New Reactors Division

Step 4 Assessment of Management of Radioactive Wastes for the UK Advanced Boiling Water Reactor

Assessment Report: ONR-NR-AR-17-025
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EXECUTIVE SUMMARY

Hitachi-GE Nuclear Energy Ltd (Hitachi-GE) is the designer and Requesting Party (RP) for the United Kingdom Advanced Boiling Water Reactor (UK ABWR). Hitachi-GE commenced Generic Design Assessment (GDA) for the UK ABWR in 2013 and completed the process in 2017.

GDA is a four step process. This report summarises Step 4 of ONR's assessment of Hitachi-GE's generic safety case for the UK ABWR design in respect of the Management of Radioactive Wastes and has been completed by ONR's Nuclear Liabilities Regulation Specialism (NLR).

The Step 4 assessment is a review of the safety, security and environmental aspects of the UK ABWR in greater detail than in the preceding steps. This consisted of an examination of the evidence that supported the claims and arguments made in the safety documentation, building on the regulatory assessments completed in Steps 2 and 3. In addition ONR has judged the adequacy of the information contained within Hitachi-GE's generic Pre-Construction Safety Report (PCSR) and its supporting documentation.

A secondary purpose of this assessment was to consider whether Hitachi-GE's submissions had satisfied the requirements of Regulatory Observation RO-ABWR-036, '*Demonstration that the approach taken to radioactive waste management reduces risks As Low As Reasonably Practicable (ALARP)'*. RO-ABWR-036 required Hitachi-GE to demonstrate that it had applied a transparent process of optimisation, leading to the adoption of options for management of radioactive wastes that will reduce risks ALARP with a clear identification of:

- The risks associated with management of the UK ABWR radioactive wastes.
- What measures are in place to mitigate the identified risks, including the adoption of relevant good practice.
- What options, or range of options, could be applied to further mitigate the identified risks.
- A demonstration of which potential risk reduction options were reasonably practicable to implement.

Within the GDA, Hitachi-GE made all the submissions that were committed to in its Resolution Plan for RO-ABWR-036. ONR found that Hitachi-GE had developed a systematic approach to optioneering that recognised relevant good practice and it was evident that Hitachi-GE had applied this approach to all the systems that will contribute to management of the UK ABWR's radioactive wastes. In doing so, Hitachi-GE provided an adequate demonstration that it is technically feasible for all the anticipated UK ABWR radioactive wastes to be managed safely using established technology, in the context of the assumed generic site characteristics and predicted UK national waste infrastructure.

ONR found that the generic safety case was constructed and explained with a very strong focus on protection of the off-site environment. Hitachi-GE did not demonstrate clearly that the design of all relevant systems had been fully optimised in order to deliver an appropriate balance between on-site safety and environmental protection. In some instances there was insufficient clarity for ONR to be able to determine the extent to which particular on-site risks had been reduced ALARP. Whilst none of the residual matters identified by ONR's assessment met the definition of a GDA Issue, this shortfall resulted in identification of Assessment Findings in this report that will need to be addressed by a future licensee during the detailed stage of design, when the characteristics of a particular construction site, the UK ABWR wastes and national waste infrastructure will be better defined. On this basis, ONR was able to formally close RO-ABWR-036 within the due process of this assessment report being approved for issue.

Hitachi-GE's proposals for management of radioactive wastes concern the following systems:

- Gaseous Waste Management Systems, including:
  - Off Gas System (OG)
  - Heating, Ventilating and Air Conditioning System (HVAC)
  - Turbine Gland Steam System (TGS)
  - Tank Ventilation Treatment System (TVTS)
- Liquid Waste Management System (LWMS), including:
  - Low Chemical Impurity Waste (LCW)
  - High Chemical Impurity Waste (HCW)
  - Laundry Drain (LD)
  - Controlled Area Drain (CAD)
  - Spent Resin and Sludge (SS)
  - Concentrated Waste (CONW)
- Solid Waste Management System (SWMS), including:
  - Wet-Solid ILW (WILW) processing system
  - Wet-Solid LLW (WLLW) processing system
  - LCW Filter Packaging Room
  - Solid Waste Facility (SWF)
  - High Level Waste (HLW) decay storage facility
  - Intermediate Level Waste (ILW) Store (ILWS)
  - Low Level Waste (LLW) Monitoring and Marshalling Area (MMA)

GDA concerns the early stages of design and provides Requesting Parties an opportunity to present proposals at a conceptual level for systems that are not integral to the reactor operations. Management of Radioactive Wastes in some cases is peripheral to the reactor operations for the UK ABWR and in such cases Hitachi-GE chose to provide a concept level of design in the generic safety case. Concept design was therefore applied to all of the SWMS, the TVTS and the majority of the LWMS.

Where the systems used in Management of Radioactive Wastes interface directly with the reactor, the regulatory expectation for GDA is for the Requesting Party to provide the same level of design that is applied to the reactor itself. Hitachi-GE defined this as ‘preliminary design’ in its generic safety case and applied preliminary design to the Off Gas System, Turbine Gland Steam system and discrete sections of the HVAC system and LWMS.

Management of Radioactive Wastes is a multi-disciplinary interest. Therefore production of this report was integrated with ONR’s assessment of several other elements of the overall safety case, which included Reactor Chemistry, Radiological Protection, Mechanical Engineering, Internal Hazards, Fault Studies, Conventional Safety and Control and Instrumentation. ONR also worked closely with the environmental regulators throughout the GDA process, in accordance with established memorandums of understanding, to ensure an efficient and integrated oversight of Hitachi-GE’s proposals in terms of both nuclear safety and environmental protection.

ONR sought assurance that Hitachi-GE adopted a precautionary approach to uncertainty, such that the viability of the intended waste management strategy and techniques is not dependent on potentially optimistic assumptions on how the UK ABWR will perform in practice.

The UK Government legislated in The Energy Act 2008 to ensure operators of all new nuclear power stations will have secure finances in place to meet the full costs of managing radioactive wastes and decommissioning. The Act requires operators to put in place a Funded Decommissioning Programme (FDP), approved by the Secretary of State, before construction of a new nuclear power station begins and to comply with the FDP thereafter. The FDP must set out the plans for waste management, decommissioning and waste disposal, estimate the associated costs and describe how the operator will ensure it has sufficient assets/funds available to meet those costs. To support operators in developing their FDPs, the government developed a 'Base Case' which lays out key strategic assumptions that are expected to define parts of the lifecycle for a new nuclear power station - certain of these assumptions are relevant to the site's strategy and plan for the management of radioactive wastes. Through the course of this assessment ONR has checked that Hitachi-GE's proposals are compatible with the Government Base Case for new nuclear power stations, or any deviations from the assumptions in the Base Case are appropriately justified.

My key assessment conclusions are:

- Hitachi-GE has developed a strategy for managing the radioactive wastes expected to arise from the operations of the UK ABWR that accords with UK law, UK government policy and ONR's regulatory expectations.
- Hitachi-GE's approach to managing the Higher Activity Wastes (HAW) expected to arise from the operations of the UK ABWR is consistent with UK government policy for new build reactors.
- Hitachi-GE demonstrated that it is technically feasible for the liquid effluents that are expected to arise from normal operations of the UK ABWR to be effectively managed using proven technology.
- Hitachi-GE demonstrated that it is technically feasible for the UK ABWR Off-Gas system and TVTS to safely manage the relevant streams of gaseous wastes.
- Hitachi-GE confirmed that all the solid radioactive wastes expected to be generated during the operations of the UK ABWR can be appropriately managed and should be disposable at current or planned facilities within the UK.
- Hitachi-GE provided sufficient evidence to meet the intent of Regulatory Observation (RO) RO-ABWR-036 and addressed the issues which led to the RO being raised, with some residual matters that are aligned to Assessment Findings in this report that the licensee will need to address during the future stages of design. RO-ABWR-036 has therefore been closed.

My judgement is based on the following factors:

- Hitachi-GE's development of an Integrated Waste Strategy and Radioactive Waste Management Arrangements, which provided a robust basis for a holistic consideration of the hazards and risks associated with management of radioactive wastes covering all steps from the points of arising through to final disposal off-site.
- Compatibility of Hitachi-GE's strategy with UK Government policy, including the relevant strategic-level assumptions in the UK Government's Base Case for new nuclear power stations associated with The Energy Act 2008.
- Hitachi-GE's systematic identification of the types and quantities of gaseous, liquid and solid radioactive wastes that are anticipated to arise during the operational phase of the UK ABWR's lifecycle, based on an adequately justified source term.

- Hitachi-GE's recognition of the waste hierarchy and the identification of waste avoidance and minimisation in all relevant areas of the generic safety case, including the sections dedicated to Reactor Chemistry.

- Hitachi-GE's application of a systematic ALARP methodology within a comprehensive suite of options studies that identified worthwhile risk reduction measures that were either adopted within GDA or captured in a Forward Action Plan for implementation in the subsequent phases of design.

- Hitachi-GE's engagement with Nuclear Decommissioning Authority Radioactive Waste Management Limited (RWM Ltd) to obtain an assessment of the disposability of the HAW expected to arise from the UK ABWR within the UK's planned Geological Disposal Facility (GDF) and Hitachi-GE's subsequent response to RWM Ltd.

The following matters remain, which are for a future licensee to consider and take forward in its site-specific safety submissions. These matters do not undermine the generic safety submission but require licensee input/decision at a specific site.

- Hitachi-GE's generic safety case did not clearly define the full range of effluent feeds (in terms of the physical, chemical and radiological properties) that it anticipated would need to be received and processed by the LCW system. In addition, Hitachi-GE was unable to present a consistent and coherent set of parameters against which the LCW output will be sentenced, either to the primary circuit via the Condensate Storage Tank (CST), recycled back through the LCW, transferred to the HCW for additional treatment or potential discharge to the environment under permission. A number of these options are inter-linked with reactor operations and thus of a much higher importance than routine effluent treatment.

  Therefore the licensee shall demonstrate for the site specific situation that:

  - It has an adequate understanding of the full range of anticipated feeds to the LCW from:
    - All stages of the reactor operational lifecycle (start-up, at power operations, shutdown and outage).
    - Normal operations and reasonably foreseeable deviations, including all design basis faults.
    - Commissioning and decommissioning.
  - It has defined or established the criteria for routing the LCW discharge during the operational phases discussed above, including recycling through the LCW, further additional treatment, dispatch back to the primary circuit or potential discharge under permission via the HCW system.
  - It has defined the performance requirements of the LCW unit operations and that this is consistently reproduced across all the LCW safety case and design documents.
  - It has established that the operating life of the LCW is encompassed by the generic case and can be substantiated and justified.
  - It has established that prior LCW optioneering has resulted in a solution that will deliver the requirements of parts a), b),and c) above as well as a suitably justified and substantiated solution that will demonstrably reduce risks as low as reasonably practicable (ALARP), or amend it to deliver them.
  - It has ensured that for all reasonably foreseeable operational events there is sufficient capability in the system to ensure that it can achieve the desired duty and integrate where necessary with the other parts of the Liquid Waste Management System (LWMS) or that the capability can be adequately adapted to deliver the required duty.

- It has ensured that the significant unexplained variation between the radionuclides content of the LCW discharge stream and the HCW system discharge stream when compared to the activity in the Condensate Storage Tank (CST) within the GDA case is reviewed and explained to ensure a consistent and coherent position is presented.

- Although Hitachi-GE demonstrated that the treatment techniques deployed within the High Chemical Impurity Waste (HCW) system could adequately meet environmental protection requirements, the generic safety case did not meet ONR's expectations with respect to the optimisation of safety. The licensee shall therefore revisit the consideration of treatment options for the HCW system, to provide a suitably justified and substantiated safety solution that will demonstrably reduce on-site risks as low as reasonably practicable (ALARP) whilst also delivering the permitted environmental protection.

- Hitachi-GE's generic safety case incorporated a recombiner stage within the Off-Gas system. However, the case failed to clearly and adequately substantiate a range of design aspects that are fundamental to recombiner safety and reliability in service. As a consequence it could not be determined whether the risks related to hydrogen ignition will be reduced SFAIRP for all reasonably foreseeable events that the recombiners will be exposed to. The most important aspects are the claims regarding:

  - The safety classification (and thus reliability)
  - Operating life
  - Method of operation and monitoring regime
  - In-service performance including exposure to post accident atmospheres and catalyst degradation which relate to the potential hazard and risk profile

  Therefore the licensee shall:

  - Establish the appropriate safety classification for all elements of the recombiner to demonstrably reduce risks as low as reasonably practicable (ALARP) at all points during the plant's anticipated operational life (i.e. 60 years).
  - Adequately substantiate the operating regime for the recombiner system during normal operations and all reasonably foreseeable events by establishing
    - The in-service performance characteristics of the catalyst
    - The method by which this performance will be maintained, utilising appropriate system cycling and duty / standby configurations (including switchover)

- Hitachi-GE's generic safety case associated with the Off-Gas system did not adequately address the following areas:

  - Consideration of the integrity of the Off-Gas system pipework and equipment, in terms of their mountings and fixings, in the event of a hydrogen explosion inside the system.
  - Composition of the main condenser feed gas to the first Steam Jet Air Ejector (SJAE) for the entire range of reasonably foreseeable conditions in the design basis.
  - A suitably comprehensive and robust justification against the requirements of the Dangerous Substances and Explosive Atmosphere Regulations (DSEAR) for all sections of the Off-Gas system.

  Therefore the licensee shall:

- Suitably substantiate and justify the reactor off-gas pipework, equipment fixings and mountings, to ensure that the system integrity is maintained in the event of a hydrogen explosion within the Off-Gas system.
- Provide a comprehensive and objective consideration of the feed gas into the reactor Off-Gas system to ensure that a suitable DSEAR justification can be formulated.
- Review the Off-Gas system design and justify compliance of the system with the requirements of DSEAR.

■ Hitachi-GE's generic safety case associated with the hydrogen hazard in the Off–Gas system failed to adequately address the following areas:

- The use of hydrogen explosion and ignition data.
- The consideration of early full or partial hydrogen hazard reduction in the Off-Gas system
- The basis of the containment integrity and hydrogen monitoring system to maintain adequate safety
- The use of post-trip purging to dilute any potential high hydrogen explosive atmosphere in the Off-Gas system.

Therefore, the licensee shall:

- Provide suitably substantiated hydrogen ignition and explosion information relevant to the operating conditions of the Off-Gas system.
- Consider options to implement early hydrogen hazard reduction (full or partial) between the first Steam Jet Air Ejector (SJAE) and the second SJAE to reduce hydrogen hazard as low as reasonably practicable.
- Justify and substantiate the containment boundary and hydrogen monitoring system to ensure adequate safety during a fault condition.
- Provide a detailed understanding of any purge of the Off Gas system that may be required as part of a high hydrogen shutdown (typically as a result of recombiner failure), justify what gases (inert or air) are used in the purge and the required flowrates recognising the potential demands on the charcoal beds.

■ While ONR was satisfied by Hitachi-GE's evidence to the effect that the postulated fault (an Off-Gas system leak) will not give rise to a flammable atmosphere in manned areas and rooms owing to the ventilation system, the case did not adequately address the potential for radioactive species to also migrate and present a hazard to people in the vicinity.

Therefore the licensee shall suitably justify and substantiate:

- The consequence analysis for the postulated fault (which Hitachi-GE defined as a 'small leak' in the generic safety case).
- The Systems, Structures and Components that will be used to inform operators that the postulated fault has taken place and to minimise the subsequent doses.

■ Hitachi-GE's considered that faults regarding moisture ingress to the charcoal beds were bounded by the total failure of the Off Gas system condenser. However, its estimates for moisture ingress in this scenario were not adequately underpinned and in addition would suggest that an additional fault of pressurisation of the Off Gas system upstream of the charcoal beds and thus problems with reactor operation would occur. Therefore the licensee shall consider all design basis faults that could provide acute moisture ingress into the charcoal beds and justify and substantiate the safety position.

■ Hitachi-GE's generic safety case associated with the Tank Vent Treatment System (TVTS) did not provide an adequate position with regard to the following:

- The derived hydrogen generation rate and thus the time to reach a flammable condition in the tanks following a ventilation failure could not be verified and thus could not be judged as conservative.
- The argument presented regarding the avoidance of stratification of hydrogen during a ventilation fault and thus the creation of a flammable gas zone earlier than expected.
- There is no consideration of gas hold-up in the waste sludges and how this will be managed in the event of sudden gas release during operation.
- The alternative hazard management strategy of draining the free liquid from the waste tanks in the event of a ventilation fault did not indicate where the waste liquors will be transferred to and whether this is reasonably practicable.
- There was no substantiation to the claim that the civil structure containing the waste tanks will provide containment in the event of a hydrogen deflagration/detonation in a waste tank.

Therefore the licensee shall:

- Justify and substantiate the hydrogen generation rate for the waste and thus that the time to create a flammable gas in the event of a fault is suitably conservative.
- Justify and substantiate the flammable hydrogen condition taking into account potential localised high hydrogen concentrations in line with tank geometry and the understanding of hydrogen buoyancy behaviour in a static air condition.
- Justify and substantiate the hold-up of gas within the sludge waste beds and how any sudden gas release into the tank ullage space will be managed to control the flammable hazard so far as is reasonably practicable.
- Justify and substantiate the liquid drainage hazard management strategy in terms of how it would be enacted and whether it is reasonably practicable to do so and its importance in the hierarchy of response to the initiating fault.
- Define what is meant by the civil structure providing 'bulk contamination containment performance' in the event of an explosion and substantiate how the civil structure will achieve this requirement.

▪ Hitachi-GE's generic case for the Solid Waste Management System (SWMS) assumed that no solid Intermediate Level Waste (ILW) will be generated from maintenance of the UK ABWR during the site's operational life, primarily due to the adoption of a 60 year design life for the primary circuit Systems, Structures and Components. While there is a low probability of the UK ABWR giving rise to significant volumes of solid ILW during the operational phase, there is clear potential for maintenance wastes, failed components (such as valves, pump components or instruments) and equipment upgrades to result in items of ILW that may give rise to waste management challenges. The licensee shall demonstrate that the UK ABWR is capable of safely managing any miscellaneous items of solid ILW that may arise during the site's operational phase from plant breakdowns or replacements.

To conclude, I am broadly satisfied with the claims, arguments and evidence laid down within the PCSR and supporting documentation for the Management of Radioactive Wastes. Therefore I consider that from the perspective of the Management of Radioactive Wastes, I have no objection to the award of a Design Acceptance Confirmation (DAC) for Hitachi-GE's UK ABWR design.

LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
BAC	Bead Activated Carbon
BAT	Best Available Technology
BSC	Basis of Safety Case
BSL	Basic Safety Level
BSO	Basic Safety Objective
CAE	Claims Arguments Evidence
CAD	Controlled Area Drain System
CD	Condensate Demineraliser
CF	Condensate Filter
CONW	Concentrated Waste System
CST	Condensate Storage Tank
DAC	Design Acceptance Confirmation
DDT	Deflagration Detonation Transition
DOP	Dispersed Oil Particulate
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations 2002
EPRI	Electrical Power Research Institute
ERIC-PD	Eliminate, Reduce, Isolate, Control, Personal Protective Equipment and Discipline
FDP	Funded Decommissioning Programme
FMEA	Failure Modes and Effects Analysis
FPCM	Fuel Pool Clean-up and Makeup Systems
GAC	Granular Activated Carbon
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GEP	Generic Environmental Permit
HAW	Higher Activity Waste
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HCW	High Chemical Impurities Waste System
HEPA	High Efficiency Particulate Air
HLD	Hot Lab Drain
HLW	High Level Waste
HVAC	Heating, Ventilating and Air Conditioning System
HWC	Hydrogen Water Chemistry
IAEA	The International Atomic Energy Agency
ILW	Intermediate Level Waste
ILWS	Intermediate Level Waste Store

ISO	International Standards Organisation
IWS	Integrated Waste Strategy
LCO	Limits and Conditions of Operation
LCW	Low Chemical Impurities Waste System
LD	Laundry Drain
LFL	Lower Flammability Limit
LLW	Low Level Waste
LLW MMA	Low Level Waste Marshalling and Monitoring Area
LLWR	Low Level Waste Repository
LWMS	Liquid Waste Management System
MDEP	Multi-national Design Evaluation Programme
NDA	Nuclear Decommissioning Authority
NRW	Natural Resources Wales
NWC	Normal Water Chemistry
OG	Off Gas System
OLNC	Online Noble Metal Chemistry
ONR	Office for Nuclear Regulation
OPEX	Operational Experience
PCSR	Pre-construction Safety Report
PCV	Pressure Control Valve
PSA	Probabilistic Safety Analysis
PSR	Preliminary Safety Report
RGP	Relevant Good Practice
RI	Regulatory Issue
RP	Requesting Party
RMWA	Radioactive Waste Management Arrangements
RO	Regulatory Observation
RQ	Regulatory Query
RWM Ltd	Radioactive Waste Management Limited
SAPs	Safety Assessment Principles
SFAIRP	So Far As Is Reasonably Practicable
SJAE	Steam Jet Air Ejector
SoDA	Statement of Design Acceptability
SS	Spent Resin and Sludge System
SSCs	System, Structure (and) Components
SWF	Solid Waste Facility
SWMS	Solid Waste Management System
TAG	Technical Assessment Guide
TGS	Turbine Gland Steam System

TOC	Total Organic Carbon
TRL	Technology Readiness Level
TSC	Technical Support Contractor
TVTS	Tank Vent Treatment System
USNRC	United States (of America) Nuclear Regulatory Commission
UK ABWR	United Kingdom Advanced Boiling Water Reactor
UK EPR	United Kingdom European Pressurised Water Reactor
VLLW	Very Low Level Waste
WENRA	Western European Nuclear Regulators’ Association
WILW	Wet Intermediate Level Waste
WLLW	Wet Low Level Waste
WQS	Water Quality Specification

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1 INTRODUCTION

1.1 Background to GDA

1. Information on the Generic Design Assessment (GDA) process is provided in a series of documents in a dedicated area of ONR's website (http://www.onr.org.uk/new-reactors/index.htm). GDA involves a rigorous regulatory assessment of the design information provided by a Requesting Party, which if completed successfully will result in the award of a Design Acceptance Confirmation (DAC) from ONR and a Statement of Design Acceptability (SoDA) from the Environment Agency and Natural Resources Wales (NRW).

2. Hitachi-GE commenced GDA for its UK Advanced Boiling Water Reactor (UK ABWR) design in 2013 and completed the process in 2017. Full technical details of the UK ABWR are available via http://www.hitachi-hgne-uk-abwr.co.uk/

3. GDA consists of four steps. A report to summarise the outputs from Step 3 for the UK ABWR was published on ONR's website (Ref. 1). Further information on the regulatory expectations for management of radioactive wastes that have informed this assessment is also available via ONR's website.

4. Step 4 consists of an in-depth review of the safety, security and environmental evidence provided by a Requesting Party. Through the review of information provided to ONR, the Step 4 assessment aimed to confirm that Hitachi-GE:

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

5. During Step 4 ONR has therefore undertaken a detailed assessment, on a sampling basis, of the safety and security case evidence. The full range of items that might form part of such an assessment is outlined in ONR's GDA Guidance to Requesting Parties (Ref. 2). This includes:

- Judging against the Safety Assessment Principles (SAPs) (Ref. 3) and relevant Technical Assessment Guides (TAGs) whether the proposed design will reduce the risks associated with management of radioactive wastes so far as is reasonably practicable (SFAIRP).
- Establishing whether the system performance, safety classification, and reliability requirements are adequately substantiated.
- Arrangements to ensure that safety claims and assumptions are realised in the final as-built design.
- Clear and traceable links between underpinning data, Topic Reports, supporting documents and the generic Pre-Construction Safety Report (PCSR).
- An objective demonstration that the design reflects UK law, government policies, standards and other regulatory expectations applicable to management of radioactive wastes.
- Arrangements to ensure any significant impacts on the management of radioactive wastes from design changes and process modifications are properly recognised and taken into account.
- An assessment of the disposability of the radioactive wastes that are expected to arise from operation and decommissioning of the UK ABWR.

6. All the regulatory issues (RIs) and regulatory observations (ROs) issued to Hitachi-GE as part of the GDA have been published on ONR's website, together with the corresponding Hitachi-GE resolution plans and ONR's confirmation of closure. This includes Regulatory Observation RO-ABWR-036, '*Demonstration that the Approach Taken to Radioactive Waste Management Reduces risks As Low As Reasonably Practicable (ALARP)'*.

1.2 Scope

7. At the start of Step 4, the scope of ONR's GDA of the UK ABWR in regard to the management of radioactive wastes was detailed in an assessment plan (Ref. 4).

8. This assessment has been carried out by ONR's Nuclear Liabilities Regulation Specialism (NLR), which was also responsible for completing assessments of Hitachi-GE's proposals for Decommissioning (Ref. 5) and Spent Fuel Interim Storage (SFIS) (Ref. 6) within the overall GDA process.

9. This report concerns ONR's consideration of Hitachi-GE's proposals for managing the radioactive wastes expected to arise during the operational phase of the UK ABWR's lifecycle. ONR's consideration of Hitachi-GE's approach to managing the wastes from decommissioning is reported in Ref. 5.

10. ONR has four fundamental expectations for the management of radioactive wastes which it expects operators of nuclear sites in the UK to meet so far as is reasonably practicable:

- The waste hierarchy should be applied, within which the production of radioactive waste should firstly be avoided or minimised.
- Radioactive waste should be managed safely throughout its life cycle, consistent with modern standards.
- Radioactive wastes should be managed in a manner that takes account of the anticipated disposal route.
- Where disposal is not available in the short-term, radioactive waste should be put into a passively safe state for interim storage pending future disposal or other long-term solution.

11. A secondary purpose of this assessment was to consider whether Hitachi-GE's submissions had satisfied the requirements of Regulatory Observation RO-ABWR-036, '*Demonstration that the Approach Taken to Radioactive Waste Management Reduces Risks ALARP'*. RO-ABWR-036 required Hitachi-GE to demonstrate that it had applied a transparent process of optimisation, leading to the adoption of options for management of radioactive wastes that will reduce risks ALARP with clear identification of:

- The risks associated with management of the UK ABWR radioactive wastes.
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- What options, or range of options, could be applied to further mitigate these risks.
- A demonstration of which potential risk reduction options were reasonably practicable to implement.

12. GDA concerns the early stages of design and provides Requesting Parties an opportunity to present proposals at a conceptual level for systems that are not integral to the reactor operations. Management of Radioactive Wastes in some cases is peripheral to the reactor operations for the UK ABWR and in such cases Hitachi-GE chose to provide a 'concept level' of design in the generic safety case. Concept design was therefore applied to all of the Solid Waste Management System (SWMS), the Tank Vent Treatment System (TVTS) and a portion of the Liquid Waste Management System (LWMS).

13. Where the systems used in management of radioactive wastes interface directly with the reactor, the regulatory expectation for GDA is for the Requesting Party to provide the same level of design that is applied to the reactor itself. Hitachi-GE defined this as 'preliminary design' in its generic safety case and therefore applied preliminary design to the Off Gas System, Turbine Gland Steam system and discrete sections of the Heating Ventilating and Air Conditioning System (HVAC) and LWMS.

14. To enable a meaningful assessment within GDA, ONR required Hitachi-GE to provide a sufficient level of design information to demonstrate that the intended UK ABWR concepts are in line with relevant good practice, capable of delivering sufficient safety margins and tolerance to faults, apply a fitting hierarchy of hazard controls and enable all radioactive wastes to be held safely on the site for the envisaged storage period.

15. ONR also considered the compatibility of Hitachi-GE's proposals for the management of radioactive wastes with relevant parts of UK Government policy, including key strategic level assumptions in the Government's Base Case for the lifecycle of new nuclear power stations associated with The Energy Act 2008.

16. The adopted scope of assessment was appropriate for GDA in light of; the status of the UK ABWR design within GDA; integration with the scope of assessment carried out by other ONR technical disciplines; differences between UK expectations for the management of radioactive wastes and custom and practice in Japan; the importance of Hitachi-GE's proposals being aligned with the UK government's base case for new nuclear power stations, and; the significance of the hazards associated with both normal operations and design basis faults involving management of radioactive wastes.

1.3 Method

17. This assessment complies with ONR internal guidance on the mechanics of assessment (Ref. 7).

18. Management of radioactive wastes involves many technical disciplines with interests in particular aspects of safety and environmental protection, such that this assessment could not be carried out in isolation and had to be integrated with the consideration of other GDA topics. Further information on the key multi-disciplinary interfaces for this assessment is provided in Section 2.3.

2 ASSESSMENT STRATEGY

2.1 Standards and criteria

19. The standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 3), relevant Technical Assessment Guides (TAGs), applicable national and international standards and Relevant Good Practice (RGP) informed from existing practices adopted on UK nuclear licensed sites.

20. ONR's Guidance to Requesting Parties (Ref. 2) provides information on the process that is applied when ONR is asked to assess a reactor design in advance of an application for a nuclear site license being made, including the principles that ONR uses when judging the adequacy of the safety and security submissions.

21. There are three potential outcomes at the end of Step 4; provision of a DAC, meaning the end of GDA for the design concerned; provision of an Interim DAC (iDAC) which identifies outstanding GDA Issues, or; no DAC being provided.

