled the Topic Report on Fire and Explosion. In this Topic Report, the RP states that the "*Yard does not contain any A-1 equipment and is not a building so does not contain any Class 1 barriers*." The Yard analysis identified a number of fire sources but does not identify any sources from pipelines (Ref. 30).

851. These examples represent where the internal hazards safety case is neither coherent nor consistent and do not demonstrate adequate consequence analysis. I do not consider this to be in line with SAPs SC.4, EHA.6 or FA.3.

852. As discussed earlier, assessment finding **AF-ABWR-IH-19** already captures the key action for the licensee to ensure that the safety case is coherent and demonstrably complete. It is my expectation that the analysis of equipment and pipelines located external to the buildings is addressed.

4.15.7 Assessment of Claims and Arguments - On-site Hazardous Materials

853. For liquids, the consequences were identified as spreading to multiple divisions with the potential to corrode SSCs. For gases, the consequences were identified as fire and explosion and as asphyxiation or poisoning of personnel within the MCR. The liquid and gas inventories were summarised in the Topic Report on Miscellaneous Hazards (Ref. 60).

854. The RP argued for liquid hazardous materials, which were considered to not be corrosive or which are present in small quantities, that their effects would be limited to a small area. The quantities were expressed in units which were inconsistent and not in line with SI units. For the R/B, I sampled item 9 of Table A-1 which gave details for an inventory of sodium pentaborate which is a skin irritant (Ref. 60). This gave a storage capacity of "28.7m", which I considered to be unclear. I then sampled item 2 of Table A-1 which summarised the Diesel (Light Oil Tank) in the EDG building and item 12 which summarised the Lube Oil in the T/B (Ref. 60) which are also potential

contributors to fire loading. The inventory for the diesel was expressed as “140kL per unit”, 2 units per division and multiplied by three divisions. The inventory for the lube oil was expressed as “37,000L” which I considered to be small quantities in relation to the bounding flood cases.

855. However, the RP argued that potential impacts to SSCs would be limited to the effects of flooding. From a flooding perspective, I consider this to be reasonable. The assessment of internal flooding is addressed in section 4.4 of this report. The assessment of fire and explosion are addressed in section 4.2 of this report.

856. The RP argued that gaseous materials can result in a fire or explosion and asphyxiation or poisoning of personnel. The assessment of fire and explosion for hydrogen is addressed in section 4.2 of this report.

857. The main consideration of asphyxiation is limited to the consideration of impacts within the MCR. The assessment of internal hazards in the MCR is covered in section 4.11 of this report. Asphyxiating gases are discussed briefly in the PCSR (Ref. 15) as also affecting the EDGs and the Back-up Building Generators (BBGs). The RP argues that due to the elevated location of the HVAC intakes, it is not credible that the atmosphere in the EDGs and BBGs would prevent delivery of the FSFs. This was not reflected nor substantiated in the Topic Report on Miscellaneous Hazards (Ref. 59).

858. As discussed earlier, assessment finding **AF-ABWR-IH-14** already captures the key action for the licensee to ensure that the safety is coherent and demonstrably complete. It is my expectation that the impact of gaseous hazards are fully characterised as part of detailed design.

859. The hazardous material safety case contains additional sub-claims which were to limit the source (sub-claim **IH_HM_SFC_5.7.1.1**), location of hazardous materials outside safety classified areas (sub-claim **IH_HM_SFC_5.7.1.2**), releases would be prevented by use of appropriate design codes and operating procedures (sub-claim **IH_HM_SFC_5.7.1.3**) and through mitigation (sub-claim **IH_HM_SFC_5.7.1.4**). These sub-claims, which specifically relate to hazardous materials, support the general claim of **IH_SFC_5-7.1** whereby internal hazards do not prevent delivery of the FSFs. The RP also notes that the storage of use of chemicals will comply with the Control of Major Accident Hazards (COMAH) Regulations 2015. As part of defence-in-depth measures, periodical patrols will be carried out by personnel to ensure that any leaks are identified and mitigated. The combination of these protection measures are in line with my expectations and with SAPs EHA.13 and EHA.14.

860. The RP has also argued that the HVAC system will prevent the likelihood of gaseous hazardous materials being propagated into the MCR compartment. Assessment of hazards within the MCR is covered in section 4.13.

861. The RP’s main claim on protection against hazardous materials is primarily through safety divisional barriers. This is in line with my expectations and with SAP EKP.5.

4.15.8 Assessment of Claims and Arguments – Transport Accidents

862. In considering the transport accident safety case, there were no Class 1 safety classified SSCs which have FSFs outside of safety classified buildings. Thus the RP only considered transports accidents associated with the R/B. T/B, Hx/B and Rw/B. The RP argued that the C/B was protected on all sides by other building structures and that there was no vehicular access route.

863. I considered that there was an analysis gap and therefore I raised Regulatory Query RQ-ABWR-1460 (Ref. 311) to highlight that smaller vehicles could enter narrower roadways / inside buildings and request clarity on vehicle movements for maintenance

/ outage operations. The RP confirmed that the exterior wall of safety classified buildings are significant RC designed for withstand against seismic, aircraft and other external hazard. The RP also argued that the SSCs are sufficiently segregated such that the consequences of a design basis vehicle impact are limited to a single division and therefore retains the ability to deliver any required FSFs (Ref. 312).

864. The RP’s sub-claims which relate to transport accidents (Ref. 15) support the general claim of **IH_SFC_5-7.1** whereby internal hazards do not prevent delivery of the fundamental safety functions. The RP argues that vehicle access will be restricted to the R/B, T/B, Hx/B and the Rw/B. The RP argues that claims will be achieved by controlling site access to vehicles, imposing speed and travel path restrictions and robust construction of safety classified buildings. Additional defence-in-depth measures include local crash barriers and the use of suitably trained and experienced operators.