22. GDA Issues relate to significant shortfalls against regulatory expectations that, while not so serious as to prevent ONR from issuing an iDAC, would need to be resolved before the issue of a final DAC. GDA Issues are defined in the Guidance to Requesting Parties as: *"Unresolved issues judged by regulators to be significant but resolvable, requiring resolution before regulatory permission for the start of nuclear island safety-related construction of such a reactor could be considered"*. Although this report has identified some remaining weaknesses within Hitachi-GE's generic safety case for the management of radioactive wastes, none of those weaknesses were judged to meet the definition of a GDA Issue (noting that the key infrastructure for management of radioactive wastes is located away from the nuclear island).

23. In accordance with the Guidance to GDA Requesting Parties, outcomes from ONR's assessment of a generic safety case that do not qualify as GDA Issues are recorded as residual matters, in the form of either Assessment Findings or Minor Shortfalls in accordance with the following definitions.

- An Assessment Finding, where:
  - To resolve the matter site-specific information is required.
  - Resolution of the matter depends on licensee design choices.
  - The matter raised is related to operator-specific features / aspects / choices.
  - Resolution of the matter requires licensee choices on organisational matters.
  - Resolution of the matter requires the plant to be at some stage of construction or commissioning.
  - Resolution of the matter requires the level of detail of the design needs to be beyond what can reasonably be expected in GDA.
- A Minor Shortfall, where:
  - The residual matter does not undermine ONR's confidence in the safety of the generic design.
  - The residual matter does not impair ONR's ability to understand the risks associated with the generic design.
  - The residual matter does not require design modifications.
  - The residual matter does not require further substantiation to be undertaken.

24. Assessment Findings do not undermine the generic safety submission and are primarily concerned with the provision of site specific safety case evidence, which is expected to become available as the project progresses through the detailed design, construction and commissioning stages. Assessment Findings must be addressed by the licensee and the progress of this will be monitored by ONR.

25. Minor Shortfalls may be of significant value to the site licensee in developing its safety case, but are not considered serious enough for ONR to require specific action to be taken by the Requesting Party and are judged to be disproportionate for ONR to expect the licensee to track (or for ONR to monitor) any actions taken to address the Minor Shortfall.

2.1.1 Safety Assessment Principles

26. The key SAPs applied within the assessment are included within Annex 1.

2.1.2 Technical Assessment Guides

27. The TAGs that have been used as part of this assessment are set out in Annex 2.

2.1.3 National and International Standards and Guidance

28. The international standards and guidance that have been used as part of this assessment are set out in Annex 3.

2.2 Use of Technical Support Contractors (TSCs)

29. It is usual in GDA for ONR to use TSCs, for example to provide additional capacity, to enable access to independent advice and experience, to apply specific analysis techniques and models, and to enable ONR‘s Inspectors to focus on regulatory decision making.

30. A single TSC from Quintessa Ltd was engaged during Step 4 to support ONR’s assessment of the Management of Radioactive Wastes for the UK ABWR. Table 1 sets out the broad areas in which this technical support was used.

Table 1

Use of Technical Support Contractor
Technical reviews of Hitachi-GE’s submissions against the SAPs, TAGs, legislation and other relevant regulatory expectations
Reporting of any shortfalls identified during reviews of Hitachi-GE’s submissions, including a commentary on their significance
Provision of independent technical advice
Support to ONR in Level 4 technical discussions with the Requesting Party
Drafting of requests for additional information (RQs) and provision of advice to ONR on the adequacy of Hitachi-GE’s responses
Drafting of reports

31. While the TSC undertook detailed technical reviews, this was done under ONR’s direction and supervision and the regulatory judgement on the adequacy of the case for managing the radioactive wastes from the UK ABWR has been made exclusively by ONR.

2.3 Integration with other Assessment Topics

32. GDA requires submission of a coherent and holistic safety case, within which ONR expects all aspects of the design relevant to the management of radioactive wastes should be addressed. Management of radioactive wastes involves a wide range of process steps that feature radiological and conventional hazards, therefore the related claims, arguments, evidence and assumptions reach across several technical areas. Consequently this assessment had to be integrated with the considerations of other GDA topics - the following list explains the key interfaces.

- **Reactor Chemistry** concerns the control of coolant chemistry and has implications for the plant functionality in relation to; core reactivity; pressure boundary integrity; fuel and core component performance; materials selection; cooling of spent fuel in the Spent Fuel Pool (SFP), and; levels of contamination on primary circuit surfaces. Therefore the UK ABWR's Reactor Chemistry regime is integral to the initial avoidance and minimisation of radioactive wastes.

  Definition and optimisation of the radioactive source term, i.e. the nature and amount of radioactivity expected to be present in the UK ABWR systems, was also a fundamental input to Hitachi-GE's demonstration that its proposals for management of radioactive wastes were technically viable and adequately safe.

  Hitachi-GE concluded that the chemistry regime it proposed for the UK ABWR, based on Hydrogen Water Chemistry with Online Noble Metal Chemistry (OLNC) and Depleted Zinc Oxide (DZO) will have no significant adverse impacts for the design of radioactive waste management systems, including the volumes of secondary wastes.

  ONR's assessment of Hitachi-GE's case for Reactor Chemistry can be found in Ref. 8.

- **Decommissioning** gives rise to a broad range of radioactive wastes, as the systems that contained radioactive materials during the site's operational phase are progressively taken out of service and removed.

  Some of the infrastructure that will support management of radioactive wastes during the UK ABWR's operational phase is expected to remain in service after the station ceases generating electricity, in order that it can contribute to the delivery of decommissioning.

  ONR's consideration of the proposals for managing decommissioning wastes is contained in the decommissioning assessment report, Ref. 5.

- **Security:** Compliance with the requirements of nuclear safeguards and measures to address threats from hostile third parties in relation to the storage of radioactive wastes are matters for consideration of ONR's Security Division, whose assessment of the UK ABWR can be found in Ref. 9.

- **Human Factors:** ONR expects that safety cases should substantiate the way actions are allocated between humans and technology, such that the dependence on humans to maintain a safe state is minimised.

  ONR's Specialist Inspector for Human Factors has considered Hitachi-GE's generic approach to optimising the demands placed on workers and minimising the potential for human error to give rise to significant consequences. Aspects of Human Factors that are specific to the management of radioactive wastes have been considered within this report.

  ONR's assessment of the UK ABWR design in the topic of Human Factors can be found in Ref. 10.

- **Radiological Protection** measures to restrict the extent of contamination throughout the plant are important in reducing the amount of radioactive wastes the UK ABWR will create.

  ONR's SAPs highlight the importance of radiation sources being eliminated or controlled before placing a reliance on the actions of individuals to maintain safety. ONR therefore sought assurance that the UK ABWR design provides for an engineered and remote means of managing radioactive wastes so far as reasonably practicable, before it will become necessary to resort to systems of work, administrative measures or personal protective equipment.

  ONR's assessment of the Radiological Protection aspects of the generic safety case can be found in Ref. 11.

- **Fault Studies** involves a consideration of fault sequences and postulated accident conditions, leading to the assignment of categorisations to the systems, structures and components (SSCs) that provide relevant lines of protection and/or mitigation.

  ONR has therefore sought assurance that Hitachi-GE's approach to categorisation and classification of SSCs has taken account of the particular requirements of management of radioactive wastes within the overall Faults Studies assessment in Ref. 12.

- **Mechanical Engineering** systems make major contributions to management of radioactive wastes, in respect of; ventilation; pumping; lifting; transfer, and; waste packaging. Creation of radioactive wastes is also a relevant consideration in the maintenance of mechanical systems, particularly where systems that come into contact with radioactive materials incorporate removable equipment that is expected to be routinely replaced and disposed of. The relevant ONR assessment report is Ref. 13.

  It should be noted that Heating and Ventilation of controlled areas for the Reactor Building and ancillary buildings is addressed in Chapter 16 of the PCSR and was considered in detail as part of ONR's Mechanical Engineering assessment and thus is not given an in-depth consideration within this assessment.

  Additionally, the Turbine Gland System (TGS) is similarly not assessed within this report, although this system is the main contributor to air ingress into the main steam condenser and thus the reactor Off-Gas system.

- **Environmental Protection** is a particularly important consideration in the management of radioactive wastes, as a holistic safety case needs to give consideration to both on-site and off-site contributors to risk.

  Consideration of these aspects has required close liaison between ONR and the environmental regulators throughout GDA, due to common interests and the need to regulate in a coordinated manner. Joint working between the regulators has been delivered in accordance with established memorandums of understanding, to ensure an efficient and integrated oversight of Hitachi-GE's proposals in terms of both nuclear safety and environmental protection.

33. During the GDA a number of Regulatory Observations (ROs) were raised by the above disciplines on elements of Hitachi-GE's generic safety case that have relevance to specific aspects of the management of radioactive wastes such as the HVAC system, the analysis of non-reactor faults, the Turbine Gland Steam system and the approach to contamination control.

34. Further background on these ROs is presented in Section 4.3, Annex 4 and on ONR's website, together with the corresponding Hitachi-GE resolution plans and ONR's confirmation of closure. ONR's NLR Specialism has contributed to the progress and

closure of these RO's throughout the course of the GDA as a normal part of multi-disciplinary working.

2.4 Sampling Strategy

35. 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.

36. This assessment has been based on a targeted sample of the evidence provided by Hitachi-GE, against the priorities set out in the Step 4 assessment plan and consistent with ONR's Enforcement Policy Statement (Ref. 14), with the highest level of scrutiny focussed on those parts of the case for management of radioactive wastes that concerned the greatest hazards and risks.

37. In order to deliver a targeted and proportionate assessment, ONR's strategy was tailored to match the status of the UK ABWR design within GDA. ONR's identified highest priorities were:

- For Hitachi-GE's radioactive waste strategy and proposed techniques to be compliant with relevant UK law, compatible with UK Government policy and aligned with other sources of regulatory expectations.
- To ensure the UK ABWR complies with the principles of the waste hierarchy, wherein the design should minimise the generation of radioactive wastes.
- Assurance that Hitachi-GE's proposals for managing radioactive wastes are based on a precautionary approach to uncertainty, so that the technical viability of the intended waste management strategy and techniques does not depend on optimistic assumptions on how the UK ABWR will perform in practice.
- To ensure the needs of radioactive waste management were recognised in all relevant areas of the generic safety case, including the sections dedicated to chemistry control, engineering, conventional safety and radiological protection.

38. Most aspects of the UK ABWR design are based on an evolution of the Japanese Advanced Boiling Water Reactor (J-ABWR), or the adoption of existing J-ABWR plant. It is relevant that some of the established waste management practices in Japan (such as on-site storage of unprocessed sludge and spent resins throughout the power station's operational phase) are not recognised as relevant good practices in the context of a new facility to be based in the UK. This has resulted in fundamental changes to the design and operational philosophies in order that management of the UK ABWR radioactive wastes will be in accordance with UK regulatory expectations, UK waste categorisations and the constraints of UK disposal routes. Therefore some of the UK ABWR radioactive waste management systems should be regarded as new plant that will be specific to the UK ABWR, rather than an evolution of the J-ABWR systems.

39. Due to the status of the UK ABWR within GDA, Hitachi-GE's generic safety case had to accommodate some unavoidable uncertainties. In such instances ONR expects that a precautionary approach should be applied, which errs on the side of safety. A particular priority in this regard was for Hitachi-GE's case to provide assurance that the technical viability of its strategy for managing radioactive wastes was not dependent on potentially optimistic assumptions on how the UK ABWR will perform in practice. ONR therefore targeted for greater scrutiny those parts of Hitachi-GE's case that may be vulnerable to 'cliff-edge' effects in the event that underpinning assumptions prove to be incorrect. This included considerations of radioactive wastes for which the final waste

categorisation – i.e. Low Level Waste (LLW) or Intermediate Level Waste (ILW) – is subject of uncertainty.

2.5 Out-of-Scope Items

40. Table 2 sets out the items that were agreed with Hitachi-GE as being outside the scope of this assessment.

Table 2

Items Deemed Out-of-Scope of this Assessment	
Financial Arrangements for Management of Radioactive Wastes	The UK Government legislated in The Energy Act 2008 to ensure operators of new nuclear power stations will have secure finances in place to meet the full costs of decommissioning and waste management. The Act requires future operators to put in place a Funded Decommissioning Programme (FDP), approved by the Secretary of State, before construction of a new nuclear power station begins and to comply with the FDP thereafter. Impartial scrutiny of the financial arrangements that underpin FDPs and associated advice to the Secretary of State is provided by the Nuclear Liabilities Financing Assurance Board (NLFAB).
Environmental Protection	The UK's environmental regulators are responsible for enforcement of the Environmental Permitting Regulations 2016 in relation to disposal of radioactive wastes from nuclear sites. Relevant aspects of the UK ABWR design have been duly considered by the Environment Agency and Natural Resources Wales within GDA and were therefore out-of-scope of ONR's assessment.

41. The Energy Act 2008 requires operators of new nuclear power stations in the UK to develop an FDP, which needs to be approved by the Secretary of State before nuclear-related construction on site can begin. The FDP must set out the plans for decommissioning, waste management and waste disposal, estimate the associated costs and describe how the operator will ensure it has sufficient assets/funds available to meet those costs (Ref. 15).

42. The Nuclear Liabilities Financing Assurance Board (NLFAB), an independent advisory non-departmental public body, will scrutinise the financial provisioning systems underpinning the FDP and provide its advice to the Secretary of State on the FDP's acceptability.

43. To ensure the Secretary of State and the NLFAB have a consistent benchmark against which to assess the cost estimates produced by operators, the UK Government developed a Base Case which contains key strategic assumptions that are expected to define parts of the lifecycle of new nuclear power stations. Certain of these assumptions are relevant to the site's radioactive waste management strategy and plan, such as:

- Intermediate Level Wastes (ILW) are assumed to be stored in safe and secure facilities on the site, pending disposal to the planned GDF. Operators are therefore expected to set out provision for safe and secure interim storage facilities on the site that are capable of being maintained or replaced until the ILW contained within them can be disposed of.

- On site storage facilities must ensure that the stored wastes will be able to meet the GDF operator's conditions for acceptance at the date scheduled for its disposal.

- Operators must be able to demonstrate that they have a workable plan for management of radioactive wastes using current technology, before construction of the station begins.
- Disposal of solid Low Level Waste (LLW) will take place to the LLW Repository (LLWR) operating in West Cumbria, or a successor facility

44. To ensure that Hitachi-GE's proposals for management of radioactive wastes were aligned with government policy, ONR checked that the safety case was either compatible with the above key assumptions or any deviations from the Base Case were adequately justified.

45. However GDA does not include any assessment of the arrangements for financial provisioning that a future operator of a UK ABWR will need to put in place to ensure sufficient monies are available to cover the costs of managing radioactive wastes and thereby comply with The Energy Act 2008.

3 REQUESTING PARTY'S SAFETY CASE

46. Throughout Step 4 the Requesting Party submitted a number of PCSR Chapters, Topic Reports, Basis of Safety Case documents and other supporting references to underpin its safety case for the management of radioactive wastes.

47. The main documents to be submitted are listed in Table 3 below. The subsequent parts of Section 3 summarise the key points of the main reports, to provide a short factual reflection of the case that Hitachi-GE provided – ONR's judgement on the adequacy of the submissions is explained in Section 4.

Table 3

Principal Hitachi-GE Safety Case Documentation for the Management of Radioactive Wastes in Step 4	
Document I.D.	**Title**
GA91-9101-0101-18000, Revision C, August 2017	Generic PCSR Chapter 18: Radioactive Waste Management (Ref. 16)
GA91-9101-0101-20000, Revision C, August 2017	Generic PCSR Chapter 20: Radiation Protection (Ref. 17)
GA91-9101-0101-23000, Revision C, August 2017	Generic PCSR Chapter 23: Reactor Chemistry (Ref. 18)
GA91-9201-0003-00425, Revision 3, July 2017	Integrated Waste Strategy (Ref. 19)
GA91-9201-0002-00054, Revision 5, June 2017.	Basis of Safety Case: Off Gas System (Ref. 20)
GA91-9201-0002-00053, Revision 9, August 2017	Basis of Safety Case: Liquid Waste Processing in the Radioactive Waste Building (Ref. 21)
GA91-9201-0002-00116, Revision 3, August 2017.	Basis of Safety Case: Solid Radioactive Waste Management System (Ref. 22)
GA91-9201-0002-00041, Revision 4, June 2017.	Basis of Safety Case: Heating Ventilating and Air Conditioning System (Ref. 23)
GA91-9201-0002-00063, Revision 1, August 2015.	Basis of Safety Cases on Radioactive Waste Human-Machine Interface (Ref. 24)
GA91-9901-0022-00001, Revision H, August 2017	Topic Report: Radioactive Waste Management Arrangements (Ref. 25)
GA91-9201-0003-00455, Revision 2, September 2015.	UK ABWR Reactor Chemistry Safety Case: Demonstration that the Primary Cooling System Operating Chemistry reduces risks SFAIRP (Ref. 26)
GA91-9201-0001-00135, Revision 5, August 2017.	Topic Report: ALARP Assessment for the UK ABWR LWMS WILW / WLLW Systems (Ref. 27)
GA91-9201-0001-00125, Revision 4, July 2017.	Topic Report on ALARP Assessment for Off-Gas System (Ref. 28)
GA91-9201-0003-01922 Revision 1, August 2017	Technical Supporting Document on the OG ALARP Report (Ref. 29)

Principal Hitachi-GE Safety Case Documentation for the Management of Radioactive Wastes in Step 4	
Document I.D.	**Title**
GA91-9201-0001-00196, Revision 0 , February 2016	Topic Report: ALARP Assessment for Reactor Area, Turbine Building, Radwaste Building and Service Building HVAC Systems (Ref. 30)
GA91-9201-0001-00134, Revision 5, August 2017	Topic Report: ALARP Assessment for Solid Waste Management System (Ref. 31)
GA91-9201-0003-01418, Revision 0, August 2017	ALARP Assessment Report for Turbine Gland Steam System (Ref. 32)
GA91-9201-0003-01800, Revision 1, February 2017	Liquid Waste Management System Process Description (Ref. 33)
GA91-9201-0003-01046, Revision 1, March 2017.	Process Flow Diagram on the UK ABWR Liquid Waste Management System (Ref. 34)
GA91-9201-0003-00329, Revision 2, December 2016	System Design Description: Dry Solid Waste Processing System (Ref. 35)
GA91-9201-0003-00328, Revision 2, December 2016	System Design Description: Wet Solid ILW Processing System (Ref. 36)
GK10-1001-0001-00001, Revision 0, March 2017.	System Design Description: Liquid Waste Management System (Ref. 37)
GA10-0511-0004-00001, Revision 1, Nov 2015.	GDA ALARP Methodology (Ref. 38)
GA91-9201-0003-00698, Revision 5, 25th July 2017	OPEX Report for UK ABWR (Ref. 39)
GA91-9201-0003-01695, Revision 0, November 2016	OPEX Report: Review of LWR LWMS and Waste Processing (Ref. 40)
GA91-9201-0003-02045, Revision 0, June 2017.	Radwaste Building Tank Vent Treatment System – Basis of Design (Ref. 41)
GA91-9201-0001-00022, Revision 5, December 2016.	Topic Report on Fault Assessment (Ref. 42)
GA91-9201-0003-02041, Revision 0, June 2017.	HAZOP 1 Study Report for the UK ABWR Liquid Waste Management System (Ref. 43)
GA91-9201-0003-00346, Revision 1, January 2016	Selection of the Treatment Technology for the LCW System, HCW System and LD System (Ref. 44)
GA91-9201-0001-00129, Revision 3, December 2016.	Topic Report on Safe Management of Radiolytic Gases Generated under Normal Operations (Ref. 45)
GA24-1001-0001-00001, Revision 3, Jun 2017.	Water Quality Specification (Ref. 46)
GA91-9201-0001-00022, Revision 6, July 2017.	Topic Report on Fault Assessment (Ref. 47)

Principal Hitachi-GE Safety Case Documentation for the Management of Radioactive Wastes in Step 4	
Document I.D.	**Title**
GA91-9201-0001-00023, Revision 13, Jun 2017.	Topic Report on Design Basis Analysis (Ref. 48)
GA91-9201-0003-01707, Revision 0, March 2017.	HLW ALARP Assessment Topic Report (Ref. 49)
GA91-9201-0003-01144, Revision 2, August 2017.	Justification of the Evaporator System (Response to RO-ABWR-0668) (Ref. 50)
GA91-9201-0003-02206, Revision 1, August 2017	Option Study for LCW System, LD System and CAD System (Ref. 51)
GA91-9201-0003-01150, Revision 0, September 2016	Response to RWM Assessment Report on UK ABWR Waste and Spent Fuel Disposability (Ref. 52)
GA91-9201-0003-01796, Revision 0, November 2016	Impact Assessment of Source Term Change to RWM Assessment Report on UK ABWR Waste and Spent Fuel Disposability (Ref. 53)
GN62-1001-0001-00001, Revision 1, June 2017	Off-Gas System, System Design Description (Ref. 54)
GA91-9201-0003-02163, Revision 0, June 2017	Response to Internal Hazards Queries on Off-Gas ALARP Report (Response to RQ-ABWR-1410) (Ref. 55)
GA91-9201-0001-00267, Revision 1, September 2017	Topic Report on Radioactive Waste Building Tank Vent Treatment System (Ref. 56)
GA91-9201-0003-01552, Revision 2, June 2017	Supporting Information for the Topic Report on Safe Management of Radiolytic Gases Generated Under Normal Operations (Ref. 57)
GA91-9201-0003-00944, Revision 4, June 2016	UK ABWR GDA Calculation of Process Source Term Value (Ref. 58)
GA91-9201-0003-01083, Revision 3, July 2016	UK ABWR GDA Calculation of Radioactive Waste End User Source Term (Ref. 59)

3.1 Generic PCSR Chapter 18 Management of Radioactive Wastes

48. Chapter 18 of Hitachi-GE's generic safety case provided a high level summary of all the UK ABWR's design, strategy and safety case aspects relevant to management of gaseous, liquid and solid radioactive wastes during the station's operational phase.

49. Management of the radioactive wastes anticipated to arise during decommissioning was a consideration to PCSR Chapter 31 and subject of a separate ONR assessment report within GDA (Ref. 5).

50. The main aims of Chapter 18 were to:

- Demonstrate that the concept for radioactive waste presented within GDA is technically feasible.
- Demonstrate minimisation of discharges of gaseous and aqueous radioactive wastes.
- Demonstrate a viable waste storage strategy, without foreclosing alternative future options for waste storage.
- Demonstrate that the wastes generated by the UK ABWR can be safely treated, stored, packaged and disposed of, to an appropriate level of detail for the purposes of GDA.
- Describe the systems and processes involved in radioactive waste management.
- Identify the claims related to radioactive waste management, and provide links to the relevant underpinning BSC documents and Topic Reports.
- Take into account possible faults and hazards and demonstrate that risks are capable of being reduced ALARP.

51. Within Chapter 18 Hitachi-GE sought to demonstrate application of the principles of the waste hierarchy to the UK ABWR by adopting all reasonably practicable measures to:

- Avoid the creation of radioactive waste.
- Minimise (in terms of mass and volume) solid and non-aqueous liquid radioactive wastes.
- Minimise the discharges of gaseous and liquid radioactive wastes off the site and minimise their impact on the environment.
- Select optimal disposal routes.

52. Chapter 18 identified all the key systems involved with management of the radioactive wastes along with their intended locations, main interfaces and the level of design applied to each system by Hitachi-GE within the overall generic safety case.

53. Wherever radioactive waste systems are integral to the reactor facility, the regulatory expectation for GDA is for the level of design development to be to the same level as the reactor, which Hitachi-GE defined as ‘preliminary design’ for the purpose of the UK ABWR generic safety case. Where a radioactive waste management system is not considered to be integral to the reactor operations, it is acceptable for Requesting Parties to provide a consideration at a conceptual level of design within GDA.

54. Therefore within the generic safety case Hitachi-GE applied ‘preliminary design’ to the Off Gas System, parts of the HVAC system and those elements of the LWMS whose function is to treat effluent with the intention of returning it to the primary circuit. A concept design was presented for the remaining waste management systems, including all of the SWMS and selected parts of the LWMS.

55. Hitachi-GE defined the key features of concept design as:

- Functional specifications (i.e. the waste inventory and disposal routes, including a consideration of the waste generation profile over time).
- Identification of bounding characteristics and capacities, volumes and rates.
- Technologies with a minimum technology readiness level (TRL) of 3.
- High-level process schemes and descriptions, typically in the form of process flow diagrams and system design descriptions.

- Definition of plant specifications, safety design requirements and safety functional requirements.
- Confidence that the identified engineering and its delivery can be executed, such that the plant can be detail designed and built.
- Hazard identification for main faults and fault groupings using FMEA and/or HAZOP and HAZID studies.
- Utilising good practices drawn from current operational experience.
- Provision of sufficient design information to enable the licensee to progress into detailed design.
- Optioneering and hazard identification using key words such as radiological and nuclear safety, maintenance, environmental impact and conventional safety.
- ALARP/BAT compliance to demonstrate that risks have been reduced, or are capable of being reduced, so far as is reasonably practicable by the licensee.

56. Table 4 shows how Hitachi-GE applied tailored levels of design to the specific UK ABWR radioactive waste management systems within the generic safety case.

Table 4

Levels of Design in GDA for Specific Radioactive Waste Management Systems		
Waste Type	**Waste Process Stream**	**Level of Design in Hitachi-GE's Generic Safety Case**
Liquid	Low Chemical Impurities	Preliminary Design
	High Chemical Impurities	Preliminary Design
	Spent Resin and Sludge	Concept Design
	Controlled Area Drain	Concept Design
	Laundry Drain	Concept Design
	Concentrated Waste	Concept Design
Gaseous	Tank Vent Treatment System	Concept Design
	Heating, Ventilating and Air Conditioning	Mixture of Preliminary and Concept Design
	Off Gas	Preliminary Design
	Turbine Gland Steam	Preliminary Design
Solid	Wet Solid Processing	Concept Design
	High Level Waste	Concept Design

57. The PCSR identified constraints that will need to be applied by the licensee of a UK ABWR to ensure safety during normal operation, fault and accident conditions. Some of these constraints were in the form of maximum or minimum limits on the values of system parameters, such as pressures or temperatures, whilst others were conditional, such as prohibiting certain operational states or requiring a minimum level of availability of specified equipment. Within the PCSR these constraints were collectively described as requirements, assumptions, or Limits and Conditions of Operation (LCOs).

58. Section 18.2.2 of the PCSR presented Level 1 and 2 claims for the LWMS and identified the source of Safety Functional Claims. Various high-level claims were made (e.g. *'total liquid radioactive waste levels from UK ABWR operation are minimised by*

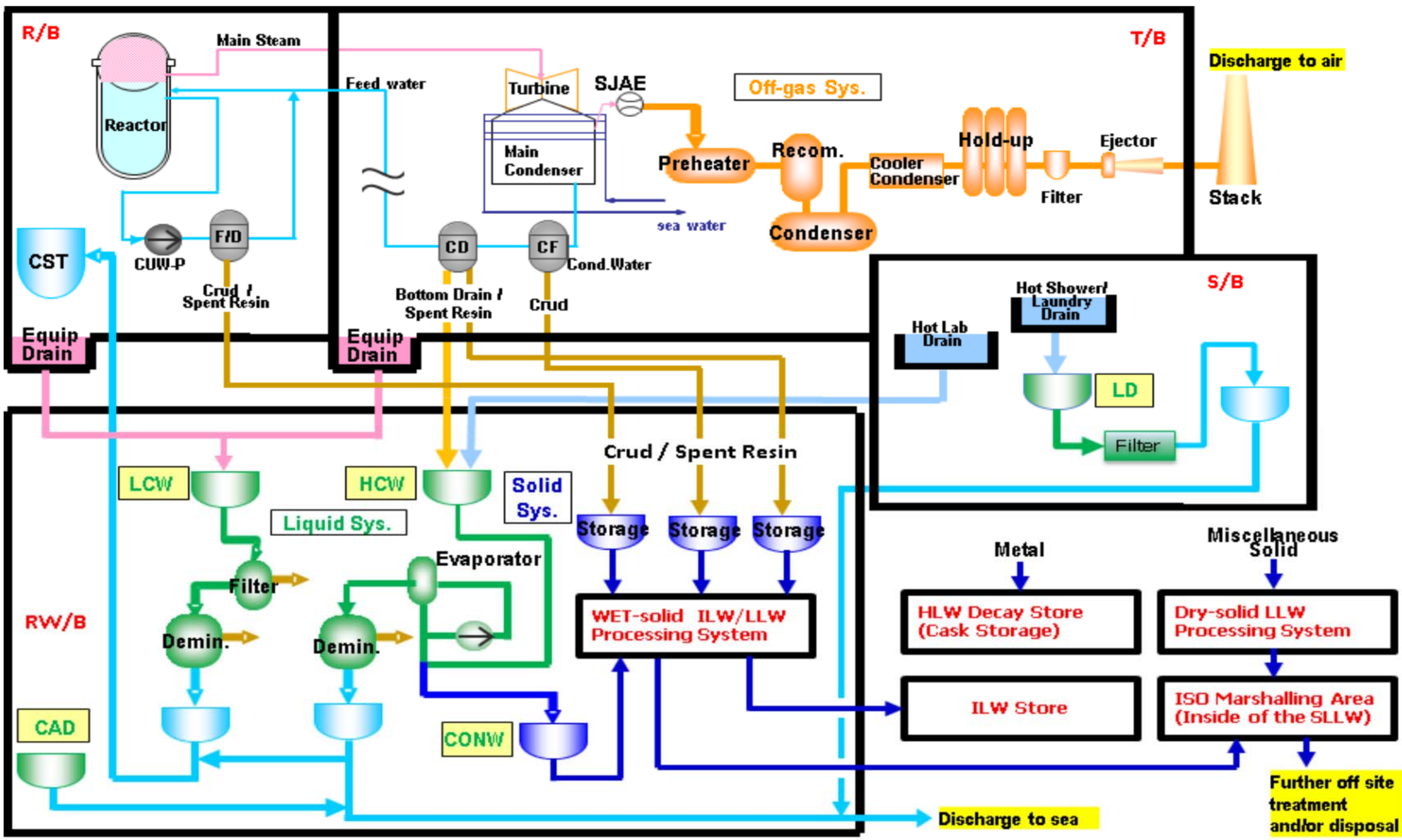
the LWMS') and many further claims were made in relation to normal operations (doses to the public and to workers) and design basis faults.

59. Hitachi-GE claimed that in the event of design basis faults, radiological consequences would be less than the currently defined UK dose limits and reduced SFAIRP. In addition there were Safety Function and Design Related Claims with design features declared to be in accordance with ISO and European Standards.

60. The PCSR described the main system features, with tables of capacities and throughput for drains, tanks and pools. The PCSR acknowledged the principles of ALARP and provided a series of flow diagrams for each subsystem, with other relevant information captured in the following Appendices:

- Appendix A – Safety Functional Claims
- Appendix B – Safety Properties Claims
- Appendix C – Document Map, which identified links to Level 1 and 2 documents in other parts of the safety case, including aspects relating to Reactor Chemistry, Radiological Protection, Environmental Protection and Mechanical Engineering

Figure 1 – Overview of the UK ABWR Radioactive Waste Treatment Systems



3.2 Liquid Waste Management System (LWMS)

61. The top-level design and operation of the LWMS was presented in Generic PCSR sub-chapter 18.2, with further details provided in BSC and Topic Report format supported by further underpinning references.

62. Hitachi-GE's stated main environmental function of the LWMS was to ensure that the activity and volume of discharges to the environment are minimised and at all times in accordance with the environmental regulator's permit. To achieve this, significant sections of the LWMS were designed to enable liquid effluents to be treated and then returned to the primary circuit for re-use.

63. Sections of the PCSR discuss the ALARP justification for the LWMS and use of OPEX, including discussion of lessons learned from world-wide operational experience and identification of relevant good practices.

64. The majority of the LWMS is housed in the Radioactive Waste Building, with some plant in the Services Building, and consists of the following subsystems:

- Low Chemical Impurities Waste (LCW) System.
- High Chemical Impurities Waste (HCW) System.
- Controlled Area Drain (CAD) System.
- Laundry Drain (LD) System.
- Spent Resin and Sludge (SS) System.
- Concentrated Waste (CONW) System.

65. The Liquid Waste Management System receives radioactive liquid waste from:

- Reactor Building.
- Turbine Building.
- Radioactive Waste Building.
- Service Building.

66. The liquid waste is primarily generated from:

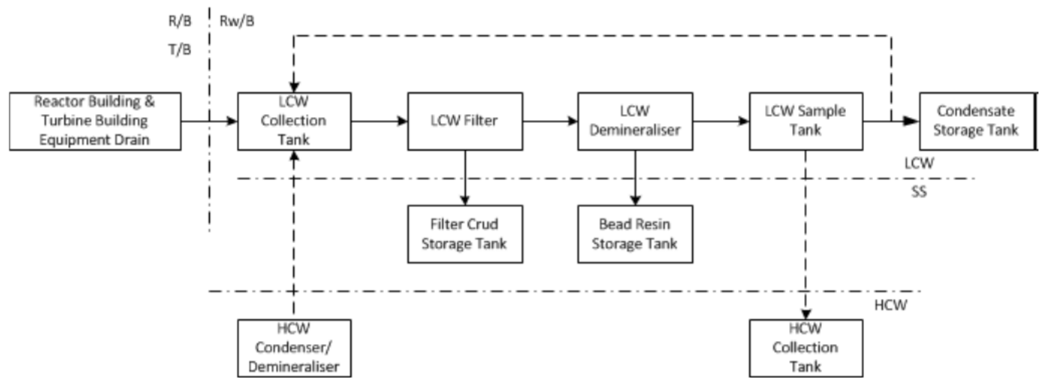
- Equipment drains.
- Floor drains.
- Chemical drains.
- Laundry facility drains.
- Controlled area drains.

67. The LCW system processes floor drain and equipment drain effluents that have a low concentration of chemical impurities and the system is therefore designed to treat relatively large volumes of effluent containing low levels of insoluble and soluble impurities. Filters are used to remove the insoluble impurities and when the differential pressure across the filter reaches a prescribed level, backwashing operations are triggered to remove the insoluble impurities collected on the filter surface. The main sources of LCW are the reactor primary coolant system in addition to the Fuel Pool Clean-up and Makeup systems.

68. As a waste minimisation measure, the LCW is designed to enable effluent to be re-used, by returning it to the primary circuit via the Condensate Storage Tank (CST).

69. In order for this route to be viable while protecting the performance of the reactor, the output from the LCW needs to align with the Water Quality Specification. Alternative routes are provided to cater for occasions when the Water Quality Specification is not initially complied with – in such circumstances effluent can be recirculated back through the LCW treatment steps, or sentenced to the HCW system as shown in Figure 2.

Figure 2: Flow Diagram for the Low Chemical Impurities Waste (LCW) Treatment System

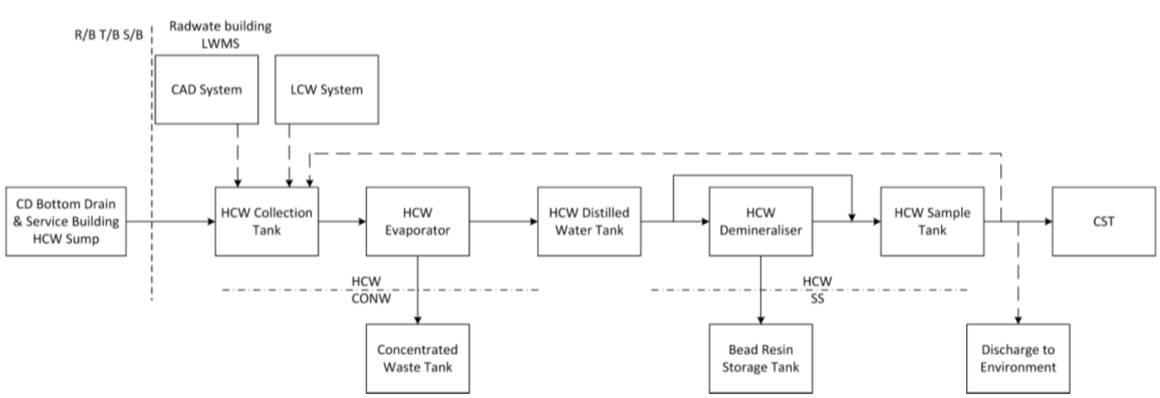


70. The HCW system is located in the Radioactive Waste Building and is provided to process that portion of the UK ABWR's radioactive effluents that typically has low quantities of radioactivity but relatively high chemical contamination including Total Organic Carbon (TOC).

71. The HCW is a single train processing system with two collection tanks and designed to be operated on a batch basis. As water in one collection tank is treated, the other collection tank receives incoming effluent. The HCW system comprises an evaporator for distillation and removal of impurities, a demineraliser for removal of soluble impurities and sampling tanks. Hitachi-GE judged that filtration was unnecessary for the HCW system, as the evaporator is designed to retain solid matter and sentence it to the CONW.

72. The main feed to the HCW are the Condensate Demineraliser (CD) bottom drain and the chemical analysis lab drains. It is also possible to route waste water consigned to the CAD system to the HCW system depending on the expected level of impurities. A link is also provided from the LCW system, such that LCW effluent that is not suitable for re-use can be diverted to the HCW if necessary. A capability is also provided to allow HCW effluent to be recirculated through the HCW treatment steps, until it meets the Water Quality Specification for re-use – at which point it can be sent to the CST.

Figure 3: Flow Diagram for the High Chemical Impurities Waste (HCW) Treatment System



73. The Laundry Drain (LD) system is located in the Service Building and processes effluent originating from the site laundry facility and Hot Shower Drain. The Hot Shower Drain effluent is generated from the hand-wash stations and shower facilities in the controlled areas. These effluent streams contain detergent, suspended solids and organic material, as well as potentially low levels of radioactive material.

74. The LD system treatment technologies are filtration and activated charcoal, to remove detergents and organic carbon. If compliant with the environmental permit authorisation, the treated water is discharged. The LD system gives rise to secondary LLW solid wastes that are dewatered and placed into 200 litre drums for transfer to the Solid LLW and Wet Solid LLW facilities for conditioning and onward disposal.

75. The Controlled Area Drain (CAD) system collects effluent from notionally non-radioactive facilities in the controlled areas of the Reactor Building and Turbine Building. This includes the drains of the local air-conditioning systems and also potentially contaminated drains from other equipment systems.

76. The Spent Sludge (SS) system in the Radioactive Waste Building collects and safely stores secondary wastes in the form of:

- Spent ion exchange resin (from; the CD demineralisers, LCW demineralisers and HCW demineralisers, Reactor Water Clean-Up System and FPCMs).
- Filter crud (from the Condensate Filter (CF) and LCW filters).

77. The wet sludges and spent ion exchange resins are stored in tanks before being transferred on a batch basis for solidification.

78. The Radioactive Waste Building also contains tanks for the storage of crud and sludge from the cleaning of condensate and fuel pool water. These tanks are vented through the Tank Vent Treatment System (TVTS) and connected to the heating and ventilating system (HVAC) to control levels of in-tank hydrogen.

Basis of Safety Case on Liquid Waste Processing in the Radioactive Waste Building

79. This Basis of Safety Case underpinned Section 18.5 of the PCSR by describing the claims and supporting arguments made in respect of the LWMS, together with references to further underpinning evidence.

80. The document contained a summary description of the LWMS components, the interfaces with the SWMS and other systems in the Radioactive Waste Building.

81. The report summarised relevant operational experience taken from a range of sources such as the Electrical Power Research Institute (EPRI), the United States Nuclear Regulatory Commission (USNRC) and published papers from international conferences. This information was gathered and reviewed by Hitachi-GE, with the intent of supporting the UK ABWR waste management strategy and to identify potential improvements to the design of the LWMS.

82. Claims, arguments and evidence in respect of the LWMS were presented, as well as a summary of key Assumptions, Limits and Conditions of Operation under the following structure:

- Claims – Arguments – Evidence (CAE):
  - Safety Requirements.
  - Categorisation and Classification.
  - Claims, Arguments and Evidence Approach.

  - Safety Function Claims.
  - LWMS CAE Tree.
  - CAE Tree for Claims from Other PCSR Chapters.
- Assumptions.
- Limits and Conditions for Operation.

83. The hazard identification process that Hitachi-GE applied to the LWMS was described, together with discharge limits and ALARP considerations for normal operations and design basis faults. Finally, an engineering justification for the extant design was presented.

Liquid Waste Management System Process Description

84. This document described operational aspects of the LWMS, comprising:

- The collection and treatment of the liquid waste streams prior to treatment.
- The collection and transfer (for solidification) of the secondary waste sludge/crud, spent ion exchange resin (powder and bead) and evaporator concentrate generated during the treatment of liquid waste streams.

85. The report explained how the LWMS was designed to operate in accordance with the following operational constraints:

- The UK ABWR will operate continuously and the LWMS must not interfere with power generation.
- The UK ABWR will operate on an 18 month cycle (17 months power generation, 1 month outage).
- The UK ABWR will be operational for a period of 60 years. The report stated that the LWMS was expected to be operational for an additional 10 years after the reactor, which covered the period of time when the last load of spent fuel was expected to undergo wet storage and cooling in the spent fuel pool.
- Each sub-system in the LWMS was designed to have two collection tanks and these tanks were intended to be operated alternately for waste receipt and processing. However the LCW system was designed to have four collection tanks and two sample tanks.

86. A description of each LWMS sub-system was provided which included the process description, process feeds, capacity and control and instrumentation. Further sections provided considerations of anticipated service requirements, control and operation, maintenance and testing, ventilation, sampling and monitoring, commissioning and decommissioning. Finally, two appendices listed the major plant items and liquid waste stream classifications.

Topic Report on ALARP Assessment for Liquid Waste Management System

87. This document reviewed the risk reduction measures associated with the LWMS, taken to a HAZOP 1 study commensurate with the level of design Hitachi-GE applied in GDA.

88. The key purpose of the document was to demonstrate that the LWMS and WILW / WLLW systems will result in a final design that ensures dose uptake to workers and members of the public from normal operations and design basis faults will be reduced ALARP, with relevant good practice (from the UK and internationally) taken into account.

89. The document aimed to demonstrate how the principles of ALARP were incorporated into the design of the LWMS and WILW / WLLW systems, including the TVTS, and further optioneering studies on the HCW treatment system. The document also identified areas requiring further development in a Forward Action Plan (FAP) for the consideration of a future licensee during the site-specific stage.

90. To ensure a systematic approach Hitachi-GE applied its GDA ALARP Methodology throughout the development of the concept design and selection of options.

91. The nature, amount and locations of the radioactive waste species intended to be processed in the LWMS over the complete plant lifecycle were defined separately in the BSC.

92. A high level BAT assessment was carried out which identified the basic technologies required to minimise discharges of liquid wastes, by re-using liquors in line with the basic philosophy of ‘concentrate and contain’ rather than ‘dilute and disperse’.

93. Hitachi-GE intended to develop the LWMS design sufficiently to enable a meaningful assessment of the hazards and risks associated with operation of the TVTS, WILW and WLLW systems and solidification of wet-solid waste in the Radioactive Waste Building. This was delivered through a series of system-specific hazard identification exercises, accompanied by qualitative risk assessments, supplemented by evidence of workshops which considered the potential for reasonably practicable options to reduce risks.

94. Hitachi-GE provided an analysis of bounding faults and identified protective measures that it broadly determined will reduce risks ALARP, whilst Hitachi-GE accepted that engineering substantiation of particular systems, structures and components (SSCs) could not be fully demonstrated during the early stages of design in GDA. Whilst Hitachi-GE acknowledged that a more detailed fault assessment will need to be carried out during the site specific stage of design, it argued that sufficient work had been completed within GDA based on the bounding faults to demonstrate that the residual risks are capable of being reduced ALARP and in all cases will comply with UK exposure limits.

95. To a concept design level, Hitachi-GE considered opportunities to optimise the number of waste management facilities and the plant layout, to provide safety benefits such as minimising the potential for contamination spread and reducing the required number of penetrations. Hitachi-GE therefore sought to reduce the lengths of pipework runs between facilities and requirements for cross-site transfers, in order to reduce hazards and risks.

96. Hitachi-GE claimed that worldwide operational experience demonstrated that the processing techniques proposed for the LCW and HCW were capable of treating the expected feeds such that the system outputs will meet the Water Quality Specification to enable the liquors to be re-used in the primary circuit. Hitachi-GE also noted that no novel processes needed to be deployed and the solidified waste packages resulting from treatment of sludges and filters will comply with the current acceptance criteria for disposal in the UK.

97. On the basis of the information provided in this report and supporting references, Hitachi-GE made a judgment that the LWMS, TVTS and WILW / WLLW system designs presented in GDA, together with a range of further potential options that are not foreclosed for detailed design, will allow the licensee to demonstrate that the risks associated with these systems are capable of being reduced ALARP.

LWMS Treatment Technology Options Studies

98. Hitachi-GE presented a range of option studies for the LWMS throughout Step 4, which focussed on the selection of techniques for the treatment of the UK ABWR liquid effluents that are anticipated to arise from normal operations and design basis faults. Arguments were presented with underpinning reasoning for the selection of particular technologies, with an explanation of how the philosophies of BAT and ALARP had been applied.

99. Hitachi-GE carried out work to compare the performance of the UK ABWR against analogous facilities in Europe, Japan and America and against GDA documents for other proposed UK reactor designs including the AP1000 and UK European Pressurised Water Reactor (UK EPR). This comparison highlighted that other facilities utilised similar effluent treatment technologies, including filtration, ion exchange and evaporation.

100. The studies were based on assessed data on the expected radiological and chemical properties of the UK ABWR effluents and drew on the knowledge of technical experts from Hitachi-GE and UK specialist TSCs. However Hitachi-GE also acknowledged that further work will be required at the detailed design stage to ensure that factors such as site selection and local infrastructure are adequately considered.

101. During the course of Step 4 Hitachi-GE chose to group together its consideration of options for the LCW, LD and CAD systems and provided separate reports to justify its choice of technology for the HCW system.

102. The assumed liquid effluent waste streams and their properties for the LCW, LD and CAD systems are presented in Table 5.

Table 5: Liquid Effluent Properties for the LCW, LD and CAD Systems

Parameter	Quantity		
	LCW	LD	CAD
Volume (maximum m^3/day)	443	34.2	33.1
Volume (normal m^3/day)	62	3.6	2.7
Total Radioactivity (Bq/cm^3)	670	0.1	-
Suspended Solids (ppm)	≤ 50	50	-
Conductivity (mS/m)	≤ 5	-	-
Total Organic Carbon (ppm)	< 0.4	-	-
Chemical Oxygen Demand (ppm)	-	80	-
Normal Hexane Extract (ppm)	-	20	-
pH	5 - 8	6 - 8	7 – 10

103. A high level BAT study was performed on these waste streams, which compared potential effluent treatment options against the J-ABWR reference design. The preferred treatment options resulting from this study were:

- LCW – Filtration and ion exchange.
- LD – Filtration and activated carbon.
- CAD – Sampling and direct discharge.

104. As additional OPEX and a refined source term was considered, Hitachi-GE revisited some elements of its optioneering and concluded that it may be beneficial to dispense

with an on-site laundry in favour of using a specialist off-site facility. Hitachi-GE noted that this alternative approach would require hand-washings and shower effluent to be routed to an alternative treatment route, most likely to be provided by a modification to either the CAD system or HCW system. In recognition of the need for a site-specific commercial arrangement to be put in place to facilitate this option, it was identified for a future licensee to take into consideration during subsequent design phases.

105. Consideration of further risk reduction measures, to ensure that risks associated with the LCW, LD and CAD systems are reduced ALARP, were described in the LWMS ALARP Topic Report. The proposed treatment options were shown to be capable of complying with the Water Quality Specification, to allow reuse of treated water via the CST, as well as meeting the proposed discharge limits for the UK ABWR.

106. Hitachi-GE noted that the principal effluent treatment options advised by EPRI for LCW systems were:

- Filtration and ion exchange.
- Ultra-filtration and ion exchange.
- Reverse osmosis and ion exchange.

107. Despite being effective separation techniques, Hitachi-GE noted potential dis-benefits from ultra-filtration and reverse osmosis included increased maintenance, higher worker dose, increased pressure requirements and a susceptibility to blocking. Hitachi-GE therefore rejected these options on the basis that they did not offer any advantages over the baseline design.

108. Hitachi-GE argued that since both the LD and CAD effluent streams contain low levels of radioactivity and a relatively simple chemical composition, the main determining factors between the available options were economy and ease of use. Hitachi-GE's position in both these cases was that the selection of any additional clean-up technologies would be grossly disproportionate to the likely safety benefits.

109. During Step 4 outputs from an effluent segregation workshop resulted in the issue of a revised set of effluent data. This data principally suggested a significant reduction in the volume of effluent that will be generated and also highlighted very low levels of radioactive contamination within certain of the effluent feeds.

110. With the exception of the HCW system, the output from these workshops broadly supported the conclusions drawn in Hitachi-GE's original BAT case.

111. To investigate this further Hitachi-GE provided further considerations of the options for the HCW system and concluded that two technical options were capable of meeting all the minimum requirements while meeting the design intent of the UK ABWR – these were 'Evaporation with Demineralisation' and Reverse Osmosis. Hitachi-GE's assessment demonstrated that there was little to differentiate between the two options, but the criteria where Hitachi-GE believed an evaporator would out-perform reverse osmosis were:

- Flexibility (Technical performance) – an evaporator would be able to deal with wider variations in the composition of feed material.
- Reliability (Technical performance) – an evaporator was expected to be more reliable.
- Secondary waste (Environment) – an evaporator was expected to produce less concentrate and other secondary waste during normal operations.

112. On this basis Hitachi-GE ultimately concluded that an evaporator should be included within the HCW system for the purposes of GDA.

113. Hitachi-GE cited operational experience from the United States gathered during its considerations of the HCW technology choice, to show that it may be possible to develop combinations of techniques that are more suited to the specific characteristics of each component of the HCW stream. These were not explored in detail within the generic case, because Hitachi-GE contended that the extent of design information available within GDA would not allow the performance of candidate treatment options to be robustly assessed – due to a need for greater detail on the precise composition of each component of the HCW feed, which to some extent is dependent on the licensee's choice of operational philosophy. Therefore Hitachi-GE noted that the findings of its studies did not preclude the operator from exploring other options, including options identified from operational experience in the US.

3.3 Gaseous Waste Management Systems

114. This section summarises Hitachi-GE's safety case for the various systems within the design of the UK ABWR that will manage gaseous wastes and are considered to pose a significant hazard, whether as a radioactive waste stream or otherwise, and that require treatment in addition to the usual ventilation installed in a nuclear building.

115. On this basis the systems under consideration here are:

- Reactor Off-Gas System.
- Tank Vent Treatment System (TVTS).

Off-Gas System

116. As the Off-Gas system is directly linked to the operation of the UK ABWR reactor, Hitachi-GE's proposals for the Off-Gas system within its generic safety case were at 'preliminary design' (i.e. to the same level as that of the reactor itself).

117. The high-level elements of Hitachi-GE's safety case for the Off-Gas system were documented in Chapter 18 of the PCSR, with links to other sections of the PCSR (specifically Chapter 7 on Internal Hazards, Chapter 23 on Reactor Chemistry and Chapter 24 on Deterministic Safety Analysis).

118. Relevant safety arguments and the outline operating philosophy of the system were primarily presented in the Off-Gas system BSC (Ref. 20), Topic Report on ALARP Assessment for Off-Gas system (Ref. 28), Topic Report on Safe Management of Radiolytic Gases Generated under Normal Conditions (Ref. 45) and the Off-Gas System Design Description (Ref. 54).

119. The Off-Gas system's primary operational function is to maintain the main condenser vacuum, which is achieved by extracting non-condensable gases from the condenser. Such gases can include:

- Air that enters the Off-Gas system via the casing of the low pressure turbine.
- Hydrogen and oxygen, generated from radiolysis of the reactor water inside the reactor pressure vessel.
- Radioactive gas that may be released from fuel due to clad failures during reactor operations.

120. Following extraction of the gas from the main condenser, the Off-Gas system is used to recombine the radiolytic hydrogen and oxygen and provide abatement of radioactive gas isotopes prior to discharge of any remaining gas to atmosphere.

121. A schematic diagram to show the arrangement of the Off-Gas system is presented in Figure 4.

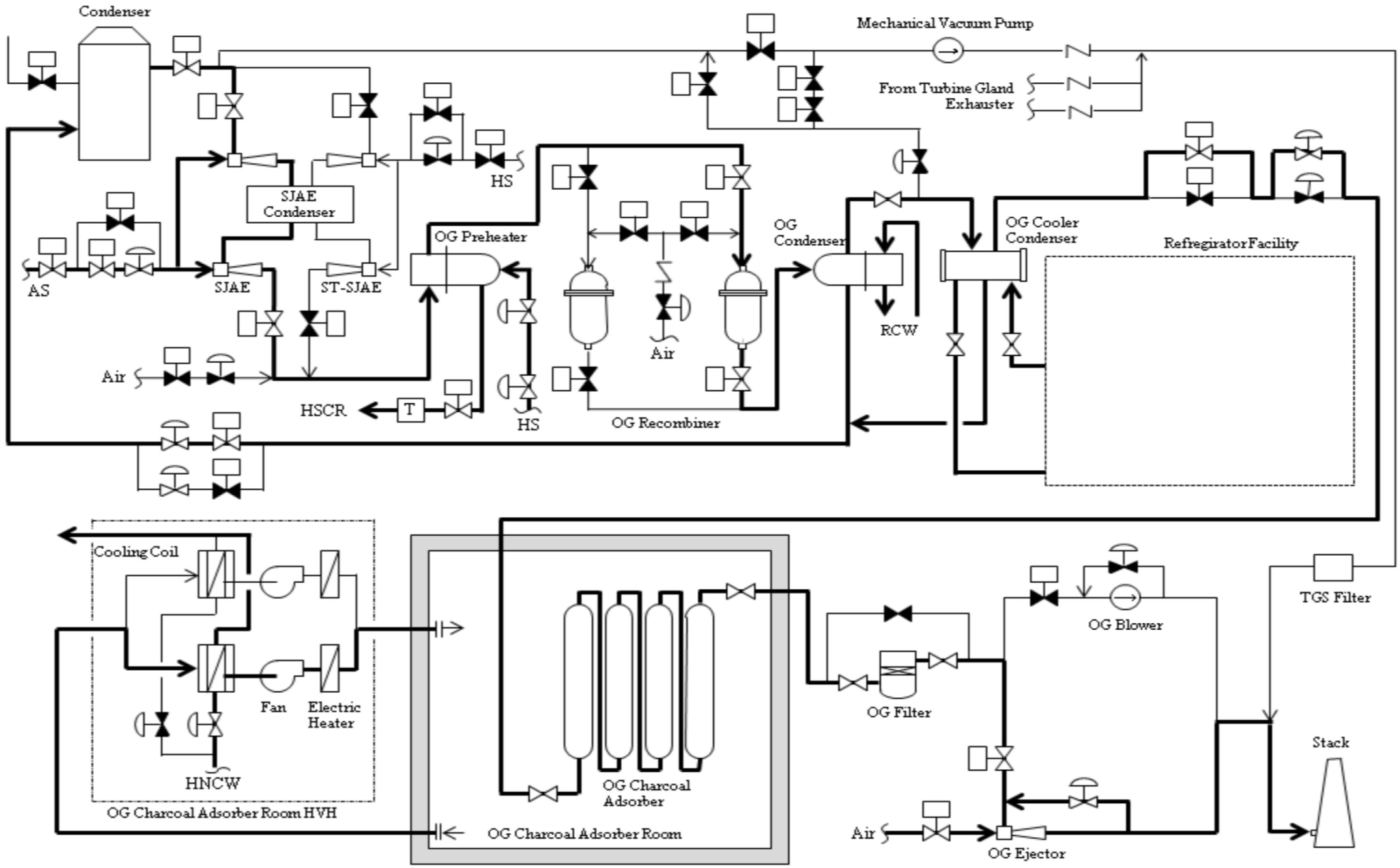


Figure 4: Schematic Diagram of the Off-Gas System

Reactor Off-Gas System Operational Basis

122. The Off–Gas system has five possible configurations, associated with three operating modes. The operating modes are:

- Start-up operation mode – which includes three different configurations.
- Rated operation mode.
- Shutdown operation mode.

123. These modes are described in the Off-Gas System BSC (Ref. 20). The configurations during start–up take the Off-Gas system through the drawing of an initial vacuum on the main condenser using a mechanical vacuum pump, then use steam ejectors to develop and maintain the vacuum during the move to at-power operations.

124. The plant configuration is arranged such that during normal power operations a two-stage steam ejector system termed the Steam Jet Air Ejector (SJAE), with an intermediate condenser (termed the SJAE condenser), maintains the vacuum on the main turbine condenser and removes the non-condensable gases. Once the gases have passed through a second steam ejector, they are pre-heated to minimise water droplets and passed through a catalytic re-combiner to remove the radiolytic hydrogen and oxygen evolved in the reactor pressure vessel during operations. The resulting off-gas is cooled, producing significant condensation. The remaining off-gas is then chilled further to produce a nominally 'dry' gas stream, which passes through activated charcoal adsorption beds to allow the decay of radioactive gases (mainly isotopes of Xenon and Krypton) by hold-up prior to passing through a final stage of HEPA filtration before discharge to the stack.

125. Hitachi-GE's overall design of the Off-Gas system is intended to have minimal moving parts during reactor operations, minimising the potential for equipment failure and delivering a relatively passive system, to reduce maintenance requirements and increase system reliability. All maintenance scheduled on the Off-Gas system is expected to be carried out during reactor outages, when the system is shut down and personnel access can be granted to the rooms holding the process plant and equipment. The operational philosophy is to exclude personnel from these areas when the Off-Gas system is operational.