865. It was already discussed above that the RP would develop a full list of vehicle movements as part of site-specific activities. It is my expectation that as part of the detailed design, that the licensee should confirm that the claims and arguments are not challenged. However, I consider that the claims and arguments are suitable and sufficient for GDA.

4.15.9 Substantiation of the Claims

866. I sampled the Internal Hazards Barrier Substantiation Report (Ref. 90) to assess the claims on the barriers. However, the report concludes that there were no miscellaneous hazards identified that would challenge the Class 1 barriers (Ref. 85). This is contrary to the information in the hazard schedule in the Topic Report on Miscellaneous Hazards which articulates that divisional barriers are in place to limit the effects on hazardous materials and transport accidents (Ref. 60).

867. Not all consequences were fully identified on the hazard schedule or the extent of the consequence. For example, the potential of a diesel pool fire was not identified even though diesel was identified as a hazardous material. However, I judged that the diesel pool fire was bounded by the more significant fires and explosions already considered in the Topic Report on Fire and Explosions (Ref. 31). Therefore I did not sample this hazard scenario further.

868. The consequences of gaseous hazards materials release were not analysed.

869. Pipeline accidents were also not identified in the hazard schedule but the RP noted these were covered in other Topic Reports.

870. This does not demonstrate consistency in the safety case for miscellaneous hazards nor provide a clear linking of hazards and associated safety measures. I consider this to not be in line with SAPs SC.4 and FA.8.

871. Assessment finding **AF-ABWR-IH-14** already captures the key action for the licensee to ensure that the safety is coherent and demonstrably complete. It is my expectation that the hazard schedule for miscellaneous hazards fully reflects the safety case.

872. I was sought clarification on the bounding case for transport accidents and the potential of impacts from smaller vehicles as part of RQ-ABWR-1460 (Ref. 311). The RP assessed vehicles impacting the R/B outer wall using the R3 impact code. It was concluded that in all the cases considered (10 to 45 tonne mass), scabbing would not occur. The worst case noted an available margin of 23%. (Ref. 3312). The licensee needs to complete the analysis with site specific information for the remainder of the buildings which fulfil FSFs. However, I am satisfied that this was a conservative approach for GDA.

AF-ABWR-IH-19 - In the development of the generic design assessment safety case, the Requesting Party identified less significant hazards or hazards not covered in dedicated topic reports as miscellaneous hazards, and made assumptions on the bounding cases. These included, for example, vehicle movements, pipeline accidents (external to buildings) and releases of hazardous gaseous materials. As site specific and detailed design information is needed to characterise these hazards, the licensee shall review, complete and update the safety case as information becomes available. This includes characterisation of gaseous hazardous releases outside of the Main Control Room and barrier substantiation against miscellaneous hazards such as vehicle impact and pipeline accidents.

4.15.10 Outstanding Issues

873. The RP has not self-identified any outstanding issues for consideration at site licensing.

4.15.11 Assessment Findings

874. During my assessment finding were identified for a future licensee to take forward in their site-specific safety submissions. The Assessment Findings identified in earlier sections of this report already cover the actions required. Details can be found in Annex 5.

875. These matters do not undermine the generic safety submission and are primarily concerned with the provision of site specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

4.15.12 Conclusion on Miscellaneous Hazards Assessment

876. To conclude, the submission provides the requisite information relating to the identification of miscellaneous hazards sources, evaluation of consequences and the identification of safety measures. Suitable and sufficient claims were made and these were generally supported by a number of arguments.

877. The safety case is incomplete but from my sampling, I am satisfied with the overall approach to miscellaneous hazards. I also take confidence that the miscellaneous hazards considered are bounded by other hazard scenarios, which are being addressed in other sections of this report.

878. The licensee has some site-specific actions to take forward in site licensing to ensure that the safety case is demonstrably complete. It is my expectation that the licensee will address the residual matters identified in my assessment. However, I am satisfied that during GDA, miscellaneous hazards have been proportionally subjected to detailed review.

4.16 Electromagnetic Interference

879. Electromagnetic Interference is the phenomena arising from the emission of electromagnetic radiation from a source (typically electrical or C&I systems) resulting in an interaction and undesired consequences in other electrical circuits.

880. The undesired consequences of electromagnetic interference vary widely, and may result in interruptions or degradation of circuit performance. This can arise as a result of lack of signals (when one is required), too high, low or undesired signals, which can ultimately lead to spurious operation, non-operation or other degraded performance of the specific receptor circuit.

4.16.1 The RP's Safety Case on EMI

881. The RP's internal Hazards case for electromagnetic interference is supported by the high level claim: **IH_E_SFC 5-7** "*Any design basis EMI/RFI event will not prevent delivery of the FSFs*". This claim is supported by a level 1 claim **IH_E_SFC 5-7.1 "***Any design basis EMI/RFI event originating from the UK ABWR GDA site will not prevent delivery of any required FSFs".*

882. In contrast with other internal hazards, delivery of these claims cannot be achieved via segregation by RC barriers, and this is reflected in the arguments put forward by the RP as given below:

- Any design basis EMI/RFI event occurring within the UK ABWR GDA site will not prevent delivery of the fundamental safety functions elsewhere on site.
- Any design basis EMI/RFI event bounded by the SRNM Pre-AMP and RIP-ASD Inverter Panel interaction.
- An EMI/RFI event will not prevent delivery of the FSFs by ensuring that the electrical equipment meets UK design and manufacture industry standards for electrical equipment, and the equipment identified by the design basis EMI/RFI event successfully completes an appropriate qualification programme.