126. The system is designed for an air in-leakage rate of between 4 - 40 Nominal (N)m^3/hr air, together with radiolytic gas composition of 262Nm^3/hr hydrogen and 131Nm^3/hr oxygen plus the radioactive gas isotopes and volatile isotopes from the reactor fuel. These isotopes are detailed in the Technical Support document on the Off-Gas system ALARP demonstration (Ref. 29).

127. With regard to the control of radioactive waste, the SJAE condenser is used to remove some volatile isotopes, such as iodine, but there will be some carry through into the re-combiner and condenser stages. The recombiner removes tritium from the off-gas, as tritium reacts chemically in the same way as hydrogen and thus is converted back into water and condensed out of the gas stream, in the Off-Gas condenser. Any further tritiated water is removed by the Off-Gas cooler-condenser, which cools the remaining off-gas to less than 10ºC and thus removes by condensation the bulk of any moisture carried over in the gas.

128. For radioactive gas isotopes, the gas is then fed into charcoal adsorbers which are sized to provide a residence time for adsorbed Krypton of 40 hours and a residence time for adsorbed Xenon of 30 days. This design basis is such that it provides a concentration profile that holds up the vast majority of the non-condensable active species within the first two charcoal beds with the subsequent two beds used as polishing beds to ensure a negligible radioactive isotope discharge. Any condensed

water from the Off-Gas system is returned to the main condenser for reinjection into the primary circuit.

129. The design basis for the re-combiner is to have a hydrogen concentration of 0.1% on a dry gas basis following re-combiner treatment. This removes the hydrogen hazard from the downstream plant and equipment.

Off Gas System Hazard Assessment

130. For the purposes of radioactive waste management, the Off-Gas system hazard assessment concerns the potential for faults to allow radioactive materials to be released from the system's containment boundary.

131. For the purposes of GDA, the design of systems that are integral to the reactor operation have to be suitably mature to allow hazard analysis to identify not just safety functional classification, but also the identification and classification of the SSCs that deliver those safety functions.

132. With regard to the hydrogen hazard associated with the Off-Gas system, it is noted that the design basis is for hydrogen to be in a stoichiometric ratio with oxygen and thus the potential explosive hazard is considerable. Hitachi-GE therefore designed the pipework and equipment from the main turbine condenser up-to-and-including the Off-Gas condenser to a design pressure of 2.45 MPa (Ref. 54). This pressure rating is greater than the maximum overpressure that Hitachi-GE considered may occur from a hydrogen detonation within the plant and equipment.

133. Hitachi-GE considered that after passing through the re-combiner the hydrogen hazard will be removed, but the downstream pipe-work and Off-Gas condenser are still designed to a 2.45 MPa pressure rating to address any pressure wave that may propagate down the pipe-work. To ensure that all the hydrogen is removed by the re-combiner, Hitachi-GE has provided both duty and standby re-combiners.

134. The standby re-combiner is warmed by trace heating to ensure that if it has to be brought online it is not brought online cold, as to do so may result in a loss of performance and thus a high hydrogen concentration gas passing into the downstream system.

135. The design intention is to monitor hydrogen concentration downstream of the Off-Gas cooler-condenser and if a high hydrogen level is detected an alarm will be raised. Furthermore, if the hydrogen concentration approaches the Lower Flammable Limit (LFL), the Off-Gas system isolation valves will be automatically closed. The isolation valves are the Condenser Air Extraction Valves in the Air Off Take System and the SJAE Driving Steam Isolation Valve in the Turbine Auxiliary Steam system, which effectively stop the removal of non-condensable gases from the main condenser. Hitachi-GE stated that this would ultimately cause the reactor to trip, owing to loss of the vacuum in the main condenser.

136. Hitachi GE noted that the hydrogen analyser downstream of the Off-Gas system cooler-condenser and the two valves associated with automatic shutdown of the system are given a Class 2 rating, in line with its hazard analysis (Ref. 54). Hitachi-GE stated that this was acceptable, based on the Class 1 reactor protection system which would detect loss of vacuum in the main condenser and automatically shut-down the reactor.

137. Hitachi-GE also considered a leak from the pipe-work associated with the Off-Gas system (Ref. 29) and noted that at certain points in the system the pressure is below atmospheric and thus any leaks in these areas would result in air being drawn into the system rather than gas being emitted from the pipe-work. As a result only certain areas

of the Off-Gas system have potential for gas to potentially leak into neighbouring areas. Hitachi-GE modelled a leak from the Off-Gas system into various rooms containing process plant and equipment and showed that the HVAC system for each room will avoid a large-scale hydrogen hazard by providing sufficient ventilation flows (Ref. 29). Additionally Hitachi-GE noted that a leak from the pipe-work would be detected by use of both temperature and activity monitors, which would automatically initiate a shutdown of the Off-Gas system by isolating the steam supply to the ejectors (Ref. 55).

138. The reason for drying the gas in the Off-Gas cooler condenser down to less than 10ºC is to avoid putting significant water onto the activated charcoal beds, as the presence of moisture may have a negative impact on the performance of the beds to adsorb radioactive isotopes. Additionally the environment within the room containing the charcoal adsorber beds will be maintained at 25ºC to ensure that the charcoal beds operate at a steady temperature, to avoid temperature fluctuations that could give rise to variation in charcoal bed performance.

139. Hitachi-GE considered the potential fault of a fire in the activated charcoal beds (Ref. 29) which has potential to lead to a failure of containment and release of the radioactivity held on the bed in a worst-case scenario. Hitachi-GE claimed a fire in a single bed will not propagate from one bed to the next, as the predicted thermal energy in the off-gas from the burning bed would be insufficient to ignite the downstream bed (Ref. 54). Hitachi-GE also modelled the release of activity from a charcoal bed in the event of a fire and the effect it would have if the activity was released via the stack, or if the activity was released within the room following a containment failure as a result of a fire. The worst-case dose assessment for both workers and members of the public is based on a charcoal adsorber containment break.

140. On the basis of the hazard analysis presented by Hitachi-GE the charcoal adsorbers were rated as Class 2 SSCs.

Tank Vent Treatment System (TVTS)

141. The TVTS is the system installed in the Radioactive Waste Building to address the off-gas from wet waste storage tanks. These tanks typically hold wet radioactive fine solids and sludges prior to the wastes being conditioned into a passive safe waste form, for either disposal as Low Level Waste (LLW) or storage as Intermediate Level Waste (ILW) in the on-site ILW store.

142. The design of the TVTS put forward in the generic safety case was not as mature as that for the Off-Gas system, as Hitachi-GE's consideration of the TVTS was limited to a concept level within GDA in reflection of the TVTS being peripheral to the reactor operations. As such the generic safety case only identified the system's safety functional requirements and categorisation, but particular SSCs to deliver the functions have not been specified at this stage.

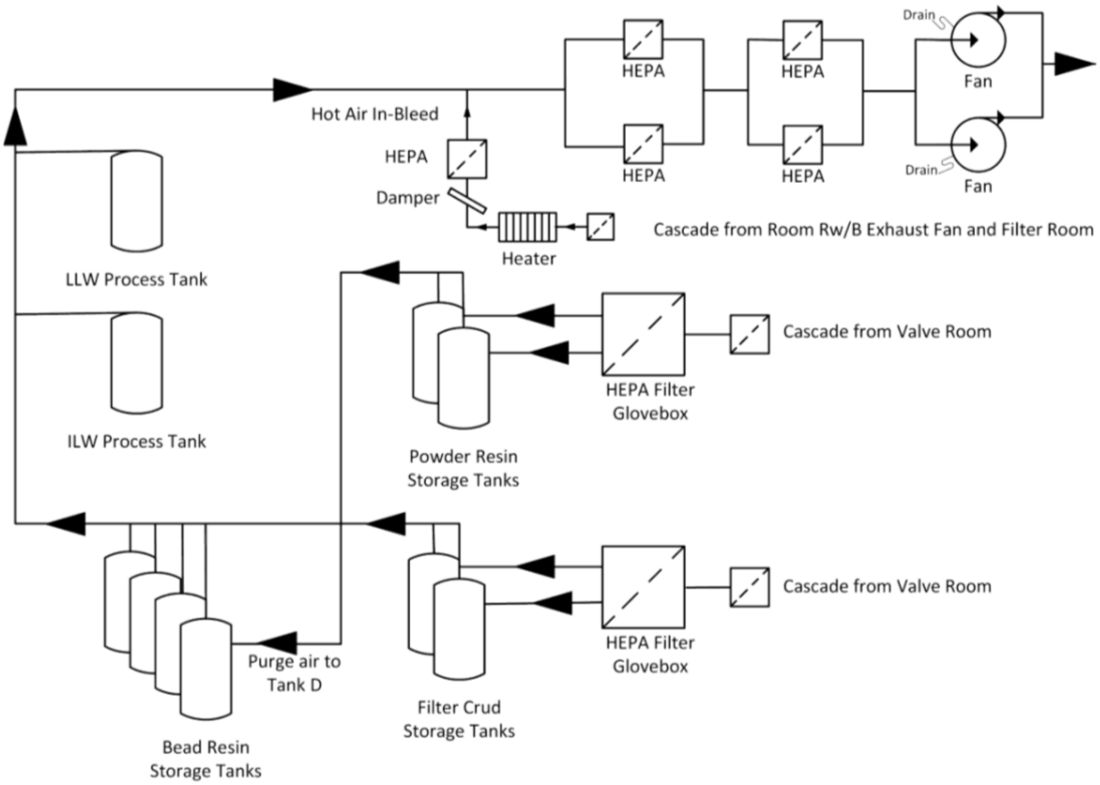
143. The safety case for the TVTS was chiefly documented in Chapter 18 of the PCSR, with links to other chapters of the PCSR (specifically Chapter 23 on Reactor Chemistry and Chapter 16 covering Auxiliary Systems). The safety arguments and outline operating philosophy of the system was presented in the Topic Report on Radioactive Waste Building Tank Vent Treatment System (Ref. 56), with underpinning information provided by the Topic Report on Safe Management of Radiolytic Gases Generated Under Normal Operations (Ref. 45) and supporting information from the Topic Report on Safe Management of Radiolytic Gases Generated Under Normal Operations (Ref. 57).

144. The primary TVTS function is to create a depression of air pressure in the ullage space of the most active tanks within the Radioactive Waste Building, so that air displaced

due to material transfers into and out of the tanks is drawn into the TVTS and thus contamination control is maintained. The TVTS also provides dilution of potentially hazardous gases which can arise within certain tanks, by providing a purging air flow through the tank ullage. These hazardous gases are typically radiolytic hydrogen and oxygen generated from active wastes.

145. The schematic arrangement of the TVTS is presented in Figure 5.

Figure 5: Schematic Diagram of the Tank Vent Treatment System



146. Hitachi-GE's proposal for the TVTS uses the following well-established ventilation technologies:

- HEPA filter air purge gloveboxes.
- Inlet HEPA filters (duty and standby).
- Extract ductwork.
- Hot air in-bled system (duty and standby).
- Primary and secondary HEPA filters (duty and standby).
- Extract fans (duty and standby).
- Controls and instrumentation.

147. During normal operations, when the tank levels are static, the tanks and associated process pipework will be maintained under a depression to minimise the potential for spread of contamination into the building. Air is drawn into the extract system via HEPA filters, which protects the external environment from back-diffusion of contamination should there be a failure of the TVTS fans.

148. The system will operate with duty and standby primary and secondary HEPA filtration and duty and standby fans, to ensure high reliability consistent with relevant good practice and current design standards. The HEPA filters both on the air inlet side and

extract side are safe-change units, to reduce the potential for spread of contamination to occur during filter changes.

149. Prior to the extract HEPA filtration, the TVTS includes a hot air in-bleed system that has both duty and standby capacity whose purpose is to reduce the relative humidity of the air flow and thus protect the filter performance.

150. The operating intent is to monitor the efficiency of the HEPA filters via standard Dispersed Oil Particulate (DOP) tests and if they are still achieving the required efficiency filters will be changed on a five yearly interval.

151. The operational arrangement of the duty and standby running of the fans is yet to be determined and has been left to a future licensee to define.

152. As part of the design of the TVTS, Hitachi-GE undertook a hazard assessment, which had limited scope owing to the system being at the stage of concept design within GDA. As such the assessment identified safety functional requirements for the various systems and the main hazards and faults only.

153. The main faults associated with the TVTS are loss of containment and build-up of hazardous/flammable gas resulting in a deflagration/detonation in either the tank ullages or ductwork, with a resulting spread of contamination.

154. Hitachi-GE addressed the reliability of the system's ventilation and filtration functions by using duty and standby filters and fans to provide the necessary reliability in line with relevant standards (Refs. 60 and 61). Treatment of the expected secondary wastes, principally contaminated filters, is considered as part of the treatment of solid wastes noting that the TVTS filters will be treated similarly to the active ventilation filters from the Reactor Building. Other minor arisings of secondary solid wastes from the TVTS are expected to be compatible with treatment and disposal via the SWMS.

155. Hitachi-GE estimated hydrogen generation rates for the expected waste streams in the tanks (Ref. 56), to provide a basis to determine the required purge rates through each tank to ensure hydrogen does not build up to hazardous levels in the tank ullage. Hitachi-GE considered the design basis event of a loss of ventilation flow from either a complete fan failure or complete power failure, within which the available safety margin was demonstrated by providing the time for various tanks to reach both 25% and 100% of the LFL of hydrogen in air – in effect setting a time limit for flow to be reinstated. Hitachi-GE also considered that should ventilation reinstatement prove difficult, the operator could drain down the most challenging tanks to reduce the source of hydrogen and increase the ullage space volume, thereby diluting radiolytic gas and providing further time to reinstate the TVTS.

156. As part of the hazard assessment, Hitachi-GE considered the rupture of a tank as a result of a hydrogen deflagration/detonation and stated that the cell structure containing the tank will withstand the event such that it will continue to provide effective bulk shielding and containment functions (Ref. 27).

3.4 Solid Waste Management System (SWMS)

157. Hitachi-GE provided a concept level design for the UK ABWR SWMS, which is expected to receive, sort and process all the solid Low Level Waste (LLW), Intermediate Level Waste (ILW) and High Level Waste (HLW) anticipated to arise from the site operations. This includes secondary wastes (such as spent filters and resins) generated by the LWMS, HVAC and TVTS. Hitachi-GE's generic case for the SWMS centres on Chapter 18 of the PCSR and is principally supported by a SWMS Basis of Safety Case and SWMS ALARP Demonstration amongst other references.

SWMS Basis of Safety Case

158. Key elements of the SWMS are:

- Solid waste processing including the LLW Marshalling and Monitoring Area (LLW MMA).
- LCW filter packaging room.
- Solid Waste Facility (SWF).
- HLW decay store.
- Wet-solid ILW (WILW) processing system (part of the Radwaste Building).
- Wet-solid LLW (WLLW) processing system (part of the Radwaste Building).
- ILW Store (ILWS).

159. Hitachi-GE intends that solid LLW will be packaged and consigned off-site for either incineration, compaction, recycling (in the case of recyclable metals) or direct disposal.

160. The SWMS is designed to be capable of processing and conditioning ILW into a passively safe form prior to a period of on-site storage pending availability of the UK's planned GDF. The WILW processing system is intended to be operated remotely on a batch basis, to control the waste inventory in the process cell and reduce the associated hazards to workers from design basis accidents. Prior to being solidified the WILW is contained in tanks, located inside shielded cells equipped with leak detection systems to ensure escapes from the tanks will be detected and the operators informed. The system allows sufficient capacity for decay storage of powder resins prior to solidification, to allow the process cell shielding requirements to be optimised against the engineering requirements of handling encapsulated waste.

161. The anticipated solid HLW arisings are activated metals from non-fuel in-core removable components that will be subjected to high levels of irradiation (such as control rods, neutron monitors, power range monitors, traversing in-core probes and neutron source units). Although these wastes are expected to be HLW when they arise, Hitachi-GE believes they will decay to ILW during the period of on-site storage prior to disposal. Hitachi-GE's proposed strategy for solid HLW is based on a period of wet storage and cooling in the Spent Fuel Pool, followed by export from the Reactor Building and dry interim storage in casks prior to final repackaging and subsequent disposal to the GDF.

162. Schematic flow diagrams of the main SWMS systems are provided in Figures 6 and 7 below.

Figure 6: Flow Diagram for the Solid ILW and HLW Systems

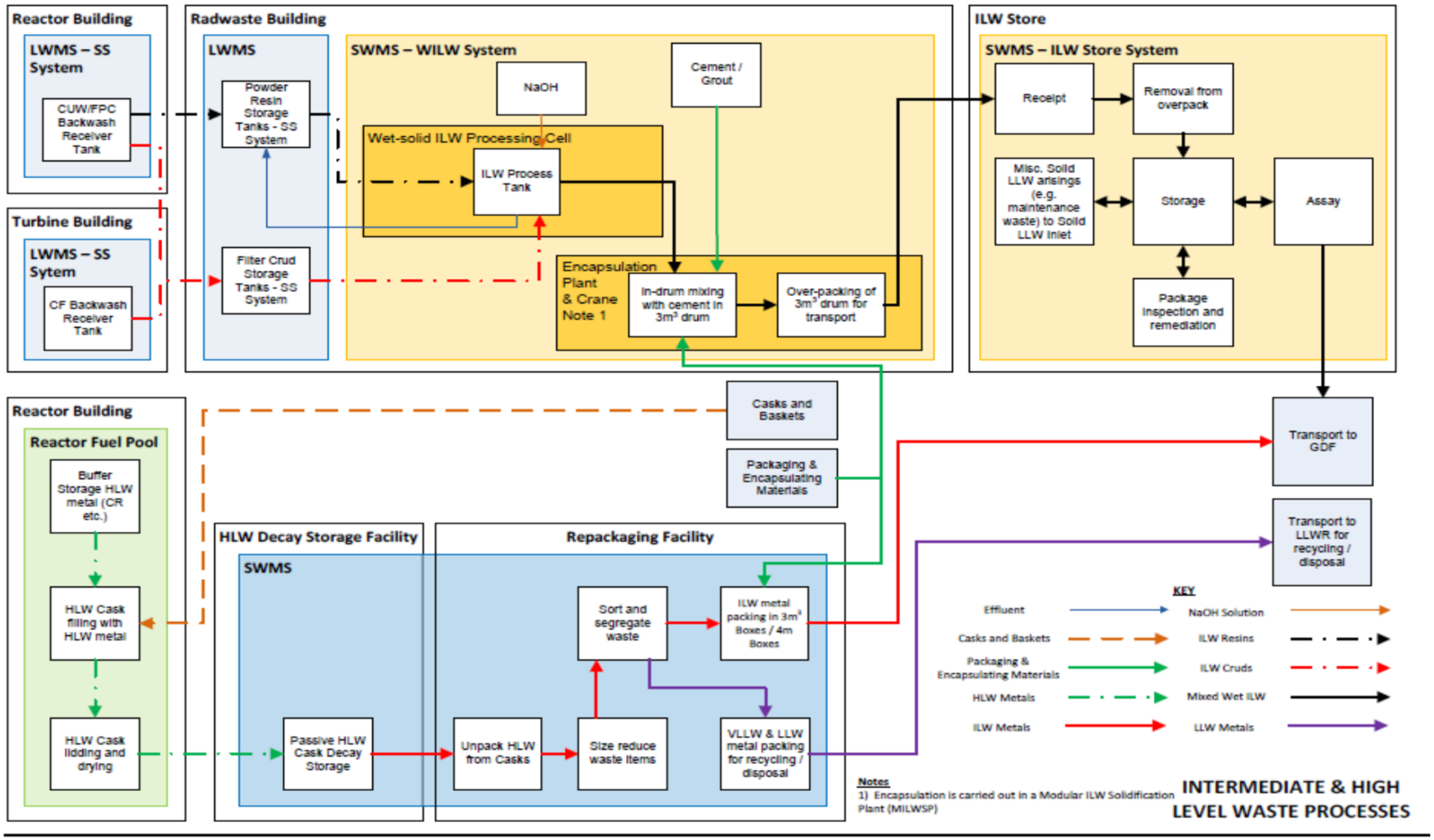
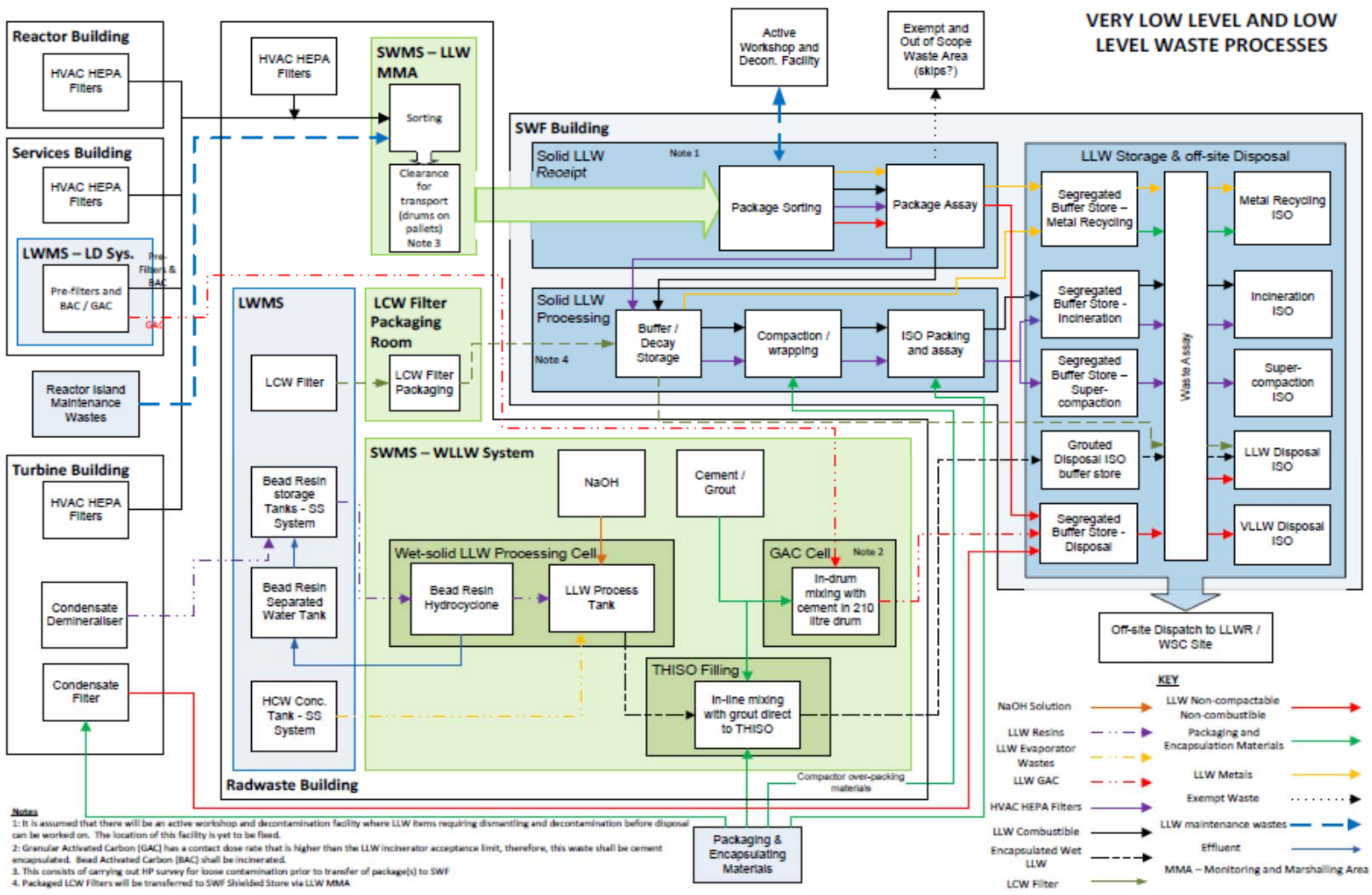


Figure 7: Flow Diagram for the Solid LLW and VLLW Systems



SWMS ALARP Demonstration

163. Hitachi-GE's original proposal was for the WLLW/WILW processing systems to be located in separate buildings. Hitachi-GE later concluded that the major hazard in this layout was the length of the pipes needed to transfer wet wastes and the potential for a pipe rupture to give rise to an off-site release. The WLLW/WILW processing systems were therefore relocated into the Radioactive Waste Building such that any leak or escape will be contained within the building structure through appropriate use of secondary containment. A key role of the WLLW / WLLW systems is to ensure that risks from wet solid radioactive waste are reduced to a level which is ALARP through successful processing and abatement, prior to waste disposal.

164. The LLW Marshalling and Monitoring Area (LLW MMA) is located on the ground floor of the Radioactive Waste Building and has the purpose of receiving solid waste from the Reactor Building, Turbine Building, Service Building and elsewhere in the Radioactive Waste Building in packages (drums, boxes, bags and wrapped items). Each package will be monitored to ensure compliance with on-site limits, prior to being transferred out of the controlled areas to the SWF. The philosophy of the LLW MMA is to transit waste packages promptly, rather than being used as an interim store.

165. The SWF will provide a centralised facility for consignment of wastes for conditioning, treatment or disposal. Hitachi-GE intends that all solid LLW from across the site will be consigned off-site for disposal via the SWF, unless the waste can be consigned directly from the facility it arises from. To achieve this, Hitachi-GE anticipates that waste will be sorted and segregated at source as far as practicable in order that the waste can be disposed via the most appropriate route. The SWF will provide:

- Limited sorting activities.
- Low force compaction.
- Package assay.
- X-ray scanning of packages to identify mis-consigned items.
- Waste storage on racks or a Shielded Drum Store.
- Decay storage of Bead Activated Carbon (BAC) drums derived from the LD system in a separate shielded room.
- Limited re-packaging of waste.

166. Anticipated waste streams at the SWF are:

- Third Height ISO containers filled with grouted WLLW.
- Condensate Filters, in third-height or half-height ISO containers.
- Miscellaneous combustible waste.
- Mixed non-combustible waste.
- High Efficiency Particulate in Air (HEPA) filters.
- Metals.
- Bead Activated Carbon and Granulated Activated Carbon.
- LCW filters in 500 litre drums.

167. The main safety requirement for the SWMS design is that radiation exposures to the public and operators are kept below prescribed limits and demonstrably reduced SFAIRP. Towards this end, Hitachi-GE provided an ALARP assessment to demonstrate the risk reduction measures that had been considered in the concept design, based on high-level fault assessments that used bounding scenarios and inventories to give an indication of potential consequences.

168. The steps employed to deliver the ALARP assessment were:

- Identification of the major hazards presented by the SWMS.
- A consideration of OPEX and good practice.
- Confirmation of the source term for the SWMS.
- Selection of preferred options for waste strategies and processing techniques.
- A holistic consideration of any impacts for other relevant waste streams.
- Identification of the major hazards and faults associated with specific SWMS systems.
- Adoption of hazard reduction measures.

169. Hitachi-GE carried out optioneering exercises for each step of waste generation, handling, processing, storage and eventual disposal of the various SWMS waste streams. This included a single study to form the holistic strategy for managing solid LLW, covering HEPA filters, Bead Activated Carbon, Granular Activated Carbon, spent filters and pre-filters, miscellaneous combustible and non-combustible wastes.

170. Each area of the SWMS was subjected to a HAZID study and FMEA to identify major hazards and design features to prevent or mitigate the hazards. Actions were placed to consider additions and changes to the design, some of which were enacted during GDA while others were captured in a Forward Action Plan for further consideration during detailed design by a the licensee.

171. Hitachi-GE acknowledged that it was not possible to provide a fully substantiated assessment of risk against the concept design SMWS within GDA as sufficient detail on the relevant SSCs will only become available at the site specific stage.

172. Hitachi-GE further acknowledged that the SWMS will need to be available for an additional period of time after the reactor finally shuts down, to help facilitate decommissioning of the site.

4 ONR STEP 4 ASSESSMENT

173. This assessment has been carried out in accordance with internal guidance on the Mechanics of Assessment within ONR (Ref. 7).

174. During the early stages of the GDA, management of radioactive wastes proved to be a challenging topic for Hitachi-GE due to a number of influential factors that had impacts for several areas of the generic safety case – for example:

- Management of radioactive wastes is subject of many UK-specific policies, standards and constraints, such that many of the established Japanese practices are not recognised as relevant good practice for a new facility based in the UK.
- The need to define and justify the UK ABWR source term, in order that Hitachi-GE could objectively demonstrate that the intended waste management methods are technically viable.
- The need for a systematic and comprehensive consideration of non-reactor faults, in order to meet ONR's expectations in respect of Fault Studies and Probabilistic Safety Analysis.
- The need to apply a design approach to the plant associated with management of radioactive wastes that met ONR's expectations for Chemical Engineering.

175. Related weaknesses in Hitachi-GE's early submissions led ONR to raise a broad range of Regulatory Issues and Regulatory Observations across several technical areas, the resolution of which has required Hitachi-GE to undertake a significant volume of work through the GDA.

176. By the end of Step 4 Hitachi-GE made considerable progress and demonstrated improved appreciation of UK expectations in a suite of revised safety case submissions provided to the regulators and achieved the closure of all relevant RIs and ROs.