883. My assessment of the RP's submissions is presented in section 4.16.2 below. In line with other sections of this report, the scope of assessment and the assessment of the RP claims and arguments are presented first. Next, I discuss my views on the RP's analysis methodology and consequence assessment results. Finally, I present my assessment of the RP's evidence of the evidence delivering the claims together with the applicable assessment findings to be taken forward by the future licensee.

4.16.2 Assessment of the RP's case

4.16.2.1 Scope of Assessment

884. My assessment covers all RP's submissions in the area of EMI during Step 4 of GDA. These are as follows:

- The Pre-construction Safety Report (PCSR) (SE-GD-0127) revision C (Ref. 15); and
- Topic Reports on Electromagnetic Interference (3E-GD-A0096) Revisions 2 to 4 (Refs. 19, 20 and 21).

885. From the above reports, I focused my assessment on the following areas:

- Suitability and sufficiency of safety case, and the claims and arguments made and in this area;
- Analysis methodology and assumptions;
- Justification of bounding EMI interaction; and
- Substantiation of the claims made.

886. The sections below cover the areas of my assessment.

4.16.2.2 Assessment of EMI Claims, Arguments and Evidence

887. Following my review of revisions 2 and 3 of the Topic Report on EMI (Refs. 19 and 20), I raised RQ-ABWR-1315 (Ref. 295). In this RQ, I requested the RP to clarify a number of shortfalls with the submission, namely:

- During Step 3 of GDA, the RP proposed a methodology in the Electro Magnetic Interference Analysis Methodology report revision 1 (Ref. 313), which proposes a seven step EMI methodology showing seemingly different scope and intent.
- The document listed a number of relevant standards and guidance but did not describe how these requirements had been assessed and considered to be met.
- The RP listed events which can give rise to internal EMI and tabulated lists of EMI emitters and SSCs which may be affected in each of the UK ABWR buildings in scope of GDA (Appendices A to K). The lists omitted EMI sources such as high voltage power cables runs.
- The Categorisation and Classification of SSCs important to safety which can be affected by EMI as not complete;
- The topic report identified an EMI/ RFI event which was considered to bound EMI hazards. The consequences of the EMI event were not identified nor were the means of detection that the interaction was taking place;
- It was not clear what signal/voltage intensity, classification and locality etc. were the most significant factors that determine the bounding case.
- The consequences of EMI source /receptor from the bounded interactions were not described.
- A list of the measures that have been identified to reduce risks associated with the EMI/RFI hazards referred to qualification to UK industry EMI/RFI standards but these were not explicitly identified.
- There was no evidence that safety measures had been identified, scored and evaluated to demonstrate that the risks of EMI had been reduced to ALARP.

888. The RP responded to the above queries in Reference 314 which was formally assessed by ONR's C&I assessor. The response provided the following additional information:

- A representation to show how the initial methodology (7 steps) mapped across the five step methodology adopted in revision 2 of the Topic Report.
- The commitment to consider all EMI sources including high voltage cables during GDA and document the consequences of the bounding and other cases during detailed design.
- A selection of measures to manage EMI and the rationale as to how EMI risk will be adequately managed during the detailed design phase.

889. The C&I assessor and I were not content with the RP's responses as they did not confirm fully how the distributed nature of EMI would be addressed. Also, they did not include the potential effects from mobile EMI sources such as mobile telephones and wireless communications from laptops and other interconnected devices that may be used during maintenance. The C&I assessor also referred to his view that that there were only limited improvements on how ALARP would be demonstrated post GDA.

890. The C&I assessor took forward this topic in Level 4 meetings (Ref. 260) and confirmed the RP had committed to make improvements to the document. These were reported in revision 4 of the Topic Report on EMI (Ref. 21).

891. The C&I inspectors assessment noted the following changes to the report:

- Measures were considered hierarchically.
- A more detailed description of how the design principles and methodology would be applied, including the management of cable design, and including the potential presence of mobile EMI emitters.
- More effective cross-reference to relevant C&I submissions.
- Explicit reference as to how ALARP would be achieved post GDA.

892. Based on the C&I assessor's assessment conclusion that the evidence provided in revision 4 of the Topic Report was sufficient, I judge that the position reached is adequate for the purposes of GDA.

4.16.3 Outstanding Issues

893. The RP has acknowledged that assessment of EMI must be regularly reviewed after GDA and during detailed design.

894. It has also acknowledged that, in order to demonstrate that the risk has been reduced to ALARP, the RP will need to develop a structured and complete justification process for the whole plant during detailed design including full consideration of the measures applied once equipment locations and cable routing are selected. This would form the basis of the ALARP demonstration to be produced.

895. On the basis that the RP has acknowledged that the assessment will be revisited to reflect the progress during detail design, I do not consider necessary to raise an assessment finding, given that the methodology issues have been resolved satisfactorily during GDA.

4.16.4 Assessment Findings

896. I did not identify any assessment findings during my assessment of the EMI safety case.

4.16.5 Conclusions of my Assessment of the RP's EMI

897. During step 4 of GDA, I coordinated my assessment of the topic report submissions with the C&I Specialist Inspector. As part of our assessment, we identified a number of shortfalls in the hazard identification methodology, the bounding case selected and the strategy proposed by the RP to ensure the risk are reduced to ALARP. The assessment has highlighted that EMI work will continue after GDA, as the design progresses into the detailed phase to cover the complete plant.

898. Overall, I am confident that a complete justification for the whole plant can be developed during detailed design, once equipment locations and cable routings are selected, without the need to implement major design modifications or placing too onerous restrictions for mobile sources.

4.17 Regulatory Issues

899. Regulatory Issues (RIs) are matters that ONR judge to represent a ‘significant safety shortfall’ in the safety case or design and are the most serious regulatory concerns. RIs are required to be addressed before a DAC can be issued.