4.1 Scope of Assessment Undertaken

177. During the GDA of the UK ABWR, ONR has:

- Assessed all the submitted revisions of the Hitachi-GE documents listed in Table 3 of this report.
- Requested and assessed additional detailed references from Hitachi-GE.
- Held technical discussions in Level 4 meetings with Hitachi-GE.
- Provided advice and guidance to Hitachi-GE on ONR's expectations for an adequate consideration of the management of radioactive wastes within GDA.
- Raised Regulatory Queries (RQs) (see Annex 5).
- Assessed the adequacy of Hitachi-GE's responses to the RQs.
- On a multi-disciplinary basis considered the inter-linkages between Hitachi-GE's submissions for the management of radioactive wastes and other parts of the UK ABWR safety case.

178. No Regulatory Issues (RIs) were raised directly against Hitachi-GE's submissions for the management of radioactive wastes during Step 4. However the management of radioactive wastes was a relevant consideration to two RIs that were raised in other assessment disciplines during earlier steps in GDA (Reactor Chemistry and

Probabilistic Safety Analysis) and were closed during Step 4 – these are summarised in Section 4.3.

179. A single Regulatory Observation (RO-ABWR-036) was raised directly against Hitachi-GE's submissions for the management of radioactive wastes during Step 3 and Hitachi-GE's work to resolve RO-ABWR-036 continued until the end of Step 4. Specific aspects of the management of radioactive wastes were also relevant to several additional ROs that were raised in other assessment disciplines (including Reactor Chemistry, Mechanical Engineering, Process Engineering and Radiological Protection). These ROs are summarised in Section 4.4.

180. Management of radioactive wastes involves a wide range of radiological and conventional safety hazards. Priorities for ONR's scrutiny were informed by the key principle of ONR's Enforcement Policy Statement – that the requirements of safety should be applied in a manner that is commensurate with the magnitude of the hazard. Therefore during this assessment ONR targeted the features of the UK ABWR that were of greatest relevance to the hazards and risks of managing radioactive wastes. Due to the status of the UK ABWR design within GDA, ONR also prioritised for scrutiny those radioactive waste management systems that were presented at a preliminary level of design (as opposed to concept design) within Hitachi-GE's generic safety case.

181. The specific evidence sought by ONR included:

- A demonstration that the design complies with the expectations of UK law, policies and regulatory standards applicable to management of radioactive wastes.
- A clearly defined and adequately documented radioactive waste management strategy.
- A demonstration that Hitachi-GE's proposals for managing radioactive wastes are deliverable using current technology.
- Justification of significant assumptions, to demonstrate that Hitachi-GE had adopted a precautionary approach to the uncertainties that are inherent to the consideration of waste management during the early stages of design.
- Challenge of specific design features, targeted on areas of the plant that will give rise to the greatest hazards and risks in the management of radioactive wastes.
- A demonstration that the intended operational regime had been challenged to reduce the hazards and risks of managing radioactive wastes ALARP.
- Arrangements to ensure any significant impacts on the management of radioactive wastes are taken into account during design changes and process modifications.
- A demonstration that the design will allow a future licensee to deploy an appropriate hierarchy of hazard control measures in the management of radioactive wastes, in respect of the principles of: Eliminate, Reduce, Isolate, Control, Personal Protective Equipment and Discipline (widely known as 'ERIC–PD').
- A demonstration that all SSCs expected to play a role in the management of radioactive wastes can realistically meet the duties claimed of them, in terms of both functionality and length of service.
- Clear and traceable links between underpinning data, Topic Reports, the PCSR and other parts of the safety case which concern the engineering of the relevant SSCs.

4.2 Assessment

4.2.1 Strategic Approach to Management of Radioactive Wastes

182. In addition to PCSR Chapter 18, Hitachi-GE provided a range of submissions within Step 4 which expressed the intended waste management strategy for the UK ABWR in order to demonstrate compliance with relevant UK government policies, UK law and regulatory expectations including ONR's SAP RW1.

183. Principal among these submissions were the Integrated Waste Strategy (IWS) (Ref. 19) and Radioactive Waste Management Arrangements document (RWMA) (Ref. 25), within which Hitachi-GE explained its policy and objectives in relation to the UK ABWR wastes, identified all the anticipated UK ABWR waste streams and demonstrated that a strategy was in place for each type of waste that can be delivered using current proven technology.

184. The IWS and RWMA also provided an effective high-level overview of the relationship between the UK ABWR safety case and the submissions that supported Hitachi-GE's engagement with the Generic Environmental Permit process as assessed by the Environment Agency.

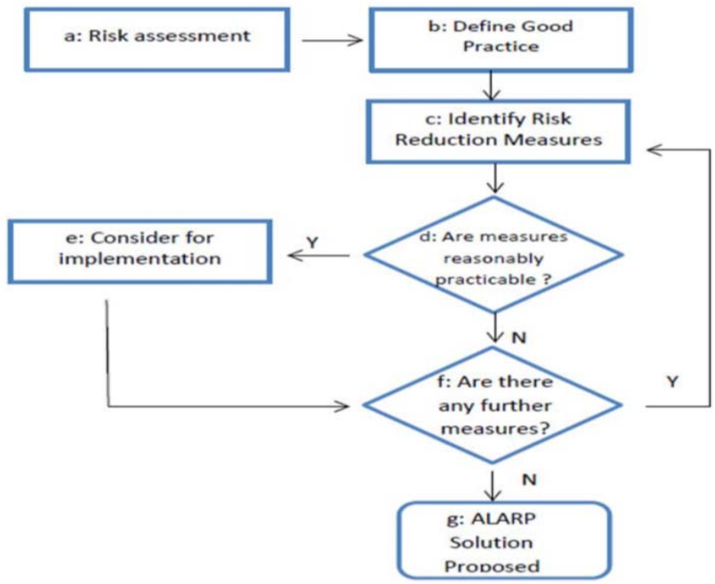
185. Within the IWS and its supporting documents Hitachi-GE demonstrated a full understanding of the key strategic level constraints associated with management of radioactive wastes on a licensed site within the UK, including:

- UK waste categorisations.
- UK legislative requirements relevant to safety and environmental protection, inclusive of the Ionising Radiation Regulations 1999.
- Availability of disposal routes for radioactive wastes within the UK, the associated waste acceptance criteria and packaging requirements.
- UK government policy and the associated regulatory expectations in regard to management of Higher Activity Wastes and spent fuel, inclusive of the expected timescales for delivery of a UK GDF.

186. It was evident throughout Step 4 that Hitachi-GE ensured the IWS and RWMA were updated in light of changes to other parts of the safety case, most importantly in response to revisions in the UK ABWR source term data. Hitachi-GE also demonstrated to my satisfaction that the strategies in place for wastes generated through the operational phase were adequately aligned and integrated with the intended approaches during decommissioning.

187. Although some aspects of the UK ABWR were presented at a conceptual level of design within GDA, Hitachi-GE demonstrated that it put in place a systematic process to enable a proportionate consideration of options, based on its GDA ALARP Methodology. The ALARP methodology enabled a comprehensive assessment of options and aligned with ONR expectations by incorporating; the assessment of risks; identification of current day relevant good practice; development of candidate risk reduction measures and a consideration of which potentially worthwhile measures may be reasonably practicable to implement.

Figure 8:
Hitachi-GE's GDA ALARP Methodology



188. Hitachi-GE's application of its GDA ALARP Methodology to the UK ABWR radioactive waste management systems was essential to address ONR's expectations in RO-ABWR-0036.A1 sub-actions (1) and (2), in respect of ensuring chosen options will reduce risks SFAIRP and that a process of optimisation had been followed and integrated into the generic safety case.

189. ONR applied a rigorous challenge to Hitachi-GE's practical application of the methodology to the major UK ABWR radioactive waste management systems during this assessment. In some instances ONR discovered some residual matters and these matters are aligned with the Assessment Findings raised within this report.

190. Hitachi-GE demonstrated a pragmatic approach to capturing potential design changes, which allowed those design changes that aligned with concept design to be implemented within GDA, while other suggested changes were taken forwards to subsequent stages of design via auditable methods in the Forward Action Plan.

191. PCSR Chapter 18, the IWS, RWMA and other supporting documents made extensive reference to the waste hierarchy and the need to ensure that the generation of radioactive wastes will be prevented or minimised so far as reasonably practicable. Importantly Hitachi-GE demonstrated that its considerations of the waste hierarchy principles was not limited to the submissions focussed on management of radioactive wastes, but were also reflected in those parts of the generic safety case that will have an impact on the ways in which wastes will be generated (most importantly Reactor Chemistry).

192. I judged that the IWS, RWMA and PCSR were robust in allowing Hitachi-GE to structure its generic safety case in a manner that took account of on-site interdependencies (e.g. between the SWMS and LWMS, consigning facilities, waste processing facilities and waste stores) and thereby enabled the management of the UK ABWR waste streams to be considered on a site-wide basis. This also provided a logical demonstration of the management of each type of waste from the point of arising through to the final steps of processing and consignment for disposal.

193. Due to the immature nature of some relevant parts of the UK ABWR design within GDA, it was not possible for Hitachi-GE to fully substantiate aspects of the waste management strategy against the expectations ONR would normally apply to a mature

operational power station. For example, full compatibility of the waste management strategy with the safety cases of all relevant facilities could not be demonstrated where the specification of particular SSCs was not available within GDA.

194. In these circumstances Hitachi-GE applied assumptions that a future licensee will need to take account of in the subsequent stages of detailed design, commissioning, operation and decommissioning. Therefore ONR rigorously challenged Hitachi-GE's use of assumptions in targeted areas of the safety case throughout Step 4, with a particular focus on potential sensitivities for the design, the presence of any 'cliff edge' effects and the importance of a future licensee being able to adopt and respond to the GDA assumptions in the right context.

195. From this section of assessment, I concluded that Hitachi-GE had developed a strategy for managing the radioactive wastes expected to arise from the operations of the UK ABWR that accords with UK law, UK government policy and ONR's regulatory expectations.

4.2.2 Disposability of the UK ABWR Higher Activity Wastes

196. In accordance with the regulators' expectations for GDA, Hitachi-GE sought an assessment from RWM Ltd (on behalf of NDA) of the disposability of the Higher Activity Wastes (HAW) and spent fuels expected to arise from operation and decommissioning of the UK ABWR. RWM Ltd reported that: *"ILW and spent fuel from the operation and decommissioning of a UK ABWR should be compatible with plans for transport and subsequent disposal of higher activity wastes and spent fuel… and the assessment process has not identified any significant issues that challenge fundamental disposability of the wastes and spent fuel expected to be generated from operation of such a reactor".*

197. In the course of its assessment, RWM Ltd identified 27 areas for further consideration (23 related to management of ILW and 4 related to spent fuel), which was consistent with expectations at this stage of the design due to the preliminary nature of Hitachi-GE's proposals and the relatively high-level assessments performed within GDA. Some of the areas identified by RWM Ltd were relevant to Hitachi-GE's proposals for the management of radioactive wastes from the site's operational phase.

198. RWM Ltd made its findings in the expectation that further development of the inventories, packaging plans and performance of the packaged wastes will be undertaken by either the Requesting Party or a future licensee. Within its response to RWM Ltd, Hitachi-GE noted that the absence of any major issues suggested much of the further work would be best addressed at the site specific phase of design and I agree that this is a reasonable approach.

199. Full resolution of RWM Ltd's advice will therefore require the input of a future licensee. Potential also exists for a future licensee to make choices on the UK ABWR detailed design and operations that may have an impact for the disposability of the station's HAW and spent fuels. If these choices were to give rise to non-disposable HAW it would not result in a non-compliance with UK law, but may impact the ability of a future licensee to achieve the ultimate delicensing of the site. I have therefore captured this residual matter in **Minor Shortfall MS-ABWR-RW-01** (see Annex 7).

200. From this section of assessment, I concluded that Hitachi-GE's approach to managing the Higher Activity Wastes (HAW) expected to arise from the operations of the UK ABWR is consistent with UK regulatory expectations and the UK government policy for new build reactors.

4.2.3 Liquid Waste Management System

Low Chemical Impurities Waste (LCW) System

201. This section of assessment focused on:

- The operation of the LCW system and its capability to meet the criteria for liquid effluent to be re-used, sentenced for onwards processing in other systems, or discharged to the environment.
- Hitachi-GE's proposals for the secondary solid and sludge wastes that will be produced from the processing of effluent in the LCW.
- The LCW system's response to fault conditions that could cause discharges of out-of-specification liquor into the CST or leaks and escapes from the system's containment boundary.
- A consideration of the design basis for the LCW, to ensure that the system will achieve the necessary water quality whilst reducing risks ALARP. This included an examination of the challenge to the LCW during normal operations and reasonably foreseeable events, together with the operational constraints placed upon the LCW.

202. I noted Hitachi-GE's intent to segregate waste liquors at source and then aggregate similar liquors together for processing on the basis of certain characteristics and considered this to be relevant good practice. Similarly, the principle of recycling LCW effluent back into the primary circuit and spent fuel pool is considered to be a relevant good practice in line with ONR SAPs RW.2 and RW.4.

203. In terms of the design basis feed to the LCW, within various documents (such as the BSC, Process Description, Water Quality Specification, Basis of Design and Process Flow diagrams) Hitachi-GE provided an operating basis and predicted condition for the inlet LCW feed that consisted of a range of conductivity, particulate and volume data.

204. However the basis of this data was not adequately explained, as it was not clear at which stage in the reactor's operating cycle the peaks in feed will occur – therefore the nature of challenge to the LCW system was not fully quantified within the generic safety case.

205. For example, the BSC stated that the peak flow rate of feed to the LCW was expected to be 443m³/day during reactor outages (with the typical throughput being 62m³/day), the liquid conductivity being a maximum of $5x10^3$μS/m (with an average of $1.5x10^2$μS/m) and a suspended solids content of 50ppm. However the documentation did not describe when or how these characteristics were expected to occur, for how long, whether they were mutually exclusive (e.g. is high conductivity and/or high particulate content going to coincide with high outage flow), or whether the quoted criteria were linked to reasonably foreseeable events when the reactor is at power or during start-up.

206. The Process Description stated a maximum flow rate and a normal flow rate, but also an annual daily average rate of 27.8m³/day and this raised questions regarding the operating intent of the system. Whilst ONR's assumption was that the tanks are intended to operate on some form of batch cycle basis, this had to be inferred as it was not made explicit within the safety case, which therefore failed to adequately describe the nature of the feed to the LCW.

207. Given that Hitachi-GE's design of the LCW was partly justified on the basis of designs at similar pre-existing plants, as presented in both the Water Quality Specification and

options studies, ONR would expect the preliminary design to include the specification of feeds to the LCW from the various stages of the reactor's operating cycle.

208. ONR would also expect the key system constraints to be set and justified in terms of both normal operations and reasonably foreseeable events, to allow subsequent detailed design and operational delivery of the various treatment stages to be bounded and confirmed as suitable.

209. Furthermore, the definition of the LCW feed was difficult to follow from the perspective of radioactive waste management as the generic safety case provided little discussion of the anticipated radioactive contents of the feed, which was covered in the Source Term documents only (Refs.58 and 59). Hitachi-GE presented both 'best estimate' and 'design basis' activity levels, which appeared to address both a point load and a cycle average. However, Hitachi-GE failed to explain when and how the design basis point load will occur and for how long this challenge will be imposed on the LCW - these factors could reasonably be expected to impact on the operability of the LCW system and doses to the workers in the locality.

210. On the basis of the evidence presented by the Requesting Party, it was difficult to assess the feed in the manner expected by ONR SAPs RW.4 and EPE.1. I have therefore captured this residual matter within **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

211. With regard to the discharge criteria from the LCW, Hitachi-GE outlined the functional requirements in its Water Quality Specification. This report did not directly give values for the LCW discharge, but presented an over-arching specification for the feed provided to the CST from where effluent can be recirculated into the primary circuit. It is noted that the design intent is to feed the LCW and HCW treated water streams into the CST and on this basis the CST Water Quality Specification is assumed to impose requirements on the LCW performance.

212. Hitachi-GE's CST Water Quality Specification makes a statement that during power operations the CST water quality is to be the same as the reactor power water values. However the case was not clear on whether this applied during start-up and shut-down of the reactor and the case was also unclear regarding the expected TOC contents of the CST water during power operations, as the reactor power operations specification did not give a value for this component of the effluent. The Water Quality Specification did contain an expectation that any organic content would breakdown during power operations, giving rise to an increase in water conductivity and this could be used as a proxy for TOC content. However, Hitachi-GE provided no clear correlation between TOC content of the CST water and conductivity of the liquor in the reactor power operations specification – thus the safety case did not clearly explain what specific control levels will be applied.

213. In several of its submissions Hitachi-GE stated that if the LCW output is found to be outside the scope of the Water Quality Specification, the liquid will be sent back to the LCW collection tanks and recycled through the LCW treatment steps. However Hitachi-GE did not objectively define what levels will generate a recognised need to recycle. Although Action Level 1 is given in the Water Quality Specification, it does not define the Water Quality specification that will initiate the LCW recycle function. Additionally the values given for this action level are presented as the equivalent of Action Level 2 values for the reactor power operations. From this aspect, action level 2 values would drive an investigation and possibly bringing the reactor to a cold shutdown state as defined in the Water Quality Specification. Thus for the specific LCW liquors, ONR would expect the generic safety case to include a clear set of limits and a definition of what action will be taken in response to those limits being reached, rather than vague wording in the Water Quality Specification.

214. The Basis of Safety Case (Ref.21) stated that in 'rare events', LCW liquor will be sent to the HCW system for processing. ONR would therefore expect the safety case should provide a clear definition of a 'rare event', together with clear objective criteria that define when the effluent transfer operation from LCW to HCW will occur.

215. At the preliminary level of design, ONR would expect the system design basis should establish the criteria for such actions to be taken and the waste streams re-routed. It was notable that Hitachi-GE did not define what it meant by a 'rare event' in this context and thus whether this was within the design basis. Given that a contingency has been defined within the safety case, I would have expected the conditions that require waste to be re-routed to the HCW from the LCW sample tanks to be part of the design basis. However, Hitachi-GE's position was unclear and I therefore captured this residual matter within **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

216. Hitachi-GE's stated design life of the LCW was 60 years operating life, plus 10 years for effluent treatment post-shutdown. However, the additional 10 year period only covers the stated timescale for the reactor's last load of spent fuel to be cooled in the spent fuel pool prior to its removal from the reactor building. Therefore the stated design life for the LCW does not appear sufficient to cover the requirements of commissioning, or any effluent treatment required during decommissioning and decontamination of the spent fuel pool and reactor pressure vessel. I have therefore captured this residual matter in **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

217. The LCW process as presented by Hitachi-GE is a two-stage process, the first stage being filtration to remove insoluble items from the liquid stream, followed by ion exchange to remove the soluble species. The ion exchange stage is intended to remove both Cations and Anions to reduce the overall conductivity of the liquid to allow it to be returned back to the reactor via the CST in line with the Water Quality Specification.

218. The basis on which Hitachi-GE selected the treatment technologies to apply to the two LCW process steps was presented in the options study (Ref. 51), which compared the 'filtration and ion exchange' option with other similar options. 'Filtration and ion exchange' was considered by Hitachi-GE to be the baseline approach, as it was consistent with the approach used on current Japanese reactors and as such has a known pedigree. However the study as presented did not clarify the criteria associated with the selection of options, in terms of how the options are differentiated and/or what the functional requirements and delivery criteria were – in terms of overall performance, with regard to the design basis feed. In this context ONR noted the unique elements of the proposed UK ABWR Reactor Chemistry regime and sought assurance that adoption of HWC with OLNC would not invalidate the Japanese OPEX.

219. The options study as presented was restricted to a consideration of three options and provided no discussion of how the three options were derived, how the three options will meet the operating requirements based on a design basis feed envelope and the discharge requirements. Furthermore, there was no explicit consideration of the secondary wastes that will be generated by each of the options and their overall safety performance, including any issues of maintenance and operability.

220. Therefore Hitachi-GE's consideration of treatment options for the LCW lacked clarity and did not provide a rigorous demonstration that risks will be reduced ALARP. In recognition that this situation does not foreclose the licensee from implementing further treatment options, I have captured this residual matter in **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

221. With regard to the required performance of the filtration and ion exchange steps, Hitachi-GE's explanation of the process requirements was found in the Options Study

(Ref. 51), which stated that for the baseline option a reduction of 99% in contamination in the effluent was expected, and in the Topic Report on ALARP (Ref. 27) which stated that a removal rate of 99% of insoluble species and 99% of active soluble species was the intended operational requirement.

222. It was evident to ONR that the above requirements were not listed in the Assumptions or Limits and Conditions given in the PCSR. I also noted that the Process Flow Diagram (Ref. 34) had a performance function that can be derived from quoted feed information, as the design basis fed to the filtration system was ≤ 50ppm solids and the outlet was ≤0.1ppm solids, giving a reduction percentage of solids of 99.8%.

223. Actual plant data Hitachi-GE quoted for an operating LCW system in Ref.51 showed a solids reduction percentage of 99.96% and thus demonstrated that the system as defined should meet the functional requirement. However, when considering the active insoluble species passing through the LCW, the Source Term documentation (Refs. 58 and 59) showed an activity reduction of insoluble specifies post filtration of only 90%. Therefore there is a significant disconnect between the stated design intent for the solid content, in terms of removal (ppm) and the insoluble source term in terms of radionuclide reduction, which was not adequately explained. Therefore I have captured this residual matter in **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

224. There were similar discrepancies between other documents that Hitachi-GE supplied in regard to the process design information.

225. As a highlighted example, the Basis of Design (Ref. 62) gave the capacity of the LCW collection and sample tanks as 177m³, whereas the Process Flow Sheet (Ref. 34) had a collection and sample tank capacity of 171m³ and the Process Description (Ref. 33) gave a working volume of 133m³ - assuming a maximum working volume as 80% of the overall tank volume this gives a total tank volume of approximately 166m³.

226. While non-alignment of these values at the concept stage of design may not be significant for safety, the widespread inconsistencies gave rise to concerns about the clarity of Hitachi-GE's communication and the rigour of Hitachi-GE's control of the documentation.

227. In a number of cases Hitachi-GE also provided a significant amount of spurious precision that would not normally be associated with a concept design and may have contributed to difficulties in controlling the design development and safety documentation. While this has not given rise to an Assessment Finding, as I consider this to be something to be addressed in the detailed design stage as part of normal business, it did lessen ONR's confidence in the overall control of the documentation and Hitachi-GE's expressed understanding of the objectives of concept design.

228. However, it is important for the process concept design to provide a clear description of the operation of the system and its integration with the rest of the LWMS and in these aspects the generic safety case contained some shortfalls. For example the discharge of the LCW is sentenced to the CST, the CST is also fed from the HCW and when necessary, as outlined in the Water Quality Specification (Ref. 46), purified water – with priority given to recycled liquors from the HCW and LCW. When the cycle average best estimate source terms were considered, I discovered that the quoted concentration of activity in the CST from both soluble and insoluble species (for radionuclides such as Cs-137 and Co-60) was higher than that given in the feed from both the LCW and HCW systems. There appeared to be no process reason as to why activity would concentrate in the CST, especially for soluble species. This gave rise to a concern over how the values had been derived and how they link with one another as the effluent is recycled. Given that derivations of source terms are significant matters for the robustness of the design, I have captured this residual matter in **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

229. Furthermore, the concept design of the LCW, in terms of its integration into the other parts of the LWMS, was not properly defined. ONR would expect the design intent and operating criteria to have been assessed and confirmed during the concept design stage, in order to ensure that the operations required of the various inputs and outputs from the LCW can be safely managed in the context of the overall LWMS.

230. For example Hitachi-GE recognised a potential requirement for collected LCW liquor (prior to treatment) or sampled LCW liquor (post-treatment) to be sent to the HCW for further processing. However, the quoted operating volume of the LCW collection and discharge tanks was $133m^3$ whereas the capacity of the HCW collection tanks was limited to $48m^3$. Further to this point, the treatment rate of the HCW was given as $1.8m^3/hr$ – thus to treat $133m^3$ of out-of-specification LCW liquor would require approximately 3 full days of HCW operations facilitated by a series of transfers between the two systems.

231. Therefore ONR would expect the safety case should provide an understanding of how liquor transfer between the LCW and HCW will occur and be controlled, to ensure the ongoing operability of both systems whilst this treatment method is implemented. However Hitachi-GE's generic case did not provide any explicit consideration of these aspects, which I considered to be a shortfall in the underpinning of the concept design in relation to SAPS RW.1, RW.4 EPE.1, EPE.2 and EPE.5.

232. Additionally, part of the regime of the LCW is to mix the tanks to take samples for analysis and thus allow the liquid to be sentenced appropriately. However Hitachi-GE's generic case did not acknowledge the potential impact of this requirement on the operations of the LCW, including the time required to carry out analysis of samples prior to allowing liquor to be released. ONR would expect this type of operational constraint to have been recognised at the concept design level, even if the depth of consideration was limited to the use of reasonable estimates and assumptions. Therefore this residual matter has been captured in **Assessment Finding AF-ABWR-RW-01** (see Annex 6).

Controlled Area Drain (CAD)

233. This section of assessment covers the CAD system as a whole, given the broad nature of the system and focusses on the operations, hazards and events that could cause the collection and discharge of inappropriate material to the environment and how this has been considered within Hitachi-GE's generic safety case.

234. The CAD system provides collection of liquid effluents from drains within the active areas of the facility that may give rise to suspect active wastes but are much more likely to be clean liquors arising from air conditioning units and other clean systems within the active area.

235. The system is designed to collect the liquor into one of two tanks, which once full will be mixed and sampled. If the sample indicates that the liquor is clean the liquor is discharged to the environment through the site discharge system. If the liquor does not meet the discharge requirement, it is sent to the HCW system. However the generic case did not provide a clear definition of the expected design basis feed to the CAD and the criteria that would lead to a decision to divert liquor to the HCW.

236. Within the quantification of discharges and limits document (Ref. 63) there was a statement that the CAD system is not included in the discharge assessment, as for normal operations it only collects condensate water from local cooling units and coolant water blow from the Reactor Building and the Turbine Building.

237. Ref. 63 also stated that only during an 'accident condition' would the waste water collected in the CAD be contaminated with radioactivity. ONR noted that this argument

appeared to be inconsistent with Hitachi-GE's approach to non-radioactive species, as the criteria for effluent diversion from the CAD to the HCW included non-radioactive components such as chemical contamination (e.g. oils and greases) that may arise from what Hitachi-GE referred to as 'reasonably foreseeable' events.

238. ONR noted the potential for radioactivity to spread and contaminate areas in the RCA over the lifetime of the plant and thereafter enter the CAD system – if this was not the case, there would be no need for routine health physics surveys to provide assurance of the control of contamination in those areas. Therefore ONR would reasonably expect that this situation would be addressed in the CAD safety case.

239. CAD discharges were not explicitly considered in the Water Quality Specification (Ref. 46). The proposed approach to sampling and monitoring (Ref. 64) discussed the radioactive species criteria for discharges, in terms of the species to be analysed, but did not provide any values or criteria in terms of limits other than the values required as the detection limits in Bq/m^3 in line with the European Union Basic Safety Standard 2004. However, the Other Environmental Regulations document (Ref. 65) provided the generic discharge criteria for CAD waste in terms of pH, chemical oxygen demand (both daily maximum and daily average), suspended solids concentration (both daily maximum and daily average) and finally a limit of normal hexane extracts (at a maximum value per day).

240. The Other Environmental Regulation document (Ref. 65) also contained a set of criteria that showed the limits for transfer of CAD liquor to the HCW and these mimicked the general discharge limits in terms of chemical composition, but in terms of radioactive species appeared to be on a Bq/yr value for both tritium and other radionuclides. The case was not clear in explaining whether this was a limit of detection value, or if the values were a rolling yearly average and/or how this situation would address potential spikes in the CAD feed owing to potential contamination spreads over the site's lifetime.

241. Although this section of Hitachi-GE's generic safety case lacked clarity, I do not believe given the relatively low hazard represented by the CAD system that there was a requirement for an associated Assessment Finding within GDA. However I do believe that the situation warrants further regulatory engagement during the next phase of the design.

High Chemical Impurities Waste (HCW) System

242. The purpose of this section is to consider the methods selected by the Requesting Party to process the HCW feed and to assess whether these methods are capable of delivering the ALARP solution and are appropriately justified and substantiated in accordance with the level of the design in GDA.

243. The description and function of the HCW system within the LWMS was summarised in Section 3. Hitachi-GE's justification of the design identified relevant legislation and regulatory guidance then described the consideration of options that was applied and the outputs from an accompanying workshop.

244. Using this methodology and assessment criteria Hitachi-GE determined that only 2 options, i.e. Reverse Osmosis or Evaporation combined with Ion Exchange, complied with the minimum functional requirements for the HCW system and all other options were rejected.

245. It is noted that some options were rejected on the grounds of being incapable of treating the organic components of the HCW feeds. However Hitachi-GE overlooked the potential for proven process technologies to be added to the scope of these

options, perhaps in sequence, which would deliver the required performance. In my opinion this oversight unduly restricted the scope of the options that were considered.

246. I also noted that Hitachi-GE's consideration of options for the HCW appeared to have been disproportionately influenced by an objective of reducing environmental discharges to a minimum, rather than seeking to achieve an appropriate optimised balance between the on-site and off-site aspects of risk as is normally expected in the combined demonstration of both ALARP and BAT. This led to a lack of clarity and rigour with respect to Hitachi-GE's assessment methodology from an ALARP perspective that significantly weakened the justification for rejecting potentially viable abatement technologies.

247. ONR is aware of potential technical challenges to the operability of evaporative technology, some of which were reflected in Hitachi-GE's own submissions during Step 4, which concern:

- Limitations in the ability to effectively treat waste streams with high TOC due to foaming.
- The effectiveness of corrosion inhibitors in addressing the accelerated corrosion rates that can occur due to the concentration of salts.
- Conventional safety aspects.
- A likelihood of an evaporator needing to be replaced within Hitachi-GE's projected 70-year lifespan.

248. Furthermore Hitachi-GE's final justification for the adoption of an evaporator (Ref. 50) noted that OPEX from the United States indicated further combinations of treatment technologies for the HCW may provide worthwhile benefits for safety, but Hitachi-GE believed the effectiveness of those further technologies could not be determined within GDA due to insufficient data being available on the component parts of the HCW feed.

249. This does not necessarily mean that the selection of an evaporator would not be a suitable or acceptable technology for the UK ABWR, but in arriving at that choice ONR would expect a more robust and logically argued consideration of treatment options that incorporates both BAT and ALARP and effectively deals with the potentially competing requirements. Therefore this residual matter has been captured in **Assessment Finding AF-ABWR-RW-02** (see Annex 6).

250. From this section of assessment I concluded that Hitachi-GE had demonstrated that it was technically feasible for the liquid effluents that are expected to arise from normal operations of the UK ABWR to be effectively managed, using proven technology.

4.2.4 Systems to Manage Gaseous Radioactive Wastes

Off Gas System

251. This section covers ONR's consideration of Hitachi-GE's generic safety case for the UK ABWR Off-Gas System from a radioactive waste management perspective and is broken down into a number of specific technical aspects of the system that ONR has sampled for the purpose of this assessment.

Off Gas System Design Basis Feed Gas

252. The purpose of this section is to consider whether the design-basis feed stipulated by Hitachi-GE is suitably conservative in relation to key design parameters and flowrates, in order that it forms a robust basis for the design of the Off-Gas system. It should be additionally noted that the design-basis feed also sets the system's inherent hazard

parameters and thus constrains the various hazard management strategies undertaken to ensure safety.

253. Key aspects of the Off Gas feed are the generation rates of hydrogen and oxygen in the turbine main condenser. The values provided are 262Nm³/hr of hydrogen and 131Nm³/hr of oxygen. These values are based on the operation of pre-existing worldwide BWRs that utilise Normal Water Chemistry (Ref. 28) and are based on a radiolytic gas generation rate of 0.1 Nm³/h/MW (thermal).

254. It should be noted that the UK ABWR is currently being designed to operate with Hydrogen Water Chemistry and Online Noble Metal Chemistry, which is a departure from the Japanese OPEX. The aim of these additional measures is to reduce the generation of corrosion products in the primary circuit and the impact of radiolysis on the structure and also reduce the amount of hydrogen that will be evolved during normal operations. Detailed discussion and analysis of this arrangement is provided in ONR's Reactor Chemistry assessment report (Ref. 8).

255. The source term of radioactivity carried over in the Off-Gas System is directly dependent on the source term derived for the reactor during normal operations and this has also been addressed by ONR's Reactor Chemistry specialists as part of their overall assessment. On this basis, the analysis is not repeated here.

256. In response to ONR query, RQ-ABWR-0783, Hitachi-GE presented the operational information with regard to radiolytic gas generation on a variety of plants (Ref. 66) that showed the actual radiolytic gas rate to be around [redacted] below the theoretical values of 0.1 Nm³/h/MW (thermal). It is noticeable that the operational values are from plants that do not operate the intended water chemistry for the UK ABWR and as such it is anticipated that the actual radiolytic gas values may actually be lower still. This shows that the design basis values provided by Hitachi-GE are conservative and are likely to be fault tolerant. On this basis I considered the position to be acceptable in line with SAPs EKP.3 and EPE.1.

Off Gas System Process Assessment

257. The purpose of this section is to consider the processes that have been put in place to manage the radiolytic and radioactive non-condensable gases from the main turbine condenser and thus the suitability of the processes to address the radioactive waste management approach.

258. The Off-Gas system uses steam ejectors to help ensure the main condenser vacuum is maintained and that the non-condensable gases are removed and treated promptly. The recombination of radiolytic hydrogen and oxygen is carried out by passive catalytic processes. Following removal of moisture by condensers, the radioactive species are removed by passive adsorbtion onto activated charcoal beds, designed to ensure that the period of hold-up of the species is sufficient to allow it to decay prior to discharge via HEPA filtration through the site stack and into the external environment. The dry off-gas is drawn over the charcoal beds by use of an air ejector downstream of the beds.

259. The passive nature of the gas transfer systems can be considered to be relevant good practice, as these systems do not have seals or direct electrical power requirements, require minimum maintenance and use current technology. Additionally the use of passive systems helps minimise the potential for sources of ignition in the event of a fault condition that may cause the radiolytic hydrogen to react. This is in line with ONR's expectations in relation to SAPs EKP.3 and EKP.5.

260. Furthermore, the use of charcoal adsorbers to remove and hold-up the radioactive species is a passive system that requires no moving parts and again is in line with the

regulatory expectation of SAPs EKP.5 and EKP.3 and is considered relevant good practice in line with operating experience worldwide. However, ONR has raised an Assessment Finding within the Reactor Chemistry assessment on the potential for a guard bed to be deployed in order to protect the charcoal adsorbers against moisture ingress (Ref. 8) and I support the Reactor Chemistry position.

261. The Off-Gas System design is in line with ASME III to provide a basis for the structural integrity of the system and to demonstrate that the ductwork and process plant and equipment will not leak. A particular focus is the ductwork and process plant and equipment between the second SJAE and the charcoal adsorber outlet valve (Ref. 20). Although this is strictly within the scope of ONR's Mechanical Engineering assessment, the use of a recognised design code for the ductwork and process plant and equipment is considered relevant good practice and will not be considered further in this assessment. However, the pressure ratings and boundaries are considered within this report as part of the following section on hydrogen hazard management.

262. The steam used to both provide the vacuum on the main condenser by the first SJAE and also for the transport of the non-condensable gas to the recombiner and thence onto the charcoal beds is removed by condensing out in shell and tube heat exchangers. The liquid is returned to the primary coolant system in order to deliver the minimisation of wastes. The condensation process may also capture some of the volatile components in the Off Gas and dissolve them into the water, thus reducing the amount of radioactive species (principally Iodine) from the gas stream. This is particularly so in the Off-Gas cooler-condenser, where the gas is cooled to less than 10ºC and thus a considerable amount of volatile species will be removed in the aqueous stream. I consider this approach to be good practice.

263. Additionally the re-combiner, which is designed to remove the hydrogen hazard, is a passive system in line with the requirements of ONR's SAP EKP.5 and should be considered to be relevant good practice, if the performance of the recombiner is suitably justified. Furthermore, the use of a catalytic recombiner allows for the vast majority of the tritium in the off-gas to be reformed into tritiated water, condensed out of the off-gas and thus recycled back into the reactor system. This minimises the amount of radioactive material discharged and disposed of, whilst recycling and re-using the liquid waste stream and I consider this to be relevant good practice.

264. The BSC (Ref. 20) provides the key performance requirements for the Off-Gas system and states that during normal operation, the recombiner performance will be such that the resultant off-gas will contain only 0.1% of hydrogen by volume on a dry gas basis. This means that for an air-in leakage rate of between 4-40 Nm^3/hr of air, based on a design-basis feed of 262Nm^3/hr of hydrogen, the efficiency of the recombiner would need to be 99.984% efficient for a 40Nm^3/hr air feed and greater than 99.998% efficient for a 4Nm^3/hr air infeed.

265. This reactive efficiency for a catalytic system is high when compared to established systems, especially given that the UK ABWR catalyst will operate in a high steam environment which will require a very high surface area to achieve the stated high efficiency recombination of hydrogen and oxygen.

266. ONR therefore raised a number of queries during Step 4 regarding the operation of the re-combiner and its performance (RQ-ABWR-1414, Ref. 67). These queries covered a wide range of operating features, related to the justification of the operational efficiency of the re-combiners. These queries included a consideration of whether oxygen injection into the Off Gas system should be adopted in order to counteract the impact from hydrogen injection into the reactor water recirculation line as part of the intended Hydrogen Water Chemistry operating regime.

267. Hitachi-GE's response (Ref. 68) was adequate in terms of both oxygen evolution in the main condenser and oxygen/air injection in the Off-Gas system. However, ONR noted there was no mention of this design element in either the system design description (Ref. 54) or the BSC (Ref. 20) which presented the Off-Gas system high-level performance and mass balance figures.

268. However the presented justification (Ref. 68) was not appropriate, because Hitachi-GE stated that the performance of the recombiner will be justified by factory acceptance testing. A factory acceptance test is unlikely to adequately replicate the UK ABWR operating conditions over the full lifetime of the recombiner catalyst.

269. Given the high levels of efficiency stipulated, the potential consequences of hydrogen ignition, the operating environment and potential variations in gas feed, I would expect a better substantiation of the recombiner performance, which should consider the long-term nature of the Off Gas system operations and the operational cycle. Although I accept there will be a significant quantity of catalyst in the recombiner (Hitachi-GE quoted 40 layers of catalyst in Ref. 68) the generic case did not provide a performance curve for the catalyst in terms of feed concentration gradient, lifetime performance or any other basis of actual operation. Thus it was difficult to gain sufficient assurance of the catalyst behaviour.

270. Therefore ONR was provided with insufficient evidence to make a judgement as to whether there will be excess catalyst in the system and thus whether the design will be suitably conservative to achieve the design intent. Although Hitachi-GE noted that the UK ABWR design basis is some [redacted] higher than operating experience, the performance of the catalytic recombiner will still need to be around 99.97% for the 40Nm³/hr air-in bleed case and 99.997% for the 4Nm³/hr air-in bleed case and thus the overall catalytic performance will not be significantly different. Therefore this residual matter has been captured in **Assessment Finding AF-ABWR-RW-03** (see Annex 6).

271. Hitachi-GE claimed that the safety classification of the plant, people and equipment associated with the function to reduce the risk of hydrogen combustion arising from radiolytic gases was a Category C safety functional requirement and thus the SSCs associated with that requirement were Class 3. This included the catalytic recombiner. However, ONR noted that the function to prevent hydrogen combustion in the event of Off-Gas recombiner failure was given as a Category B safety functional requirement and thus the SSC's associated with that requirement were Class 2.

272. ONR noted that it would not be a normal design approach for the equipment to ensure a hazardous situation does not arise, in line with SAP EKP.3 (Table 1 Level 1 prevention of abnormal failures by design), to be of a lower safety classification than the SSCs needed to address that hazard after it has been created. This is especially noticeable as Class 3 SSCs tend to have a definable failure rate of 10^{-1} to 10^{-2} per annum and thus in a 60-year operating life, it would be reasonable to assume that the recombiner will fail to meet its safety function at some point. It is noted that the recombiner system is a duty/standby arrangement with the standby recombiner preheated to avoid any moisture formation on the catalyst and this is to provide a higher level of reliability for the recombiner operation.

273. Additionally Hitachi-GE did not explain the basis on which the duty/standby recombiners would be switched over. This was because the safety case relied on any loss of recombiner performance leading to an Off-Gas system shut down and ultimately a reactor trip, with the reactor trip recognised as the relevant safety function. Therefore the only justification within the safety case for providing two recombiners was the potential need for parallel operation during reactor start-up, as described in the Technical Support Document to the Off Gas system ALARP demonstration (Ref. 29), but otherwise there appeared to be no objective justification for the duty/standby recombiner configuration given the Class 3 claim made.

274. Given the operating intent is to shut down the reactor should the recombiner fail in a way that presents a hazardous situation and that the recombiner is designed to have the catalyst replaced, I found no real justification for the duty/standby nature of the design, other than one could consider it a potentially conservative position.

275. In order to ensure adequate operation of the catalytic recombiner, there is a requirement to preheat the gas feed into the recombiner, to minimise the ingress of water droplets. This is because water droplets that impact on the surface of the catalyst will interfere with the catalyst performance, which may lead to a hazardous condition. Hitachi-GE assessed the preheater as being a Class 3 SSC. Therefore on the basis of the assumed operational life of 60 years, it would be likely that the preheater would fail at some point – potentially resulting in a hazardous condition. The OPEX presented by Hitachi-GE in the Technical Supporting Document to the Off Gas ALARP Report (Ref. 29) confirms that failures have occurred in recombiners for multiple reasons, including moisture ingress. On this basis the residual matters have been captured in **Assessment Finding AF-ABWR-RW-03** (see Annex 6).

Off Gas System Hydrogen Hazard

276. It should be noted that the assessment of the hydrogen hazard is considered as part of the normal process operation of the Off-Gas system as hydrogen is generated and dealt with as part of the overall UK ABWR design intent, although it is acknowledged that this also has an impact on the Reactor Chemistry assessment (Ref. 8) and the Radiological Protection assessment (Ref. 11).

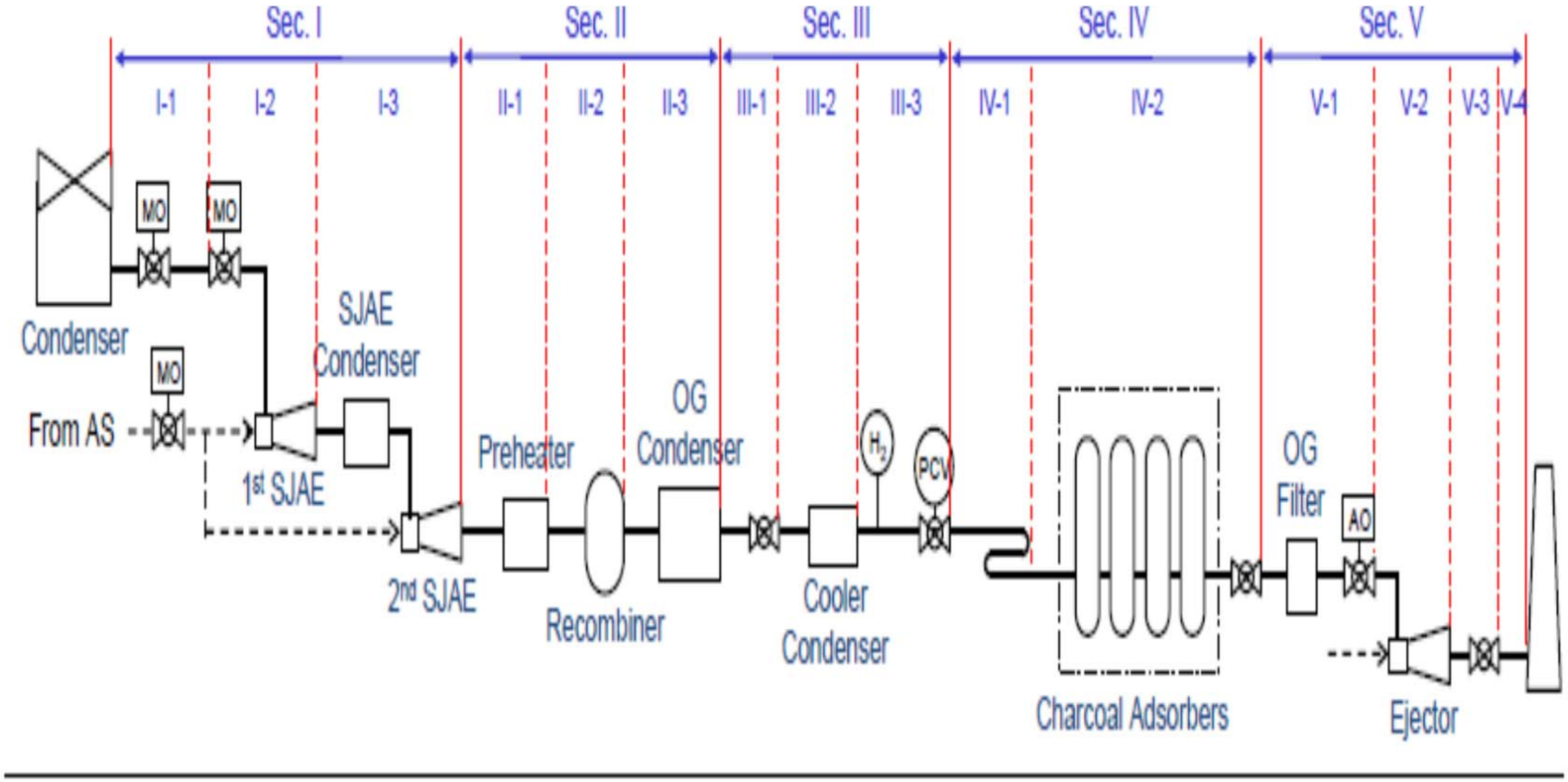
277. Hydrogen is considered on a dedicated basis within the Off-Gas system as it poses a significant fire and explosion hazard and this could be a means for releasing radioactive species outside the primary containment in an uncontrolled manner. ONR's assessment prioritised the operation of the reactor at power rather than during the start-up and shut down phase, as this is when the largest amount of radiolytic gas will be made. However, safe shut-down of the Off-Gas system in the event of a fault is considered.

278. Steam ejectors are used to provide an inert atmosphere in the Off-Gas system for transporting the non-condensable gases, including radiolytic hydrogen and oxygen, together with radioactive species. Hitachi-GE presented the composition of the off-gas at various sections in the Off-Gas system (Ref. 55) and asserted that the presence of steam will provide a sufficiently dilute environment in which a flammable atmosphere is avoided (Ref. 45 and Ref. 57).

279. For the purpose of this element of its safety case, Hitachi-GE considered the Reactor Off-Gas System in 5 discrete sections, outlined below and in Figure 9:

- Section 1 Main condenser to 2nd SJAE outlet.
- Section 2 2nd SJAE to OG condenser outlet.
- Section 3 OG condenser outlet to the Pressure Control Valve (PCV) between the Cooler-Condenser and Charcoal adsorber.
- Section 4 PCV to Charcoal Adsorber outlet valve.
- Section 5 Charcoal adsorber outlet valve to stack.

Figure 9:
Reactor Off-Gas System Sections for the Purpose of Hydrogen Management



280. The five nominated sections of the Off-Gas system are in themselves further subdivided, to provide clarity of each individual area and allow for the system to be assessed appropriately at each stage. Additionally, Hitachi-GE presented the following data on the Lower Flammable Limits (LFL) of hydrogen in a steam atmosphere to show that during the transfer operations the radiolytic gas is below the flammable limits and therefore safe:

Table 6

Lower Flammability Limits for Hydrogen in Air and Steam				
Atmosphere	Pressure	Radiolytic Gases (Hydrogen & Oxygen)	Hydrogen	Oxygen
Steam	0.4 MPa	21.8 mol.%	14.5 mol.%	7.3 mol.%
	7.0 MPa	16.6 mol.%	11.1 mol.%	5.5 mol.%
Air	Atmospheric	n/a	4 vol. %	Atmospheric

281. This assessment has considered the flow of gas through the system and given further consideration to the faults that may occur at specific points.

282. For the gas flow between the main condenser and the first SJAE as part of Section I in Figure 9 above, the gas composition is considered by Hitachi-GE to be the following (Ref. 29).

Table 7

First Stage SJAE Inlet Normal Operational Conditions (operating pressure 3.39 kPa (abs))				
Values Entering the OG system from main condenser	kg/kmol	kg/hr	kmol/hr	% by mol
Air	29	[redacted]	[redacted]	[redacted]
Hydrogen	2	[redacted]	[redacted]	[redacted]
Oxygen	32	[redacted]	[redacted]	[redacted]
steam (accompanying)	18	[redacted]	[redacted]	[redacted]

283. This gives a concentration rate of hydrogen in steam below the LFL given previously and thus in the opinion of Hitachi-GE adequate safety is delivered. However, the system operating pressure is sub-atmospheric and thus this position could be considered to be unsubstantiated as the flammability data presented by Hitachi-GE to justify safety is for a positive pressure condition and there is no discussion within the case why these values are applicable for the operating condition with the off-gas system. Note that this does not mean that the position is incorrect or unsafe, just not substantiated.

284. Additionally the condition considered is for an air-in leakage rate of 40Nm³/hr and does not cover the full envelope of air leakage presented by Hitachi-GE. If I considered the air in-leakage to be only 4Nm³/hr (at the other end of the operating envelope), assuming all other gas species are the same and that the reduction in air-in leakage does not impact on the carry over steam from the main condenser, the percent by mole concentration of hydrogen would increase to [redacted] Although still below the LFL presented in Table 6 and the Technical Supporting Document on the Off Gas ALARP report (Ref. 29), it appears that Hitachi-GE has not always considered the theoretical worst case in terms of hydrogen concentration.

285. Given the operating pressure of the main condenser is approximately 5 kPa (abs), the suction pressure at the SJAE is around 3.4 kPa (abs) and the design pressure of the pipe is 2.45 MPa, I consider that even if there is a deflagration the overpressure would not be sufficient to rupture the Off Gas system pipework. However, a resultant shockwave may impact on the surrounding structure and pipework supports with potential to cause pipe failure due to overstress, rather than overpressure. Consideration of this mechanism of pipe failure should be addressed and this residual matter has therefore been captured within **Assessment Finding AF-ABWR-RW-04** (see Annex 6).

286. I also noted that this specific gas stream did not meet relevant good practice in respect of the requirements of the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR), in that, during normal operations, the flammable gas mixture is above 25% of the LFL. However, given that this is the feed condition from the condenser as part of the operation of the reactor, it appears that no reasonably practicable measures can be taken to meet the 25% target and thus I would consider the position to be adequate. However I noted that Hitachi-GE provided little discussion to explicitly justify why it is not reasonably practicable to meet the DSEAR expectation for the gas composition and this is a shortfall in the provided argument.

287. At the first SJAE, steam is used to generate the vacuum at the main condenser and draw the non-condensable gases out of the reactor coolant and into a treatment process. The ejector routinely uses approximately [redacted] tonnes of steam at a feed pressure of around [redacted] bar. In the technical support document (Ref. 29) Hitachi-GE provided the ejector outlet gas composition, which gave a hydrogen concentration of [redacted] by mole, which is less than 25% of the quoted LFL presented in Table 7 – thus Hitachi-GE concluded that this section of the process complied with DSEAR.

288. However the LFL value quoted by Hitachi-GE is for a 0.4MPa pressure and ONR noted that the actual pressure at the outlet of the ejector will be lower, thus the LFL was not necessarily fully justified for the operating condition. Additionally, Hitachi-GE's report stated that the operating pressure at the outlet will be 16.67 kPa (abs), which ONR believes to be incorrect, as the pressure at the discharge point of a steam ejector is usually above atmospheric, even when subject to further vacuum downstream owing to the expansion and pressure loss of the steam. I consider that Hitachi-GE's quoted figure actually relates to the pressure in the SJAE condenser, which is sub-atmospheric and is achieved by condensing out the drive steam from the SJAE, approximately 4.8te of steam per hour. This raised further concerns regarding the understanding of the operation of the system presented by Hitachi-GE. It may be that the depression created by the SJAE condenser is significant enough to generate a sub atmospheric condition at the discharge of the first SJAE, but given the relatively large volume of steam involved, this would seem unlikely.

289. Furthermore, it was noted that the hydrogen concentrations presented by Hitachi-GE were for only the 40Nm³/hr case. If the lower air-in leakage rate of 4Nm³/hr is considered, the hydrogen concentration is still less than 25% of the LFL and on this basis I am content with the position.

290. However, I noted that the case, in totality, presented by Hitachi-GE was not complete or comprehensive for all aspects of the operating envelope and this was not in line with regulatory expectations. Therefore this residual matter was captured within **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

291. For the gas composition in both the SJAE condenser and the ductwork to the second SJAE, Hitachi-GE presented a worst-case outflow position in Ref. 29 as shown in Table 8 below.

Table 8

SJAE Condenser Outlet Normal Operational Conditions (operating pressure 16.67 kPa (abs))				
Values Entering the OG system from main condenser	kg/kmol	kg/hr	kmol/hr	% by mol
Air	29	[redacted]	[redacted]	[redacted]
Hydrogen	2	[redacted]	[redacted]	[redacted]
Oxygen	32	[redacted]	[redacted]	[redacted]
steam (accompanying)	18	[redacted]	[redacted]	[redacted]

292. Hitachi-GE acknowledged that this gas composition exceeded the LFL. However Hitachi-GE stated that if the gas were to ignite, the overpressure would only be a deflagration rather than a detonation and on that basis the overpressure would only increase by a maximum factor of 8, in line with a deflagration overpressure from a stoichiometric mix of hydrogen in air. Therefore Hitachi-GE claimed that even if there was an event and subsequent overpressure, it would only reach 133.36 kPa (abs) and given the design of the condenser and pipework is to 2.45 MPa the system will not fail and cause a release.

293. As noted previously, Hitachi-GE's case considered only the 40Nm³/hr air-in leakage case and if we consider the full range of anticipated air-in leakage and thus the 4Nm³/hr the resultant hydrogen concentration is approximately 16% by mole, which is around 0.3% higher than the case stated by Hitachi-GE as the worst case. In both scenarios the hydrogen concentration exceeds the LFL presented in the safety argument in Ref. 29. However Hitachi-GE's case presented LFLs at pressures (0.4MPa) significantly higher than those anticipated in the operating range of the system and thus this matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

294. ONR's expectation would be for the hydrogen hazard to be minimised at the earliest opportunity, so far as reasonably practicable, which may be earlier than the current recombiner location. Thus ONR requested Hitachi-GE to present a consideration of options and provide assurance that the use of catalytic recombination within Sector 1 of the Off-Gas system had not been foreclosed to a licensee in future detailed design (RQ-ABWR-1514, Ref. 69). Hitachi-GE's response (Ref. 70) stated that it was not technically feasible to place the recombiner between the main condenser and the first stage SJAE, as the backpressure caused by the recombiner would cause the main condenser pressure to rise and thus impact on turbine and power generation operations and I accepted this argument.

295. However, I noted that Hitachi-GE had not apparently considered any form of catalytic recombiner in either the pipe from the first SJAE to the SJAE condenser, or from the SJAE condenser to the second SJAE (Section 1-3 in Figure 9). There appeared to be no consideration of the potential to introduce any catalyst at these stages. Whilst I would not expect a full-sized recombiner to be placed in Section 2, it may be possible to achieve a worthwhile degree of hazard reduction by inserting a relatively small amount of catalyst into the pipework that will not significantly impact the system's operations.

296. The efficiency of surface catalysis is based on the surface area of the catalyst, the speed of the catalytic reaction and the concentration of reactants in the gas. As the concentration gradient declines, than so will the reactivity. I was therefore concerned that in the gaseous discharge from the SJAE condenser, when the hydrogen/oxygen concentration is highest, there was no apparent consideration of catalysis to reduce the gaseous concentration to below that considered flammable. Catalyst in this

location would not necessarily have to achieve a highly efficient conversion to significantly benefit the safety margins. While I accept that the SJAE condenser off-gas contains a significant amount of water droplets that may reduce catalyst performance, I believe that Hitachi-GE has not provided a sufficient consideration of options to demonstrate whether risks are reduced SFAIRP. The generic case showed a propensity for Hitachi-GE to consider that each individual process step should achieve the complete functionality required, rather than consideration being given to the opportunities for step-wise hazard reduction – this form of thinking appears to have artificially constrained Hitachi-GE's consideration of options from a hazard reduction perspective.

297. While the inclusion of some form of catalyst in this area may create a further stream of secondary radioactive waste, which would need to be considered and addressed, the safety case should provide an objective assessment of this detriment against the potential benefits for hazard reduction. On this basis this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

298. Furthermore, in none of the above stages did Hitachi-GE's generic safety case demonstrate how the system complies with DSEAR. If the design base values are assumed to be conservative, even with radiolytic gas rates that are 30% less in volume the result would be a hydrogen concentration during normal operations of 75% of the LFL. Although there has been some discussion and engagement on this issue with ONR's Inspectors of Nuclear Liabilities Regulation and Internal Hazards (Ref. 55), Hitachi-GE has not adequately justified why this position should be considered satisfactory beyond asserting that, "this is what the process gas streams are" and that any changes to the process would be, "grossly disproportional". On this basis this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

299. The safety case as presented notes that the gas in the SJAE condenser will be above the LFL for hydrogen in a steam mixture, and although it may ignite, there is insufficient run up distance in the condenser to allow a deflagration to propagate into a detonation. The case notes that the internal tubes in the condenser would provide "obstacles" to the flow, and thus support acceleration of a flame front, but it would be insufficient to cause a detonation. Hitachi-GE did not adequately substantiate this argument.

300. The design of most shell-and-tube type condensers is such that the shell side of the condenser is baffled to provide a tortuous path for the gas and condensable vapours to pass over the cooling tubes, providing the longest possible residence time to allow heat transfer to take place. Given the increased flow path and congested nature of the environment, I would have expected a more detailed and knowledgeable safety argument for an item in preliminary design, which undoubtedly would be similar to an existing plant configuration. I can conceive of a number of safety arguments, both qualitative and potentially quantitative, that could be presented to justify the safety of the SJAE condenser and feed pipework leading to the second SJAE, which would contain gas of a potentially flammable composition.