900. There are no RIs relevant to internal hazards.

4.18 Regulatory Observations

901. An RO is raised when ONR identifies a potential regulatory shortfall which requires action and new work by the RP for it to be resolved. During GDA I raised a number of ROs which were discussed in earlier sections.

902. A summary of ROs related to internal hazards can be found in Annex 4.

4.19 Comparison with Standards, Guidance and Relevant Good Practice

903. This assessment has been carried out in accordance with HOW2 guide NS-PER-GD-014, ‘Purpose and Scope of Permissioning’ (Ref. 5).

904. ONR’s document “Guidance to Requesting Parties” (Ref. 1) sets out ONR’s expectations to requesting parties with regard to the GDA process for the safety and security assessment of nuclear power stations intended for construction and operation in Great Britain. I have assessed the RP’s submissions against the expectations set out in this guidance and in my view the submissions are in broadly in line with the guidance provided.

905. The standards and criteria adopted within this assessment are principally the SAPs (Ref. 6), internal hazards TAGs (Ref. 8), relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites. These are listed in Annexes 1 to 3 and used compared against throughout section 4 of my assessment.

4.20 Overseas Regulatory Interface

906. No overseas regulatory interactions have taken place.

5 CONCLUSIONS

907. This report presents the findings of my Step 4 internal hazards assessment of the Hitachi-GE UK ABWR.

908. My assessment focused on the suitability and sufficiency of the claims, arguments and evidence presented in the Topic Reports and in the PCSR revision C. I gave particular focus to hazard identification, analysis methodologies and criteria, consequence analysis, suitability of the engineering safety measures and to the adequacy of the redundancy, segregation and separation of SSCs delivering the FSFs in the UK ABWR design.

909. I have reviewed the safety case against the applicable expectations of ONR's SAPs and relevant international guidance. I am satisfied that within GDA:

- The RP gave appropriate consideration to internal hazard identification, used appropriate tools and techniques in the consequences analysis and identified suitable safety measures.
- In the area of internal fire and explosions, the RP undertook significant analysis to justify the bounding fire and explosions scenarios and the substantiation of Class 1 barriers.
- The RP developed analysis methodologies which are appropriate to the type of blast hazard sources, and selected bounding scenarios to substantiate the Class 1 barriers.
- The RP has undertaken a systematic identification of flooding and steam release sources, release paths and consequences analysis. The claims were supported by the requisite arguments and evidence.
- The RP significantly revised its analysis methodology of pipe whip and jet impact and undertook a tremendous amount of analysis. As the detailed design of all pipework and for all buildings will be completed post GDA, the completion of the entire scope of the analysis will be undertaken post GDA. The RP provided reasonable confidence that there is flexibility in the design to enable full substantiation of the Class 1 barriers without major plant modifications.
- The RP identified and characterise conventional missile sources from rotating equipment and pressure vessels and substantiated the Class 1 barriers. Consideration was also given to turbine disintegration and its potential impact with Hx/B.
- The RP identified and characterised the response of the UK ABWR structures to all dropped load impacts identified during GDA.
- The RP identified areas where "exceptions to segregation" of SSCs exist, identified all applicable internal hazards and undertook a consequences analysis. Specific documentation for the areas inside the PCV, MSTR and MCR were also submitted. The RP demonstrated that sufficient SSCs would remain available to deliver the FSFs.
- The RP commenced its study to identify credible combined internal hazard events and substantiation of Class1 barriers. This will be completed post GDA during the detailed design and when the site specific considerations become available.
- The RP proactively identified engineering changes and outstanding issues which were captured in their database for implementation during the detailed design.
- The RP reasonably addressed all my RQs and ROs. Any outstanding shortfalls have been reflected in my assessment findings.

910. To conclude, I am satisfied with the claims, arguments and evidence laid down within the PCSR and supporting documentation for internal hazards. I consider that from an internal hazards view point, the Hitachi-GE UK ABWR design is suitable for construction in the UK subject to future permissions and permits beings secured.

911. Several assessment findings (Annex 5) were identified; these are for future licensee to consider and take forward in their site-specific safety submissions. These matters do not undermine the generic safety submission and require licensee input/decision.

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Annex 1

Safety Assessment Principles

SAP No	SAP Title	Description
ECE.1	Engineering principles: civil engineering. Functional performance.	The required safety functions and structural performance of the civil engineering structures under normal operating, fault and accident conditions should be specified.
ECE.6	Engineering principles: civil engineering. Loadings.	Load development and a schedule of load combinations, together with their frequencies, should be used as the basis for structural design. Loadings during normal operating, testing, design basis fault and accident conditions should be included.
ECE.13	Engineering principles: civil engineering: structural analysis and model testing.	The data used in structural analysis should be selected or applied so that the analysis is demonstrably conservative.
ECS.2	Engineering principles: safety classification and standards. 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	Engineering principles: safety classification and standards. 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.
EDR.1	Engineering principles: design for reliability. Failure to safety.	Due account should be taken of the need for structures, systems and components to be designed to be inherently safe, or to fail in a safe manner, and potential failure modes should be identified, using a formal analysis where appropriate.
EDR.2	Engineering principles: design for reliability. Redundancy, diversity and segregation.	Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components.
EDR.3	Engineering principles: design for reliability. Common cause failure	Common cause failure (CCF) should be addressed explicitly where a structure, system or component employs redundant or diverse components, measurements or actions to provide high reliability.
EDR.4	Engineering principles: design for reliability. 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.
EHA.1	Engineering principles: external and internal hazards. 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.

SAP No	SAP Title	Description
EHA.3	Engineering principles: external and internal hazards. 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.5	Engineering principles: external and internal hazards. 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.
EHA.6	Engineering principles: external and internal hazards. 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	Engineering principles: external and internal hazards. Cliff-edge effects.	A small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences.
EHA.12	Engineering principles: external and internal hazards. Flooding.	Facilities should be shown to withstand flooding conditions up to and including the design basis event. Severe accidents involving flooding should also be analysed.
EHA.13	Engineering principles: external and internal hazards. 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	Engineering principles: external and internal hazards. 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	Engineering principles: external and internal hazards. Hazards due to water.	The design of the facility should prevent water from adversely affecting structures, systems and components.
EHA.16	Engineering principles: external and internal hazards. 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	Engineering principles: external and internal hazards. Appropriate materials in case of fires.	Non-combustible or fire-retardant and heat-resistant materials should be used throughout the facility.
EHA.19	Engineering principles: external and internal hazards. Screening.	Hazards whose associated faults make no significant contribution to overall risks from the facility should be excluded from the fault analysis.
EKP.1	Engineering principles: key principles. 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	Engineering principles: key principles. Fault tolerance.	The sensitivity of the facility to potential faults should be minimised.
EKP.3	Engineering principles: key principles. Defence in depth.	Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple

SAP No	SAP Title	Description
		independent barriers to fault progression.
EKP.5	Engineering principles: key principles. Safety measures.	Safety measures should be identified to deliver the required safety function(s).
ELO.4	Engineering principles: layout. 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.
EMC.2	Engineering principles: integrity of metal components and structures. Highest reliability components and structures.	The safety case and its assessment should include a comprehensive examination of relevant scientific and technical issues, taking account of precedent when available.
EQU.1	Engineering principles: equipment qualification. 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.
ERL.2	Engineering principles: reliability claims. Measures to achieve reliability.	The measures whereby the claimed reliability of systems and components will be achieved in practice should be stated.
ERL.4.	Engineering principles: reliability claims. Margins of conservatism.	Where safety-related systems and/or other means are claimed to reduce the frequency of a fault sequence, the safety case should include a margin of conservatism to allow for uncertainties.
EPS.3	Engineering principles: pressure systems: Pressure relief.	Adequate pressure relief systems should be provided for pressurised systems and provision should be made for periodic testing
EPS.4	Engineering principles: pressure systems. Pressure relief.	Overpressure protection should be consistent with any pressure-temperature limits of operation.
EPS.4	Engineering principles: pressure systems. Overpressure protection.	Overpressure protection should be consistent with any pressure-temperature limits of operation
ESS.11	Engineering principles: safety systems. Demonstration of adequacy.	The adequacy of the system design to achieve its specified functions and reliabilities should be demonstrated for each safety system.
FA.3	Fault analysis: general. Fault sequences.	Fault sequences should be developed from the initiating faults and their potential consequences analysed.
FA.7	Fault analysis: design basis analysis. Consequences.	Analysis of design basis fault sequences should use appropriate tools and techniques, and be performed on a conservative basis to demonstrate that

SAP No	SAP Title	Description
		consequences are ALARP.
FA.8	Fault analysis: design basis analysis. 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.
FA.9	Fault analysis: design basis analysis. Further use of DBA	DBA should provide an input into the safety classification and the engineering requirements for systems, structures and components performing a safety function; the limits and conditions for safe operation; and the identification of requirements for operator actions.
NT.2	Fault analysis: design basis analysis. Linking of initiating faults, fault sequences and safety measures.	There should be sufficient control of radiological hazards at all times.
SC.4	The regulatory assessment of safety cases. Safety case characteristics.	A safety case should be accurate, objective and demonstrably complete for its intended purpose.

Annex 2

Technical Assessment Guide

TAG Ref	TAG Title
NS-TAST-GD-005 Revision 7	Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)
NS-TAST-GD-014 Revision 4	Internal Hazards

Annex 3

National and International Standards and Guidance

National and International Standards and Guidance
Reactor Harmonisation Working Group: Safety Reference Levels for Existing Reactors. Western European Nuclear Regulators' Association (WENRA), September 2014. http://www.wenra.org/media/filer_public/2014/09/19/wenra_safety_reference_level_for_existing_reactors_september_2014.pdf
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Specific Safety Requirements No. SSR-2/1. Safety of Nuclear Power Plants: Design. International Atomic Energy Agency (IAEA), 2016

Annex 4

Regulatory Issues / Observations

RI / RO Ref	RI / RO Title	Description	Date Closed	Report Section Reference
RO-ABWR-0012	Presence of Single Doors on Class 1 Nuclear Safety Barriers	The proposed UK ABWR design includes single doors (i.e. not lobbied) on safety Class 1 barriers segregating different divisions within the (R/B. These doors have the same nuclear safety function and are required to withstand the same hazard loadings as the nuclear safety barriers segregating different divisions. This RO required Hitachi-GE to review its current design with an aim to: a) demonstrate that the number of doors on Class 1 safety barriers is minimised, b) provide a second door, where reasonably practicable, and c) for the remaining single doors, engineer local and remote alarms and provide a robust justification in line with the relevant good practice established in the UK.	10th February 2017	2.3 3.2 4.2.2.5 4.9.4.1
RO-ABWR-0020	UK- ABWR Internal Hazards Safety Case for the Main Steam Tunnel Room	In GDA Step 2, there was sufficient information for ONR to raise a concern about the absence of segregation of the main steam lines and feed water lines within the MSTR. This RO required Hitachi-GE to: a) review the MSTR plant layout and give consideration to different options from the existing design, b) provide detail arguments and evidence to underpin the claims made and c) produce an ALARP justification for the MSTR. The outcome of this ALARP study should be a rigorous justification of the UK ABWR design.	14th June 2017	3.2 4.11.3 4.12.2.2 4.12.4
RO-ABWR-0044	Demonstration UK ABWR has been designed to safely manage radiolysis gases generated under normal operations	The reactor chemistry assessment looked at aspects of the UK ABWR design from the perspective of managing radiolysis gases (H2 and O2) and subsequent treatment to remove these gases. In GDA Step 3, there was evidence to suggest UK ABWR may have been designed to take account of the need to safely manage radiolysis gases generated under normal operations. However Hitachi-GE's approach was not complete and may not meet regulatory expectations for making an adequate safety case in the UK context. This RO was issued to make clear ONR's expectations regarding Hitachi-GE's demonstration that UK ABWR has been designed to safely manage radiolysis gases generated under normal operations.	21st April 2017	3.2 4.2.3.3
RO-ABWR-0056	Demonstration that adequate optioneering has been carried out for the removal of Spent Fuel from the	There is a need to show that for spent fuel removal out of the reactor building, adequate optioneering has been carried out and that the approach being taken can demonstrate that the design reduces risks	29th March 2017	2.3 3.2 4.9