301. However, none of these arguments were presented in the UK ABWR generic safety case and I found the substantiation of the argument that a deflagration to detonation transition would not occur lacking. Although ultimately, the SJAE condenser and downstream pipework is designed to withstand 2.45 MPa and thus is fault tolerant in line with EKP.5, I do not consider the safety substantiation associated with the potential for the fault to occur in the first place (i.e. the generation of a deflagration of hydrogen) to be sufficient. On this basis this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

302. The consideration moves on to the gas flow from the second SJAE to the pre-heater and recombiner. As with the first SJAE, the drive steam is around [redacted] tonnes per hour at around [redacted] bar. Hitachi-GE provided in the technical support document (Ref. 29) the ejector outlet gas composition which gives a hydrogen concentration of [redacted] hydrogen by mole, which is just less than 25% of the LFL quoted in the document and represented in the table above, thus for this section, the process complies with DSEAR. The case as presented does not reflect the full envelope, but only the 40Nm³/hr air in leakage scenario; however, when I consider the 4Nm³/hr air in leakage scenario, the off gas composition is less than 25% of the LFL and thus acceptable.

303. ONR was concerned that as part of the consideration of this section of the hydrogen case (Ref. 29), Hitachi-GE presented an overpressure case in the event of deflagration, with a normal pressure of 127kPa (abs) and an overpressure of 1016 KPA (abs) (see Ref. 29, table B8). This seems unusual given the fact that the main claim is that the gas mixture in the ductwork and pipework after the second SJAE is at or below 25% of the LFL and thus not flammable. I therefore consider this an erratum in the submission of the case and will not consider the position further. At this point the gas enters the preheaters and recombiners and if operating normally then the hydrogen is eliminated from the gas stream and the hazard is removed.

Off Gas System Hydrogen Hazard Fault Assessment

304. This section considers fault situations in the Off Gas system and the potential for hazardous conditions to arise as a result of a fault. In terms of the most significant hydrogen hazard, the technical supporting document to the Off Gas ALARP report (Ref. 29) considers the worst case failure, which is complete loss of recombiner performance owing to rapid or sudden catalytic poisoning, with any subsequent steam condensed out of the gas stream by both the Off Gas condenser and cooler condenser, giving a subsequent gas composition of mostly hydrogen and oxygen:

Table 9

Loss of Recombiner Capacity – with 100% of the Accompanying and Driving Steam Removed	
Component	% by mol
Air	9.3
Hydrogen	60.5
Oxygen	30.2
Steam	0

305. Again the case as presented does not consider the actual worst case given that the range of air in leakage is 40-4Nm³/hr and that for the 4Nm³/hr scenario, the hydrogen concentration would be 65.99% by mole and the, oxygen content would be 33.21% by mole and again the scenario is not in line with the regulatory expectation of addressing the full range of the proposed design basis envelope.

306. The scenario as presented notes that the potential for deflagration to detonation transition is unlikely given that there needs to be a number of failures, but it does not explain what these systems are or quantify how they prevent/mitigate the hazard. The only identified safety system in the hazard analysis is the Class 2 hydrogen monitoring system located downstream of the cooler condenser.

307. Should there be a sudden failure of the recombiner, then the safety argument presented notes that the deflagration overpressure would be 8 times the operating pressure and the operating pressure is stated in the case as 103 kPa (abs), nominally atmospheric pressure (Ref. 29) and Hitachi-GE consider this overpressure multiple to

be conservative stating that it would not be expected to be reached as this is for a stoichiometric mix of hydrogen in air. However, Schroeder et al (Ref. 71) note that for hydrogen oxygen mixtures the overpressure from deflagration is greater, possibly up 9.5 times. This calls into question the extrapolation of data used in the technical supporting report (Ref. 29) which is based on hydrogen / air data.

308. Similarly the analysis of deflagration detonation transition considers it possible for this fault, however again the basis of this is for hydrogen in air mixtures rather than gases with an enriched hydrogen oxygen concentration. It is possible that because there is more inert gas (non-reactive nitrogen) in the hydrogen air data, the size of the detonation cells and the thus the subsequent DDT run up distances are invalid. If size of the detonation cell is over estimated when compared to the actual gas mixes, this would in turn invalidate the calculated pipe length required for deflagration-detonation transition. Therefore I cannot consider that the case presented by Hitachi-GE is demonstrably conservative or adequately substantiated and on this basis this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

309. Ultimately the safety case presented by Hitachi-GE for the complete failure of the recombiner fault (Ref. 29) is that even if a detonation occurs the equipment is designed to contain the overpressure anticipated. This is incorrect as the equipment upstream of the Off Gas condenser outlet valve (the end of Section 3-1 on Figure 9) is designed to address detonation overpressure as the design pressure is 2.45MPa, but the equipment downstream of the Off Gas condenser outlet valve is only designed to 0.11 MPa. Given the fault and hazard analysis presented in the technical supporting document (Ref. 29) acknowledges that deflagration could occur even based on hydrogen/air data rather than hydrogen/oxygen data, the design basis appears inadequate.

310. ONR has queried this position (Ref. 72) and received a response (Ref. 73) which stated that Hitachi-GE considered the position to be adequate in line with the response to a previous query, RQ-ABWR-1410 (Ref. 55). This is not a valid argument. Hitachi-GE's response to RQ-ABWR-1410 is that the fault is highly unlikely to occur, owing to the number of failures required - these being a failure of both the recombiners, failure of the hydrogen detection system and failure to manually or automatically isolate the Off-Gas system.

311. These claims are incorrect and not adequately underpinned; the fault under consideration is the sudden poisoning of the duty recombiner. As discussed previously, there is no duty/standby switchover of recombiners presented in the case and as per the assessment finding previously raised in this report there is a requirement for the licensee to justify the duty / standby change over process and operational parameters.

312. With regard to a hydrogen detection failure, the hydrogen detection system is downstream of the cooler condenser which has a design pressure of 0.11MPa and the detector will recognise that the fault has occurred and thus mitigation of the flammable/explosive atmosphere, rather than prevention, would occur. ONR queried the response time of the hydrogen detection system to a fault (Ref. 72) and the response noted that the conservative time would be 20-30 minutes (Ref. 73). Based on a hydrogen and oxygen design basis feeds of 262Nm^3/hr for hydrogen and 131Nm^3/hr of oxygen, then this would give a total gas volume in 30minutes of around 190Nm^3, which would probably be sufficient gas volume to fill most if not all of the downstream pipework including the charcoal adsorbers and thus the safety argument presented is inadequate, in terms of avoiding a flammable gas mixture in the parts of the Off-Gas System that have a design pressure of 0.11MPa.

313. Similarly if the isolation happens in line with this 30 minute timescale, then all that is achieved is mitigation with regard to the quantity of flammable /explosive gas generated and the time at risk associated with the hazard. It would not prevent a

deflagration or deflagration-detonation transition event with potential loss of containment.

314. Hitachi-GE also argues that there is no source of ignition for a flammable hydrogen mix, given that Hitachi-GE considers that the only source of ignition for a flammable mixture of hydrogen in the system is the recombiners (Ref. 55). Again this is not in line with UK regulatory expectations and good practice, in that the regulatory expectation for the frequency of ignition of a flammable hydrogen mixture is 1. This is based on the fact that the ignition energy of a flammable hydrogen mixture is low, for example for a stoichiometric mixture of hydrogen in air, the ignition energy is 0.017mJ (Ref. 75), but for a stoichiometric mixture of hydrogen and oxygen, the ignition energy is even lower at 0.0012mJ. Given the fault under consideration is closer to the latter condition and the low ignition energy required, I find the argument regarding a lack of source of ignition inadequate.

315. Furthermore, as this fault covers gas conditions closer to a hydrogen/oxygen mixture than a hydrogen/air mixture, there is need to consider the detonation energy argument presented by Hitachi-GE. Hitachi-GE considers that instantaneous detonation is not possible given the high ignition energies involved. However, this may not be the case for a hydrogen/oxygen gas mixture, indeed Matsui and Lee (Ref. 76) note that the critical energy for detonation ignition of a stoichiometric mixture of hydrogen and oxygen is 1.58Joules, whereas for a stoichiometric mixture of hydrogen in air, it is 4.16 x 10^6 Joules.

316. Also Zhang et al (Ref. 77) demonstrate that the critical ignition energy for a stoichiometric hydrogen/oxygen mixture is 8.73 joules at 298K and 100 kPa. Given these relatively low energy values for hydrogen/oxygen mixtures, this further supports the previous assessment finding regarding the need for the licensee to substantiate the deflagration and detonation safety arguments for the Off-Gas system with suitable data, rather than relying on extrapolation of hydrogen/air behaviour.

317. Finally, given all of the above, I consider the safety argument in terms of fault that may lead to a flammable atmosphere in the reactor Off-Gas system downstream of the OG condenser outlet valve to be inadequate. It may be the process plant and equipment could withstand any potential overpressure that may arise, even if the design basis does not state a credible overpressure withstand requirement and Hitachi-GE have presented some arguments to that point (Ref. 55). However, the position is not properly substantiated or justified and this residual matter has therefore been captured in **Assessment Finding AF-ABWR-05** (see Annex 6).

318. I note that the generation of a hydrogen hazard in the process outside of normal operations is predicated on the failure of the catalytic recombiner to operate in line with its specified efficiency. I have already raised an assessment finding on the justification of the operating efficiency of the recombiner earlier in the assessment. I will now consider, as part of the generation of faults, the potential for recombiner failure. The operating experience presented in the ALARP submission and technical supporting documents (Ref. 28 and Ref. 29) show that in the past recombiners have failed for a number of reasons.

319. However, Hitachi-GE presents the argument that the quantity of catalyst (40 layers) is such that sudden degradation of the recombiner would not occur (Ref. 20 and Ref. 28). Additionally as part of a number of queries associated with recombiner performance and behaviour, Hitachi-GE has asserted in their replies that the catalyst degrades gradually and that this drop off in performance would be monitored by the operator via a number of conditions including the operating temperature and pressure of the recombiner outlet gas as well as the hydrogen monitor (Ref. 29). There is no evidence presented by Hitachi-GE to support this assertion regarding gradual degradation.

320. Furthermore, if I consider that the operating parameters of pressure and temperature are being used to help monitor recombiner efficiency , then to generate a 4% hydrogen concentration in the dry off-gas (i.e. the LFL) and thus a hazardous condition, the recombiner efficiency for the 40Nm³/hr case would be 99.35% and thus the drop off in performance in terms of pressure and temperature would in all likelihood be within the operating variation of the catalyst in respect to small changes in feed rate. Therefore the argument that parameters other than hydrogen concentration will inform the operator of gradual degradation of catalyst behaviour is unsubstantiated and unacceptable. Similarly Hitachi-GE has not demonstrated an empirical understanding in regard to what the term 'gradual degradation' means, as no performance data regarding catalysts has been supplied. On this basis this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

321. I also note that as stated previously the time Hitachi-GE expect the hydrogen monitor to detect a gas condition that is moving away from normal operations is 30minutes (Ref. 73).

322. ONR has similarly raised what the alarm and automatic trip hydrogen levels are for the monitor (Ref. 72) to try to understand the conservatism in the design, between the alarm and trip function and an actual hazardous condition and provide a consideration of the potential level and speed of catalytic degradation that may be acceptable.

323. Hitachi-GE responded that the set points will be determined during the site specific phase (Ref. 73), but that the intent would be to design the system such that the hydrogen trip would be set at 25% of the LFL where reasonably practicable taking into consideration the time delay for detection and measurement tolerances. Given that monitoring of hydrogen is a fundamental contributor to safety, I would have expected the Requesting Party to provide a more definitive position at the preliminary stage of design. As the generic safety case contained aspirational statements, and did not provide full assurance that the design will support implementation of trip points to deliver ALARP risks, this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

324. The hydrogen detector downstream of the cooler condenser is intended to be Class 2 system, but there are known issues with hydrogen detectors and the fact that hydrogen detectors are known to "drift" out of calibration.

325. ONR has therefore queried the calibration frequency of the hydrogen detector (Ref. 72) and Hitachi-GE's response is that the intention is to deliver calibration within every 18 months (Ref. 73). I am not convinced that the frequency is suitable defined to adequately substantiate the safety functional class claimed on the instrument and note that Hitachi-GE's response allows for the licensee to consider the calibration and maintenance regime in detail when the instrumentation is specified. Therefore this aspect will need to be monitored during the site specific design and specification stage.

326. Additionally on detection of a high hydrogen situation from the hydrogen monitor located downstream of the cooler condenser, the automatic trip function is a Class 2 system which both shuts down the steam feed to the SJAE and also shuts down the extract from the main condenser. Ultimately this results in build-up of non-condensable gases in the main condenser and thus a reactor trip. What is not clear in the safety documentation is how the main condenser and also the Off-Gas Systems are purged once the trip function is enacted given the potential hydrogen hazard.

327. In the case of the Off-Gas System, it is noted that on shutdown of the SJAE steam, there would be some purge of it at the second SJAE using air, however, there are no details with regard to the capacity of this purge and the rate and there is no understanding presented with regard to potential hazard that may be created by this air

purge given that the trip function would not have activated if the catalytic recombiners had not suffered some form of performance failure.

328. I accept that the Off-Gas System has a controlled purge during normal shut down operations, but this condition is part of normal reactor shutdown when the hydrogen hazard produced by the reactor is reduced owing to the reduced power of the reactor, not when there is a trip during on-power operations. On this basis this residual matter has been captured in **Assessment Finding AF-ABWR-RW-05** (see Annex 6).

329. As part of the assessment ONR considered the integrity of the Off-Gas system containment boundary and although the structural integrity is not within the range of this assessment, I will consider whether Hitachi-GE has undertaken sufficient analysis of the fault that a leak occurs from the Off-Gas System. I do note that only in two sections does the Off-Gas System normally operate at positive pressures and thus only in these areas would gas leak out of the containment boundary. In other areas it is likely that air would leak into the containment.

330. The areas where the system is normally at a positive pressure are from the first SJAE to SJAE condenser and also from the second SJAE to the pressure control valve downstream of the cooler condenser. However, given the assessment is considered to be based on single failure criterion and that criterion is currently the structural integrity of the pipework, then the areas of failure that have gas containing hydrogen at a positive pressure are limited to the first stage SJAE to the SJAE condenser, and the second stage SJAE to the recombiners.

331. I note the work undertaken by Hitachi-GE with regard to the release of gas into rooms and the dispersion modelling of that gas (Ref. 29). Hitachi-GE claim that any release either small leak or significant loss would be detected by the temperature and activity monitors in the rooms. However, there appears to be no discussion regarding the location of the sensors relative to the ventilation, which is designed to avoid a flammable hazard, and the type of activity detectors (α or βγ type).

332. I note the modelling carried out by Hitachi-GE and accept that the initial release will be steam blanketed below the LFL and that the rooms the gas will be released into are ventilated in line with the modelling I accept that there will not be a hydrogen hazard associated with the release as the dispersion of the hydrogen is such that it will not generate a flammable hazard.

333. However, what does not appear to be addressed within the case as presented is the potential radioactive species that may migrate and also consideration of radioactive species being transported down the room ventilation ducting and whether these species may plate out or condense out with the steam and present a hazard to people in adjacent rooms or people in corridors where they may be doing work for extended time, not just traversing the area. Furthermore, there is no clarity as to what occurs in the event of an alarm being raised and whether any reactor shut down is based on a single alarm, or some form of multiple voting system. Additionally there is a need to understand how access to such areas is restricted during operation to ensure in the event of a release operators do not inadvertently access the room and are exposed to the radioactive species. This matter gave rise to **Assessment Finding AF-ABWR-RW-06** (see Annex 6).

Off Gas System Charcoal Adsorber Assessment

334. The purpose of this section is to consider the operation of the charcoal adsorber system to remove the radioactive species and ensure that the size of the adsorber is suitable and sufficient to achieve an ALARP position and minimise the gaseous discharges so far as is reasonably practicable, and also meet the environmental

requirements specified by the environmental regulator. This also includes the consideration of faults that could give rise to a hazardous situation.

335. I have reviewed the document presented on the charcoal adsorber performance and note that the reaction kinetics associated with the performance are presented as conservative for both the Xenon and Krypton adsorbtion coefficients (Ref. 28 and Ref. 29) and thus the volume of charcoal intended to be used, based on the source term concentrations is such that there should be an excess of material and bed volume to achieve a clean gas.

336. This provides a conservative design and significant margin of safety with regard to the residence time of radioactive isotope in the bed and also the potential for the activated charcoal to be poisoned over time by the decay products of the Krypton and Xenon isotopes that may hinder the adsorbtion process. The case as presented adequately covers the ability of the charcoal beds to meet the design basis presented here. I have not considered the derivation of the gaseous source term as this is part of the Reactor Chemistry assessment and I have no intention of repeating that assessment. On this basis I am content with the size of the charcoal beds specified in the design.

337. However, I have considered the potential faults that may give rise to problems with both the charcoal beds and the structural integrity of the adsorber tower. The issue of a potential hydrogen deflagration or detonation in the charcoal adsorbers is covered in the hydrogen hazard section and therefore there is **Assessment Finding AF-ABWR-RW-06** above regarding the design pressure of the adsorber towers as part of the overall system downstream of the Off Gas condenser outlet valve.

338. However, there is potential for the charcoal in the towers to catch fire as this has been known to happen from the operational experience presented (Ref. 28 and Ref. 29).

339. Hitachi-GE has presented the temperature profile for heat transfer between the four towers in the event of a fire in one of the adsorber towers and this shows that a fire would not propagate between towers. However, Hitachi-GE has undertaken a conservative assumption, that in the event of a fire, it has assumed that all the active species on the adsorber beds are released from them and into the stack. On this basis, there have been improvements made to the design with regard to temperature monitoring of the adsorber beds. I consider this release approach to be a suitably conservative analysis.

340. However, there is no discussion with regard to how the individual beds would be isolated and whether there is the ability to bypass the affected bed and allow the reactor to be taken off power in a controlled manner, reducing the source terms and shutting down from power over time whilst addressing the fire. Such an approach avoids a trip of the reactor and the subsequent problem with treating the off-gas in the main condenser after the bed fire has ceased as there is no route to purge the Reactor Off-Gas System once a charcoal bed has been isolated in the current configuration. The configuration of the charcoal beds has been considered within the Reactor Chemistry assessment (Ref. 8) and on this basis I am not going to raise any assessment finding, but support the Reactor Chemistry position.

341. A further hazard to the operation of the charcoal absorbers is the potential for water ingress onto the charcoal beds. The impact of water on the charcoal bed is twofold; it causes any gas adsorbed on the bed to be de-adsorbed and also blocks any further adsorbtion, until it is removed by drying of the bed by passing through the bed warm dry gas.

342. Hitachi-GE presents faults regarding moisture ingress, and considers the bounding case to be the complete failure of the Off-Gas system condenser (Ref. 29). From this fault condition, Hitachi-GE has calculated the possible transfer of steam that can be

passed through the PCV into the system over an eight hour period (Ref. 29). This is approximately 400kg (over the eight hour period). Based on the complete failure of the Off Gas condenser there needs to be somewhere for the 4.5Te per hour of steam from the second SJAE to go, if not, then the conditions upstream of the PCV will pressurise well above the approximately 1.5 bar(a) that is in the calculation presented in the case (Ref. 29).

343. On this basis, the flow of steam through the PCV would increase, however, the backpressure created in the rest of the Reactor Off-Gas System would quickly result in no flow of non-condensable gases to the second SJAE as the steam in the second SJAE would not draw the gas though the ejector. Furthermore, the line between the SJAE condenser would pressurise as ejector performance dropped off, and this would lead to a failure of the SJAE condenser system owing to an increase in non-condensable gas. This in turn would result in loss of steam flow in the first SJAE and therefore loss of depression in the main condenser and ultimately a reactor trip.

344. Although I consider that the rate of steam flowing to the charcoal absorber would be significantly greater than the 40kg/hr calculated in the case (Ref. 29), I am not convinced that the Reactor Off-Gas System would operate for eight hour period as postulated in the submission for the fault. Therefore, it may be that the case as presented gives an overly pessimistic position with regard to steam ingress, but I have insufficient information to make an adequate judgement and thus raised this residual matter within **Assessment Finding AF-ABWR-RW-07** (see Annex 6).

345. Furthermore, the case as presented considers the acute ingress to be the bounding case, whereas, there appears to be no consideration of potentially chronic moisture ingress over an extended period.

346. For this consideration, the fault in question would be the gas being fed forward to the charcoal adsorbers to be out of specification, but not significantly, for example, it may be there is an unrevealed fault with the off-gas cooler condenser such that feed gas to the charcoal beds is saturated with moisture at 30ºC and this would cause some moisture to build up on the adsorbers over time and there to be a slow impairment of function. The uncertainty is that there is little visibility of how this fault is considered within the safety case on the basis of the documents I have sampled.

347. It may be that the consideration during the fault analysis was such that there are sufficient indicators and alarms to alert operators to any such fault condition and therefore consideration is dismissed further, but this is not presented in the sample I have looked at, principally the basis of safety case and the ALARP Topic Report (Ref. 20 and Ref. 28). This aspect will need to be addressed during the site specific phase, when the monitoring and safety systems for the charcoal adsorbers and the gas feed to the charcoals adsorbers are fully specified.

Tank Vent Treatment System (TVTS)

348. This section covers ONR's consideration of Hitachi-GE's safety case for the TVTS including fault conditions and hazard analysis.

349. The principal hazard associated with the TVTS system is the generation of hydrogen by the radiolysis in a number of the waste treatment storage tanks. Hitachi-GE has proposed a hydrogen generation rate based on a given G-value and calculated emissive energy for the various wastes in the various tanks (Ref. 57).

350. Hitachi–GE has presented a fault as a bounding worst case given the assumption that the tanks are filled to their operating limit and thus the gas ullage is minimised.

351. The bounding fault presented by Hitachi-GE is that the TVTS ventilation system fails and thus there is a static gas condition and so the hydrogen is not purged from the tank and can build–up within the vessel. Therefore the calculation provides the time for the tank ullage to reach both 25% of the LFL and the LFL for hydrogen in air for the defined tank ullage (Ref. 45). Hitachi-GE also presented that if there is a problem with re-establishing the ventilation, then certain tanks can be drained to increase the ullage space and thus increase the time to flammability.

352. It is noted in the case (Ref. 56 and Ref. 45) that for the sludge wastes, the radiolysis is likely to generate both hydrogen and oxygen into the off gas, whereas for the ion-exchange wastes, typically only hydrogen is released as oxygen tends to be held within the ion exchange matrix as a compound. Furthermore in the static air condition, Hitachi-GE presents an argument, that there would be no stratification of the gas owing to buoyancy effects and that Brownian motion would ensure this and thus the arguments regarding time to both 25% of the LFL in the bulk gas ullage and to the LFL in the bulk gas ullage are valid. These values are presented in Table 10 below.

Table 10

Estimated Time to 25% and 100% of LFL for Tanks Within the Radioactive Waste Building		
Tank	Time to 25% LFL (1% hydrogen in air)	Time to LFL (4% hydrogen in air)
Powder resin storage tank	5.9 hours	23.6 hours
Filter crud storage tank	8.4 days	33.6 days
Resin bead Storage Tank D only	89 days	356 days

353. In terms of the design of the TVTS for normal operation, it appears to comply at a concept level with that expected for any such ventilation system in line with what appears at this stage, suitable redundant systems to maintain a highly reliable operation. On this basis I do not intend to assess the functionality of the design, but expect that during the detailed design stage the individual flow rates to tanks and purge requirements will be better defined.

354. I have considered the fault condition regarding the loss of ventilation to the tanks for whatever reason. As part of this I have examined the calculations that derive the rate of hydrogen generation and thus the time to cause the hazard. The shortfall I find in the presented calculation (Ref. 57) is that it does not refer back to the source term. I have considered the source terms (Ref. 58) and find I am unable to link this to the derived energy in terms of emissive energy (Ref. 57). On that basis I cannot judge whether the position adopted by Hitachi-GE is conservative and thus I have raised this residual matter within **Assessment Finding AF-ABWR-RW-08** (see Annex 6).

355. Additionally, the understanding provided by Hitachi-GE regarding the potential buoyancy effects of hydrogen seems questionable in that the expectation is that there would be little or no stratification effects as the driver would be Brownian motion. However, the positon is static air and work undertaken in ventilation of rooms re hydrogen release (Ref. 74) show that stratification can occur with buoyancy, although the main driver is the release mechanism, and the applicability of this to a static tank, where the gas release mechanism is diffuse at the surface of the liquor, is questionable, but the underlying physical behaviour of the gas is not.

356. The safety concern is that the hydrogen builds up in flammable concentrations at the high points in the ullage and thus creates a flammable hazard in a much smaller timescale than expected. I would expect the analysis to be much better qualitative position in terms of either buoyancy vs Brownian motion arguments or a much better

quantitative position. I note that the formation of a small flammable hazard at the high point in the tank ullage may not cause a significant hazard and that the dutyholder will need to understand how much hydrogen can cause a flammable atmosphere that could create a sufficient overpressure to damage the tanks containment and from this derive a time for this to occur, allowing for some of the hydrogen to dissipate and diffuse away. On this basis I have captured this residual matter within **Assessment Finding AF-ABWR-RW-08** (see Annex 6).

357. Additionally although there is discussion on the agitation and transfer of waste out of the tanks (Ref. 27) there is no discussion regarding the build-up and accumulation of flammable gases in the sludge and resin beds over time and how the potential rapid release of this gas, either by bed rollover (i.e. build-up of gas in the bed such that the buoyancy of the solid is affected and there is a sudden gas release owing to the buoyancy disturbing the bed), or agitation prior to waste transfer, will be addressed.

358. There appears to be no consideration as to how much gas could be retained within the various waste forms or how the ventilation system would manage any sudden release. There has been significant work on gas retention in radioactive sludges at Pacific Northwest National Laboratory (PNNL) by Gauglitz et al since the mid-1990s and the factors affecting gas hold up in waste beds are presented within the PNNL papers.

359. The effects of sudden hydrogen release in sludge tanks is a known phenomenon and as such I would expect it to be considered as part of the operating regime and hazard analysis, and I would therefore expect it to be considered in the safety case even at the concept state of the design and it does not appear to be presented or considered. I have therefore raised this residual matter within **Assessment Finding AF-ABWR-RW-08** (see Annex 6).

360. As part of the hazard management strategy associated with addressing the potential for a high hydrogen atmosphere in the tanks ullage, Hitachi-GE considers that if the restoration of ventilation is not possible, an alternative hazard management strategy would be to drain the free liquid and transfer it to another vessel. Although I consider the hazard management strategy to be potentially suitable, as the draining of the free liquid will increase the ullage volume in the tank and also change the tank ullage dynamic and draw air into the tank, thus creating a gas flow and increasing the mixing of the gas contents.

361. However, the concern is the ability to adopt this as a hazard management strategy, as there is no clear designation as to where the free liquid may be transferred to. Additionally, given there must be a significant system failure to mean that the duty and standby nature of the ventilation system is inoperable; it may be that this hazard management strategy is not viable. This residual matter has therefore been captured in **Assessment Finding AF-ABWR-RW-08** (see Annex 6).

362. Finally as part of the case presented by Hitachi-GE, the position post fault occurring and the hazard being realised (i.e. there is either a deflagration or detonation in one of the waste tanks in the radioactive waste building) is that the cell structure will be such that, post event, it will provide bulk shielding and containment (Ref. 27).

363. Whilst I have not examined in detail the overpressure modelling for the cells, given that the design of the radioactive waste building is concept only, it is possible that the cell containing a waste tank may maintain a certain level of integrity. However there is no quantifiable value associated with the requirement of the design to perform post event.

364. It is feasible for the structure to be designed to resist a hydrogen explosion. However as the local structural behaviour within the Radwaste Building has not been included in the scope of GDA, it is not available to be assessed at present. Although it is likely that following an explosion the cell could provide bulk shielding, I am less convinced that

the structure will provide bulk containment of activity as the meaning of 'bulk contamination containment' has not been defined. This residual matter has therefore been raised within **Assessment Finding AF-ABWR-RW-08** (see Annex 6).

365. From this section of assessment I concluded that Hitachi-GE had demonstrated that the UK ABWR Off-Gas system and TVTS are capable of managing the relevant streams of gaseous wastes with risks reduced ALARP.

4.2.5 Solid Waste Management System

366. This section of assessment considers the robustness of the concept designs Hitachi-GE proposed within GDA for the various sections of the UK ABWR SWMS.

Solid ILW Inventory

367. I sought assurance that Hitachi-GE had identified a comprehensive set of solid waste streams that can reasonably be expected to arise during the UK ABWR's operational phase and noted that the generic case for the SWMS did not appear to consider the likelihood of any significant amount of solid ILW arising during the 60 years of reactor operations.

368. RQ-ABWR-1473 was therefore raised, Hitachi-GE's response to which identified the following reasoning:

- While some metallic components from within the Primary Containment Vessel are expected to be replaced during the operational phase, and may be subject of activation, Hitachi-GE believes they will be categorised as either HLW or LLW and managed accordingly.
- The UK ABWR will be provided with decontamination facilities (although the detailed design of the system was out of scope for GDA).
- All the SSCs outside the Primary Containment Vessel that Hitachi-GE assessed as having the potential to become ILW due to contamination during the operational phase will be designed with an intended service life of 60 years.
- Hitachi-GE intended that any solid ILW that arises during the 60 year life of the reactor would be managed as an 'off normal condition' by the licensee.