RI / RO Ref	RI / RO Title	Description	Date Closed	Report Section Reference
	Reactor Building.	So Far As Is Reasonably Practicable (SFAIRP). The management of spent fuel from the reactor building is important given the potential risks posed to workers and members of the public by its inadequate execution. In particular addressing ONR's concerns about the consequences associated with high risk activities. The objective of this RO was to clearly define ONR's expectations for the demonstration of adequate optioneering. The management of spent fuel covers the safe removal of spent fuel from the Spent Fuel Pool, loading the spent fuel into the transfer container and its export from the R/B.		4.9.4.1
RO-ABWR-0078	Exceptions to Segregation	The fundamental principles of segregation, redundancy and diversity were not applied in line with expectations in ONR'S SAPs and, specifically, EDR.2. There was also a lack of a systematic internal hazards identification and consequences analysis, including identification and justification of suitable and sufficient safety measures to deliver the FSF. Furthermore, the claims, arguments and evidence presented are not coherent. Therefore, the internal hazards safety case in this area is not in line with ONR's expectations. This RO aims to deliver a) A high level design philosophy for the approach to exceptions to segregation for all C&I, Electrical and Mechanical SSCs; b) A systematic analysis of Internal Hazards consequences and identification of safety measures to deliver the FSFs; c) Cohesive claims, arguments and evidence and d) Demonstration of ALARP.	2nd October 2017	3.2 4.10.2.2 4.10.4
RO-ABWR-0079	Turbine Disintegration Safety Case	Hitachi-GE's proposed safety case on turbine disintegration is based on combined deterministic and probabilistic aspects. Hitachi-GE's proposed Design Basis safety case is based on a single missile hitting the Hx/B. The site location of the Hx/B was not optimised against turbine disintegration and a robust deterministic safety case required development. ONR had particular concerns with the proposed methodology, claims and arguments, ALARP and the lack of optioneering studies. The aim of this RO is to ensure that a robust deterministic safety case is developed by: a) Clearly define and substantiate the number of missiles generated by a turbine disintegration event, and impact with buildings, during Design Basis and Beyond Design Basis events; b) Develop a robust deterministic safety case and c) Provide an ALARP justification.	2nd October 2017	3.2 4.8.3 4.8.7
RO-ABWR-0082	Substantiation of Class 1 barriers against internal hazards loads	During Step 4 the RP submitted Topic Reports acknowledging that Class 1 barriers are predicted to fail against a significant number of	31st October 2017	2.3 3.2

RI / RO Ref	RI / RO Title	Description	Date Closed	Report Section Reference
		internal hazard events, including dropped loads, pipe whip and missile and combined hazards. The RP has argued that, in the majority of the cases, detailed design information is required to substantiate the barriers, thus preventing resolution before the end of the GDA process. However, this argument is not robust, as it appears that the outstanding analysis is not dependent on design information which is pertinent to site specific information or licensee choices. The aim of this RO is to: obtain clarity on the full set of cases where Class 1 barriers are predicted to fail against all internal hazard loads; to obtain assurances, based on robust evidence, that all Class 1 Class 1 barriers of the UK ABWR reference design can withstand all foreseeable internal hazard loads, including dropped loads, pipe whip and combined hazards; to obtain consequence assessment of high energy systems so far excluded on the basis of their operational regime and demonstration that all reasonably practicable measures will be implemented; and to obtain confidence that, in all cases where the assessment of GDA reference design has resulted in the predicted failure of Class 1 barriers, all reasonably practicable measures are available and will be implemented to demonstrate the sustained integrity of the barriers, ensuring that detailed design considerations during site-licensing do not result in significant changes to layout or the design of generic Class 1 barriers.		4.4.5 4.6.2.3 4.6.3 4.7.2.4 4.8.3 4.9 4.9.4.1 4.9.3 4.14.2.3

Annex 5

Assessment Findings

Assessment Finding Number	Assessment Finding	Report Section Reference
AF-ABWR-IH-01	As the Requesting Party carried out limited compartment-wide fire modelling and did not consider the full combustible inventories (e.g. “minor” cabling or cabling in ducts) in their assessment, the licensee shall complete the fire modelling to: ▪ Demonstrate that the divisional fire barriers are substantiated against the worst-case fire conditions resulting from fire spread across rooms within a fire compartment. ▪ Include all cable inventories, detailed routing and transient loads, and confirm the fire resistance of the compartment barriers. ▪ Demonstrate that appropriate mechanical and/or natural ventilation rate data have been taken into consideration in the above calculations.	4.2.2.4 4.11.2.3
AF-ABWR-IH-02	The Requesting Party’s safety case does not fully demonstrate that combustible inventories have been reduced so far as is reasonably practicable in locations such as the Turbine building and the Back Up Building. As a result, during the site specific phase the licensee shall minimise them and develop features, controls and procedures to demonstrate: ▪ Hazard reduction at source by removing inventories from within buildings (e.g. relocation of combustible inventories such as day tanks to outside the Back Up Building) so far as is reasonably practicable. ▪ The sustained integrity of all fire barriers including those in the Turbine and Back Up buildings against the fire loading as these barriers have not been characterised. ▪ That the spread of liquid releases is prevented by provision of bunding or other measures in line with UK Relevant Good Practice.	4.2.2.4 4.11.2.3
AF-ABWR-IH-03	Given that the substantiation of nuclear safety significant barriers requires all barrier components to withstand all relevant internal hazards, the licensee shall develop the design specification for all penetrations including Heating, Ventilation and Air Conditioning (HVAC) penetrations, fire dampers, doors, door monitoring systems, hatches, infill panels / block work in line with UK relevant good practice.	4.2.2.5 4.6.3 4.7.2.3 4.9.4.1 4.13.2.2
AF-ABWR-IH-04	As the assessment of hydrogen hazards has not demonstrated that the explosion risk has been reduced to as low as reasonably practicable, the licensee shall confirm that the following has been addressed and incorporated into the internal hazards safety case: ▪ All reasonably practicable options are implemented to prevent hydrogen build-up during normal operation and fault conditions, with a suitable safety margin. ▪ The potential for deflagration and transition to detonation is eliminated so far as is reasonably practicable. ▪ There is suitable and sufficient provision for inerting and purging of the flammable atmospheres. ▪ Hazardous area classification has been undertaken and there is control of ignition sources at all times. ▪ The equipment specification is such that it would withstand peak pressure and impulse associated with	4.2.3.3 4.2.3.4

Assessment Finding Number	Assessment Finding	Report Section Reference
	deflagration and detonations, and the effect of oxygen rich mixtures has been considered. ▪ The off-gas system pipework, components, Turbine Building barriers and penetrations are confirmed to withstand the peak pressure, impulse and reflected shock wave. ▪ The off-gas charcoal bed vessels and components withstand the thermal and pressure loads associated with charcoal bed fires without loss of structural integrity.	
AF-ABWR-IH-05	The Requesting Party's analysis to demonstrate barrier substantiation against High Energy Arcing Faults (HEAF) is not consistent with the switchgear specification in the Electrical Engineering submissions and the oil mist explosion assessment assumed a single exemplar fluid to derive evidence of barrier substantiation. The licensee shall therefore use the specific switchgear fault current, and the physical and chemical properties of the specific oils selected during the site-specific design stages to confirm that the barriers are suitably substantiated against HEAF and oil mist explosions.	4.2.3.2 4.2.3.5
AF-ABWR-IH-06	As the exclusion of consequential failure of pressurised components from assessment is not fully justified, the licensee shall demonstrate that blast domino effects do not take place in the UK ABWR so far as is reasonably practicable. This includes providing evidence to support the following: ▪ The assumed integrity of high energy pipework, including the main steam lines, following internal blast in the Turbine Building. This is because the non-divisional barriers have only been substantiated against a single line blast. ▪ High trinitrotoluene (TNT)-equivalent sources in the turbine building do not impact the off-gas system and that there are no cliff edge effects associated with a single air receiver blast.	4.3.2.4
AF-ABWR-IH-07	Given that the Requesting Party's flooding safety case relies on the position relative to flood heights and sustained availability of Structures, Systems and Components (SSCs) during internal flooding events, the licensee shall use site-specific information to undertake further analysis, including sensitivity studies. This shall include: ▪ Ensuring that the SSCs located above the maximum flood height, and those SSCs placed on pedestals above the localised floor height, are not challenged. The licensee shall also confirm the available margins and suitability of all engineered measures supporting the case. ▪ Determination of the maximum inventory of water including inexhaustible water supplies and assessment of their impacts on nuclear safety significant barriers and fundamental safety functions. ▪ Determination of the consequences of a catastrophic Spent Fuel Storage Pool (SFP) failure resulting in an internal flood hazard.	4.4.4 4.4.5
AF-ABWR-IH-08	As the Requesting Party's safety case relies on the qualification and sustained availability of SSCs during flooding scenarios, the licensee shall ensure that equipment that could be potentially submerged / wetted and have an impact on Class 1 SSCs are suitably qualified.	4.4.4
AF-ABWR-IH-09	The Requesting Party's assessment of safety-significant steam releases was limited to two systems, a reduced set of rooms and short release durations. The licensee shall therefore address the following as part of the site-specific assessment: ▪ Evaluate all steam release sources (including those operating at high or medium energies for short periods of time).	4.5.1.2 4.5.1.3 4.5.2.1 4.11.2.3

Assessment Finding Number	Assessment Finding	Report Section Reference
	▪ Demonstrate how engineered measures, SSCs design requirements and/or operator actions deliver the isolation times assumed. ▪ Ensure that the steam release compartments are able to withstand the maximum overpressure with a suitable margin. ▪ Ensure that the design requirements of SSCs essential to deliver claimed measures are adequately identified and subsequently inform SSC qualification requirements during detailed design. This includes, for example, the requirements on electrically-driven valves needed to isolate the Residual Heat Removal System (RHR) trains to enable injection via the Flooder System of Specific Safety Facility (FLSS) into the reactor well following loss of an operating RHR train.	
AF-ABWR-IH-10	As the Requesting Party's assessment of pipe whip and jet impact was based on a representative set of scenarios, break locations and targets, the licensee shall complete the local and global pipe whip and jet impact consequences analysis for buildings containing structures, systems and components important to safety using the as-designed pipe runs, and confirm that all barriers claimed against the pipe whip and jet impact are substantiated. This shall include: ▪ Identification and assessment of all intermediate break locations and confirmation of the bounding pipe break locations used in barrier substantiation. ▪ Quantification of the jet impact load on barriers. ▪ Prediction of pipe movement, the consequential dynamic effects and impact on barriers shall be supported by appropriate modelling. ▪ Quantification of consequential pipe-to-pipe domino effects, for plant areas, and the effects on Class 1 barriers. ▪ Definition of timing of operations and the consequences of the bounding scenarios for all systems pressurised for <1% per year. ▪ Demonstration that consequences associated to failure of moderate energy systems are bounded by high energy systems. ▪ Substantiation of non-divisional Class 1 barriers claimed to provide protection against pipe whip and other internal hazards as appropriate.	4.2.3.4 4.6.2.3 4.6.3 4.6.4 4.6.6 4.7.2.4 4.7.7 4.11.2.3 4.12.2.2 4.14.2.3
AF-ABWR-IH-11	As a result of the predicted partial failure by scabbing and potentially cone cracking of a number of Class 1 barriers following conventional internal missile impact, the licensee shall implement measures to prevent these failure modes from affecting structures, systems and components in a separate safety division. These shall include so far as is reasonably practicable: ▪ Consideration of measures to protect the barriers, or selection of pressurised / rotating equipment with design features or limits of operation that reduce the energy of missiles; ▪ Selecting the location and developing the design of structures, systems and components to prevent consequential hazards and/or structures, systems and components' unavailability. ▪ Providing a demonstration of how the assumed failsafe state of the structures, systems and components is delivered under the hazard conditions.	4.7.2.2 4.7.2.3 4.7.2.4 4.9.7 4.11.2.3 4.14.2.3
AF-ABWR-IH-12	The Requesting Party's assumed location for the Heat Exchanger Building in the Generic Design Assessment plot plan is not optimised against low trajectory turbine missile strikes following a disintegration event. Consequently, the	4.8.4

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	licensee shall demonstrate that the risk to this building has been reduced to As Low As Reasonably Practicable.	
AF-ABWR-IH-13	As the Requesting Party's case for exceptions to segregation relies on assumptions, design choices and failsafe considerations not fully developed in the Generic Design Assessment phase, the licensee shall provide evidence to justify that the risk presented by each exception to segregation structure, system and component is reduced to As Low As Reasonably Practicable. Appropriate consideration and justification shall be given to the options available, including consideration of the hierarchy of safety measures.	4.10.2.2
AF-ABWR-IH-14	As the Requesting Party has not fully developed the hazard schedules for each internal hazard during Generic Design Assessment the licensee shall complete them to ensure the following: ▪ Appropriate reference is provided to all internal hazard events in the UK ABWR design basis; ▪ The specific location and extent of the hazards is appropriately documented; ▪ All claimed safety measures and remaining systems to deliver the Fundamental Safety Functions are explicitly documented.	4.4.5 4.6.2.2 4.8.5 4.10.2.2 4.11.2.2 4.12.2.2 4.12.4 4.14.2.2
AF-ABWR-IH-15	Flooding as a result of a Loss of Cooling Accident during outages has the potential to spread to the Reactor Building and exceed the design capacity of key Class 1 barriers. The licensee shall therefore develop and implement all reasonably practicable design options, including engineered measures, to prevent the spread of flooding from the Lower Dry Well to the Reactor Building.	4.11.2.3
AF-ABWR-IH-16	As the peak pressures associated with Boiling Liquid Expanding Vapour Explosions (BLEVEs) or blasts following high energy line breaks inside containment could exceed the damage threshold for claimed structures, systems and components, the licensee shall develop plans, procedures and limits of operation to ensure that they are operated below the superheat limit with a suitable safety margin.	4.11.2.3
AF-ABWR-IH-17	During the Generic Design Assessment phase, additional A-2 accumulators have been introduced in the Primary Containment Vessel to ensure Safety Relief Valve actuation during a station blackout. As the Requesting Party's internal hazard case inside the Primary Containment Vessel (PCV) discounts the potential for consequential blasts following a single blast event, the licensee shall ensure so far as is reasonably practicable that single failure of an accumulator does not result in domino effects or unacceptable consequences to structures, systems and components.	4.11.2.3
AF-ABWR-IH-18	As the Requesting Party's evidence for substantiation of barriers claimed against combined hazards is based on a representative set of rooms, scenarios and consequential effects, the licensee shall perform the following as part of the development of a site specific safety case: ▪ Complete the screening assessment of combined internal and external hazard combinations as appropriate, and provide justification for those screened out. ▪ Analyse all credible external and internal hazards combinations and quantitatively justify the adequacy of Class 1 barriers.	4.10.2.2 4.12.2.2 4.13.2.2 4.14.2.3

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AF-ABWR-IH-19	In the development of the generic design assessment safety case, the Requesting Party identified less significant hazards or hazards not covered in dedicated topic reports as miscellaneous hazards, and made assumptions on the bounding cases. These included, for example, vehicle movements, pipeline accidents (external to buildings) and releases of hazardous gaseous materials. As site specific and detailed design information is needed to characterise these hazards, the licensee shall review, complete and update the safety case as information becomes available. This includes characterisation of gaseous hazardous releases outside of the Main Control Room and barrier substantiation against miscellaneous hazards such as vehicle impact and pipeline accidents.	4.4.5 4.8.5 4.14.2.3 4.15.1 4.15.5 4.15.6 4.15.9