369. Whilst there is a low probability of the UK ABWR giving rise to major volumes of solid ILW during the operational phase, there is clear potential for maintenance wastes, failed components (such as valves, pump components or instruments) and required equipment upgrades to result in items of ILW that may give rise to waste management challenges. I have therefore raised **Assessment Finding AF-ABWR-RW-09** (see Annex 6).

Management of HLW

370. Within Ref. 49 Hitachi-GE identified the following metallic SSCs that have potential to be activated to HLW at the point they need to be removed from the reactor, with an expectation that the process of radioactive decay prior to the GDF becoming available will enable disposal as ILW:

- Control Rods (CRs)
- Local Power Range Neutron Monitors (LPRMs)
- Neutron Source Units (NSU)
- Start-up Range Neutron Monitors (SRNMs) and

- Traversing In-core Probes (TIPs)

371. After removal from the reactor, Hitachi-GE intends that all HLW will be stored in the spent fuel pool for a period of 10 years, which is equivalent to the assumed wet storage period for spent fuel. The design intent is for the same packages and infrastructure used for export and storage of spent fuel to be used in managing the heat generating metals. I noted that Hitachi-GE believes it will take 20 years for the levels of decay heat from Hafnium Control Rods to reduce to a level that would allow the rods to be packaged directly into containers suitable for consignment to the GDF.

372. RQ-ABWR-1408 sought further assurance that a 10-year storage period was optimal for HLW, such that Hitachi-GE's proposals would reduce the risks of managing the HLW SFAIRP. Within its RQ response, Hitachi-GE explained:

- All of the non-fuel in-core removable components from the reactor have been estimated to be HLW on removal and sufficient space to accommodate this is available in the SFP, which I judged to be a suitably conservative position.
- Hitachi-GE based its strategy on an assumption that a disposal route to the GDF for the HLW will not be available until 2100, which is reasonable as this date aligns with advice from NDA RWM.
- Any required size reduction and packaging of the HLW will take place close to the time of its consignment off-site for disposal, giving benefits of reduced hazards due to the effects of radioactive decay and ensuring the packages used will comply with the GDF requirements.
- A fully substantiated ALARP demonstration for HLW cannot be provided until a specific spent fuel export and storage system is selected by the operator, and I accepted that detailed design of the canister was out-of-scope for GDA.

373. While I remain of the view that 10 years of wet storage in the SFP may not be the optimal strategy, Hitachi-GE demonstrated that its proposal is technically feasible and based on conservative logic. The licensee will have the opportunity to give a timely reconsideration of the approach to HLW during the site specific stage, when a greater level of information will be available on the relevant SSCs. Therefore I do not believe an Assessment Finding is required at this time, given that the UK ABWR design will not unduly constrain the options available during detailed design and a suitable level of oversight will be provided via normal regulatory business.

Consideration of Relevant Good Practice in the SWMS

374. ONR's assessment of early revisions of the Topic Report on ALARP for the SWMS found several inadequacies in the provided arguments.

375. While the report made clear that Hitachi-GE had carried out optioneering in relation to the SWMS, the process employed was not reported in an open and transparent manner with no clear linkages to any consideration of hazards nor any identification of tangible design features that had been incorporated to minimise risks SFAIRP.

376. The presented arguments were also overly focussed on the back-end of the waste management process, with insufficient consideration provided to the preceding steps of waste avoidance, minimisation, generation and conditioning such that a holistic consideration of the system-wide risk profile had not been provided. This left ONR unable to judge whether any particular step in the SWMS would place workers at undue risk.

377. ONR therefore raised RQ-ABWR-0910 and RQ-ABWR-0911 to request further evidence to demonstrate that Hitachi-GE's development of the SWMS concepts was

based on an appropriate consideration of the principles of ALARP and Relevant Good Practice.

378. In response to these RQs, Hitachi-GE acknowledged the need to provide a clearer demonstration of ALARP and identify where RGP had been incorporated into the SWMS design. This recognition led to a major overhaul of the ALARP Demonstration itself and updates to the underpinning references. Within the RQ responses and revised report, Hitachi-GE provided:

- An objective and clear definition of the scope of optioneering that had been carried out within GDA, combined with an open and transparent description of the outstanding work that will need to be addressed during the site specific stage of design including explicit forward actions
- A clearer demonstration of how the principles of ALARP and RGP had been applied to Hitachi-GE's considerations of the complete waste management process
- Recognition that the OPEX report for the UK ABWR contained limited information on management of radioactive wastes, which was addressed through a dedicated collation of good practices
- Further optioneering studies, including a consideration of the site wide management of solid LLW

379. Hitachi-GE made significant progress in this area of its safety case through Step 4, such that I am content the final suite of submissions are fit-for-purpose for GDA and provide a clearly defined basis for the licensee to take forward into the detailed design of the SWMS.

Arrangement of the LCW Filter Change Cell

380. The performance of the filters which serve the LCW system within the Radwaste Building is expected to gradually deteriorate over a number of years, to the point where the filters will need to be replaced with new elements. The spent filter unit is drained in-situ, then transferred into a 500litre drum within the dedicated LCW Filter Change Cell, the loaded drum is later exported within a shielded over-pack to the LLW MMA for onward processing.

381. Assessment of the SWMS BSC and SWMS System Design Description found some apparent inconsistencies between the two submissions, in regard to the extent of manual operations and the provision of containment during the process of filter change out. Therefore RQ-ABWR-1229 was raised to further explore the basis of the safety case in these areas.

382. Hitachi-GE subsequently confirmed that LCW Filter change out will be a remote operation, until the point when the 500 litre drum containing the spent filter is placed into a shielding over-pack and removed from the LCW Filter Change Cell. Hitachi-GE noted that the anticipated dose rates from the spent filters would prohibit workers from carrying out swabbing of the outside of the 500litre drum, therefore the swabbing will be achieved robotically.

383. Hitachi-GE confirmed that loaded 500litre drums will be lifted over a dwarf wall within the cell using a telescopic hoist mounted on an over-head trolley equipped with a grapple and all lifting operations are intended to be carried out remotely.

384. When manual bolting of the over-pack lid takes place outside the LCW Filter Change Cell the claim is made that the over-pack and lid will provide sufficient shielding to

reduce dose uptake to acceptable levels for a manual operation as assessed in the 'normal dose uptake assessment' for the operations.

385. I was not fully convinced by some elements of Hitachi-GE's response, particularly in regard to the potential risks to operators that may arise from reasonably foreseeable deviations from normal conditions and the potential need to recover from design basis faults involving the over-head trolley. Potential may also exist to reduce the extent to which reliance is placed on an open drain system for containment of spills. Furthermore it was unclear to what extent the arrangement of the cell and lifting equipment would allow contingency measures to be deployed, should the dose rate from a spent filter exceed the levels anticipated.

386. Whilst these aspects will certainly require further attention during the site specific stage of design, I am content that ONR's Radiological Protection Specialism has raised an appropriately scoped Assessment Finding within its consideration of the application of ALARP to the SWMS and LWMS. Therefore I do not believe it is necessary to raise an additional AF on this matter here.

Consideration of Maintenance in the Design of the SMWS

387. ONR's assessment of the SWMS ALARP Demonstration uncovered that established custom and practice in regard to maintenance of the radioactive waste systems of the J-ABWRs was a philosophy of 'time-based periodic maintenance'. However starting in Step 2 of the GDA, Hitachi-GE noted an intention to implement reliability-centred maintenance on the UK ABWR in order to reduce worker doses and reduce the probability of maintenance-induced initiating events.

388. On this basis I developed a concern that the SWMS maintenance requirements did not appear to be as well understood as the design itself. Therefore RQ-ABWR-0875 was raised, to ensure that a sufficient and timely consideration of maintenance requirements would be applied to the consideration of design options in accordance with SAPs ELO.1, EMT.1, EMT.7 and EAD.1. The RQ also asked Hitachi-GE to confirm what considerations had been given to the potential for maintenance to result in the unnecessary generation of radioactive wastes.

389. Hitachi-GE's response to RQ-ABWR-0875 highlighted:

- Further considerations given to the UK ABWR maintenance philosophy within GDA in response to Regulatory Observations; RO-ABWR-016 (Mechanical Engineering Design Process Arrangement), RO-ABWR-018 (Examination, Inspection Maintenance and Testing, Isolations and Configurations) and RO-ABWR-0062 (Testing and Maintenance of Safety Systems)
- Alignment of Hitachi-GE's consideration of maintenance for the SWMS with the generic improvements to the design process secured in response to the above three ROs.
- Assurance that the level of design applied to the SWMS within GDA was at concept level and the system did not contain any Long-Lead Items, therefore Hitachi-GE claimed that a timely consideration of maintenance could be applied during subsequent detailed design.
- The prominence of maintenance as a relevant consideration within Hitachi-GE's Human Factors Specification.
- Specific examples where issues of maintenance had been identified in HAZOP studies of the SWMS concept designs within GDA and influenced the options selection process.
- Hitachi-GE asserted that waste arisings from maintenance will be minimal, highlighted an expectation for consumable SSCs (such as HEPA filters) to be used

to their design capacity and SSCs that require regular maintenance will be located outside the SWMS process cells.

390. I note that all three of the quoted ROs were satisfactorily resolved and closed prior to the end of GDA. Whilst it is therefore evidential that Hitachi-GE has made major improvements to its generic consideration of maintenance during the GDA process in response to multi-disciplinary concerns from ONR, I found some elements of the response to RQ-ABWR-0875 were unsatisfactory.

391. I believe it is clear that Hitachi-GE's expectations in relation to the amounts and types of radioactive wastes that will be generated by maintenance activities are potentially optimistic. However this matter is central to AF-ABWR-RW-09 above and therefore I will not raise a further Assessment Finding here.

392. It is also not entirely clear that the improved generic approach to the consideration of maintenance will be comprehensive enough to capture the radioactive waste management systems that deal with relatively low radiological hazards, but whose maintainability can give rise to significant logistical and operational issues (such as process bottle-necks and backlogs of waste accumulations). It will therefore be important for the licensee to ensure that the detailed design and practical application of maintenance give sufficient consideration to the waste management system logistics and reliability. However I am content that ONR oversight of this matter can be adequately secured as part of normal regulatory business.

393. As a result of this section of its assessment, I concluded that Hitachi-GE had demonstrated that all the solid radioactive wastes expected to be generated during the operations of the UK ABWR will be appropriately managed and should be disposable at current or planned facilities within the UK.

4.3 Regulatory Issues

394. 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. All the Regulatory Issues (RIs) and Regulatory Observations (ROs) issued to Hitachi-GE as part of the GDA have been published on ONR's website, together with the corresponding Hitachi-GE resolution plans and ONR's confirmation of closure.

395. Two RIs of relevance to management of radioactive wastes were issued by ONR's Reactor Chemistry and PSA specialisms during GDA and are summarised in Annex 4:

- **RI-ABWR-0001** Definition and Justification for the Radioactive Source Terms in UK ABWR during Normal Operations
- **RI-ABWR-0002** UK ABWR Probabilistic Safety Analysis: Project Plan and Delivery

4.4 Regulatory Observations

396. Regulatory Observations (ROs) are raised when ONR identifies a potential regulatory shortfall which requires action and new work by the RP for it to be resolved. Each RO can have several associated actions.

397. **RO-ABWR-0036**, '*Demonstration that the approach taken to radioactive waste management reduces risks ALARP'* was raised directly in relation to Hitachi-GE's submissions for the management of radioactive wastes during Step 3 of the GDA and Hitachi-GE's work to address this RO continued until the end of Step 4. RO-ABWR-036 required Hitachi-GE to show:

- The methods chosen for management of radioactive waste for the UK ABWR will reduce risks SFAIRP, and
- A process of optimisation has been followed, that this process can be demonstrated to ONR in a transparent manner, and that it forms part of the safety-case for the UK ABWR

398. In response to RO-ABWR-036 Hitachi-GE provided all the documentation required in its resolution plan, within which it demonstrated the adoption of an appropriately scoped GDA ALARP Methodology and its application to all the UK ABWR radioactive waste management systems in a proportionate manner that aligned with the hazards present in each system and the status of the designs within GDA.

399. Through the assessment of this evidence (combined with Hitachi-GE's responses to ONR's Regulatory Queries), as summarised in Section 4 of this report, I am satisfied that Hitachi-GE's safety case for the Management of Radioactive Wastes at the end of Step 4 is now adequate for the purpose of leaving GDA. Whilst this assessment has identified a number of residual matters, these matters are aligned with Assessment Findings identified in this report and will therefore need to be addressed by the licensee, none of which are significant enough to give rise to a GDA Issue and prevent the closure of RO-ABWR-036.

400. To conclude, based on this assessment, Hitachi-GE has provided sufficient evidence to meet the intent of RO-ABWR-036 and addressed the issues which led to the RO being raised. RO-ABWR-036 has therefore been closed. However, there are a number of Assessment Findings identified in this report that capture residual matters which will need to be resolved by the licensee.

401. During the course of the GDA several further ROs were raised by ONR in other technical disciplines, which had implications for particular aspects of the management of radioactive wastes. ONR's NLR Specialism has contributed to the development, progress and closure of the RO's as a normal part of multi-disciplinary working. These RO's are listed below and summarised in Annex 4.

- **RO-ABWR-0006** Source Terms
- **RO-ABWR-0011** Safety Case for Spent Fuel Pool and Fuel Route
- **RO-ABWR-0025** Hitachi-GE Nuclear Energy Ltd. Safety Case Process and Capability
- **RO-ABWR-0035** Robust justification for the materials selected for UK ABWR
- **RO-ABWR-0037** Safety Case for Faults not Directly Related to the Reactor
- **RO-ABWR-0045** UK ABWR – Operational Experience (OPEX)
- **RO-ABWR-0054** UK ABWR – Chemical/Process Engineering Design approach. The UK ABWR design was rigorously challenged during GDA to reduce its reliance on embedded pipework, floor drains and equipment drains in order to comply with UK expectations for containment of radioactive materials and wastes.

  Hitachi-GE's process engineering design approach was challenged by ONR via RO-ABWR-054. ONR assessed Hitachi-GE's response to the Regulatory Observation (Ref. 78) and confirmed the closure of the RO on the ONR website.

- **RO-ABWR-0064** Design approach to identification and provision of both permanent and temporary features necessary for the adequate control of radioactive contamination across the full lifetime of UK ABWR
- **RO-ABWR-0071** Turbine Gland Steam System: Discharges and Optimisation
- **RO-ABWR-0073** Robust demonstration that the design of the UK ABWR off-gas system reduces risks SFAIRP
- **RO-ABWR-0075** Robust demonstration that the design of the UK ABWR HVAC system has been adequately conceived and reduces risks SFAIRP

4.5 Assessment Findings

402. During my assessment nine residual matters were identified for the licensee to take forward in its site-specific safety submissions in the form of Assessment Findings. Details of these are contained in Annex 6.

403. 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. These items are captured as assessment findings.

404. In accordance with the Guidance to Requesting Parties (Ref. 2), such residual matters were recorded as Assessment Findings within this report if one or more of the following applied:

- To resolve the matter site-specific information is required;
- Resolution of the matter depends on licensee design choices;
- The matter raised is related to operator-specific features / aspects / choices;
- Resolution of the matter requires licensee choices on organisational matters;
- Resolution of the matter requires the plant to be at some stage of construction or commissioning;
- Resolution of the matter requires the level of detail of the design needs to be beyond what can reasonably be expected in GDA

405. Assessment Findings are residual matters that must be addressed by the Licensee and the progress of this will be monitored by ONR.

4.6 Minor Shortfalls

406. During this assessment one residual matter was identified as a minor shortfall in the safety case, as it was not considered to be serious enough to require specific action to be taken by the licensee in response to ONR. This minor shortfall relates to further work on the assessment of disposability of higher activity wastes that has already been identified by RWM Ltd and Hitachi-GE and would not impede the UK ABWR's ability to comply with UK law.

407. In accordance with the Guidance to GDA Requesting Parties, a residual matter is recorded as a minor shortfall if it does not:

- Undermine ONR's confidence in the safety of the generic design.
- Impair ONR's ability to understand the risks associated with the generic design.

- Require design modifications.
- Require further substantiation to be undertaken.

5 CONCLUSIONS

408. This report presents the findings of my Step 4 assessment of the Hitachi-GE UK ABWR in the topic of management of radioactive wastes.

409. A collection of Assessment Findings and one Minor Shortfall were identified; these are for a future licensee to consider and take forward in its site-specific safety case. These matters do not undermine ONR's confidence in the generic safety submission.

5.1 Key Findings from the Step 4 Assessment

410. I am broadly satisfied with the claims, arguments and evidence laid down within the PCSR and supporting documentation for the Management of Radioactive Wastes. I therefore consider that from the perspective of the Management of Radioactive Wastes, I have no objection to the award of a DAC for the Hitachi-GE UK ABWR design.

411. My key assessment conclusions are:

- Hitachi-GE has developed a strategy for managing the radioactive wastes expected to arise from the operations of the UK ABWR that accords with UK law, UK government policy and ONR's regulatory expectations.
- Hitachi-GE's approach to managing the Higher Activity Wastes (HAW) expected to arise from the operations of the UK ABWR is consistent with UK government policy for new build reactors.
- Hitachi-GE demonstrated that it is technically feasible for the liquid effluents that are expected to arise from normal operations of the UK ABWR to be effectively managed using proven technology.
- Hitachi-GE demonstrated that it is technically feasible for the UK ABWR Off-Gas system and TVTS to safely manage the relevant streams of gaseous wastes.
- Hitachi-GE confirmed that all the solid radioactive wastes expected to be generated during the operations of the UK ABWR can be appropriately managed and should be disposable at current or planned facilities within the UK.
- Hitachi-GE provided sufficient evidence to meet the intent of Regulatory Observation (RO) RO-ABWR-036 and addressed the issues which led to the RO being raised. Some residual matters are aligned to Assessment Findings in this report that the licensee will need to address during the future stages of design. RO-ABWR-036 has therefore been closed.

412. Overall, based on the samples undertaken, I am broadly satisfied that the claims, arguments and evidence laid down within the PCSR and supporting documentation submitted as part of the GDA process present an adequate safety case for the generic UK ABWR design in regard to the Management of Radioactive Wastes.

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65. Hitachi-GE Nuclear Energy, Other Environmental Regulations, Revision G, GA91-9901-0027-00001, September 2017.

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Annex 1
Safety Assessment Principles

SAP No	SAP Title	Description
MS.2	Leadership and Management for Safety	Knowledge should be captured and communicated within the organisation in a systematic, appropriate and reliable manner to all those who need to make safety decisions. Documents and records relevant to safety should include those for modifications and decommissioning.
SC.1	Safety Case Production Process	The process for producing safety cases should be designed and operated commensurate with the hazard, using concepts applied to high reliability engineered systems.
SC.2	Safety case process outputs	The process for producing safety cases should take into account the needs of those who will use the safety case to ensure safe operations. It is essential that the safety case documentation is clear and logically structured so that the information is easily accessible to those who need to use it. This includes designers, operations and maintenance staff, technical personnel and managers who are accountable for safety.
SC.3	Lifecycle aspects	Control of hazards should be demonstrated in a safety case before any associated risks materially exist. The safety case for each stage should take account of future lifecycle stages, i.e. it should build on the safety case for previous stages and show that the safety intent for subsequent stages will be achieved. Any constraints that apply in subsequent stages should be detailed in the safety case in which they are identified. The safety case for decommissioning should have been considered in all previous lifecycle stages. In the case of early, unplanned permanent shutdown of a facility, the safety case should be revised to address any safety implications arising from the early shutdown and to identify any changes to the strategy and timescales for decommissioning.
SC.4	Safety case characteristics	A safety case should: (a) explicitly set out the argument for why risks are ALARP; and (b) link the information necessary to show that risks are ALARP, and what will be needed to ensure that this can be maintained over the period for which the safety case is valid; (c) support claims and arguments with appropriate evidence, and with experiment and/or analysis that validates performance assumptions; (d) accurately and realistically reflect the proposed activity, facility and its structures, systems and components; (e) identify all the limits and conditions necessary in the interests of safety (operating rules); and (f) identify any other requirements necessary to meet or maintain the safety case such as surveillance, maintenance and inspection.
SC.5	Optimism, uncertainty and conservatism	The safety case should present a balanced view of the level of knowledge and understanding, and of the resultant risks. It should provide a proportionate justification that includes appropriate conservatism but without undue pessimism. Otherwise, it

		can mislead those who need to use the safety case to take decisions on risks and on managing safety. An unbalanced case will also fail to identify areas where more work might be needed, either to support the current conclusions or to provide a valid basis for any subsequent work if the safety case needs to be revised (e.g. due to a proposed plant modification or a change to the operating regime or procedures). This principle encompasses optimism and uncertainties in the design of a facility (e.g. material properties, defects and dynamic behaviour) and in the basis of the safety case (e.g. analytical methods and codes, underlying assumptions, data, margins and factors of safety). Areas of uncertainty should be offset by a precautionary approach.
SC.6	Safety case content and implementation	The safety case for a facility or site should identify the important aspects of operation and management required for maintaining safety and how these will be implemented.
ECE.26	Engineering Principles - Provision for Decommissioning	Special consideration should be given at the design stage to the incorporation of features to facilitate radioactive waste management and the future decommissioning and dismantling of the facility.
ELO.1	Layout and Access	The layout should make provision for construction, assembly, installation, erection, decommissioning, maintenance and demolition.
EHF.1	Human Factors Integration with Design, Assessment and Management	A systematic approach to integrating human factors within the design, assessment and management of systems and processes should be applied throughout the facility's lifecycle.
FA.2	Identification of initiating faults	The process for identifying faults should be systematic, auditable and comprehensive, and should include planned operating modes and configurations, shutdown states, decommissioning operations, and any other activities which could present a radiological risk.
FA.3	Fault Sequences	Fault sequences should be developed from the initiating faults and their potential consequences analysed. Following the end of operations, a new fault analysis is likely to be needed to cover the decommissioning phase.
RL.1	Land Quality Management	A strategy should be produced for the control and remediation of any radioactively contaminated land on the site.
EMT.1	Engineering principles: maintenance, inspection and testing	Safety requirements for in-service testing, inspection and other maintenance procedures and frequencies should be identified in the safety case.
ENM.1	Engineering principles: control of nuclear matter	Strategies should be made and implemented for the management of nuclear matter.
NT.2	Numerical targets and legal limits – Time at Risk	There should be sufficient control of radiological hazards at all times.
RP.7	Radiation Protection	The dutyholder should establish a hierarchy of control measures to optimise protection in accordance with IRR99.
RP.5	Decontamination	Suitable and sufficient arrangements for decontaminating people, the facility, its plant

		and equipment should be provided.
RP.6	Shielding	Where shielding has been identified as a means of restricting dose, it should be effective under all normal operation and fault conditions where it provides this safety function. The Safety case should take into account any post-operational period prior to final decommissioning.
RW.1	Radioactive Waste Management Strategy	The management of radioactive waste is a function potentially spanning all the stages of the lifecycle of a facility. A strategy should be produced and implemented for the management of radioactive waste on a site which should be integrated with the decommissioning strategy.
RW.2	Generation of Radioactive Waste	The safety case should describe approaches to decommissioning that will ensure waste minimisation and include a demonstration that the rate of production of radioactive waste has been minimised.
RW.3	Accumulation of Radioactive Waste	The total quantity of radioactive waste accumulated on site at any time should be minimised so far as is reasonably practicable.
RW.4	Characterisation and Segregation of Radioactive Waste	Radioactive waste should be characterised at appropriate stages in terms of its physical, chemical, radiological and biological properties.
RW.5	Storage of Radioactive Waste and Passive Safety	Radioactive waste should be stored in accordance with good engineering practice and in a passively safe condition.
RW.6	Passive Safety Timescales for Radioactive Wastes	Radiological hazards should be reduced systematically and progressively. The waste should be processed into a passive safe state as soon as is reasonably practicable.
RW.7	Making and Keeping Records for Radioactive Waste	Information that might be needed for the current and future safe management of radioactive waste should be recorded and preserved.

Annex 2
Technical Assessment Guides

TAG Ref	TAG Title
NS-TAST-GD-005	Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)
NS-TAST-GD-021	Containment: Chemical Plants
NS-TAST-GD-024	Management of Radioactive Materials and Radioactive Wastes on Nuclear Licensed Sites
NS-TAST-GD-026	Decommissioning
NS-INSP-GD-034	LC34: Leakage and Escape of Radioactive Material and Radioactive Waste
NS-TAST-GD-051	The purpose, scope, and content of safety cases
NS-TAST-GD-057	Design Safety Assurance
NS-TAST-GD-081	Safety aspects specific to storage of spent nuclear fuel
NS-TAST-GD-088	Chemistry of Operating Civil Nuclear Reactors
NS-TAST-GD-094	Categorisation of Safety Functions and Classification of Structures and Components
NS-TAST-GD-098	Asset Management

Annex 3
National and International Standards and Guidance

National and International Standards and Guidance
Safety of Nuclear Power Plants: Design. Safety Requirements, IAEA Safety Standards Series No. NS-R-1. IAEA. Vienna. 2000. www.iaea.org.
Methods for the Minimization of Radioactive Waste from Decontamination and Decommissioning of Nuclear Facilities, Technical Report Series 401.
Safety of Nuclear Fuel Facilities, IAEA Safety Standards Series No. NS-R-5.
Fundamental Safety Principles, IAEA Safety Standards, Safety Fundamentals SF-1.
WENRA Statement on Safety Objectives for New Nuclear Power Plants, November 2010.
WENRA Reactor Reference Safety Levels, September 2014.
WENRA Waste and Spent Fuel Storage Safety Reference Levels, Report of Working Group on Waste and Decommissioning (WGWD), Version 2.2, April 2014, http://www.wenra.org/media/filer_public/2014/05/08/wgwd_storage_report_final.pdf
Joint Guidance, The Management of Higher Activity Radioactive Waste on Nuclear Licensed Sites, February 2015 Revision 2.
Industry Guidance - Interim Storage of Higher Activity Waste Package – Integrated Approach, November 2012.
Approved Code of Practice, Managing Health and Safety in Construction – Construction (Design and Management) Regulations 2015.
Approved Codes of Practice, Working with Ionising Radiation – Ionising Radiations Regulations 1999.
Reducing Risks, Protecting People; HSE Books 2001.
HSE Criterion for Delicensing Nuclear Sites, May 2005, http://www.onr.org.uk/delicensing.pdf
Delicensing Guidance, Guidance to Inspectors on the Interpretation and Implementation of the HSE Policy Criterion of No Danger for the Delicensing of Nuclear Sites, 13th August 2008, http://www.onr.org.uk/delicenceguide.pdf

Annex 4
Regulatory Issues / Observations

RI / RO Ref	RI / RO Title	Description	Date Closed	Report Section Reference
RI-ABWR-0001	Definition and Justification for the Radioactive Source Terms in UK ABWR during Normal Operations	The definition of the radioactive source term, namely the nature and amount of radioactivity, is a fundamental part of understanding and being able to control the hazards associated with any nuclear facility. This definition should be based upon a suitable and sufficient justification, which should demonstrate that the derived values are appropriate to be used within the safety case, in whatever capacity is necessary. Failure to adequately define or justify the source term could ultimately mean that the design, operations or controls specified may not be soundly based. It would also prove difficult to demonstrate that associated risks have been reduced So Far As Is Reasonably Practicable (SFAIRP).	19/10/2016	2.3
RI-ABWR-0002	UK ABWR Probabilistic Safety Analysis: Project Plan and Delivery	States ONR's expectations with respect to Hitachi-GE developing and delivering a suitable and sufficient Probabilistic Safety Analysis (PSA) for the UK ABWR Fault Analysis (FA) as part of the GDA submission. Hitachi-GE is required to deliver a suitable and sufficient scope PSA for GDA developed in line with UK obligations in order for ONR to undertake a meaningful assessment against regulatory expectations, including SAPs FA.10-14. In addition the regulatory expectations on PSA are summarised in SAPs Targets 7 to 9 and ONR's PSA Technical Assessment Guide.		
RO-ABWR-0006	Source Terms	Sets out the regulators' expectations regarding operational states in UK ABWR for the RP to demonstrate that source terms have been reduced So Far As Is Reasonably Practicable (SFAIRP) and that Best Available Techniques (BAT) has been applied. The entire scope of the regulators' interest in this topic extends to design basis and severe accidents.	03/04/2017	2.3
RO-ABWR-0011	Safety Case for Spent Fuel Pool and Fuel Route	To define the scope of the SFP and fuel route safety case to be incorporated into future revisions of the PCSR. The purpose of this Regulatory Observation is to consider the fuel route up to export of the spent fuel from the reactor building.	12/06/2017	
RO-ABWR-0025	Hitachi-GE Nuclear Energy Ltd. Safety Case Process and Capability	Hitachi-GE needs to ensure that its organisational processes and competencies for the production of safety cases are robust and implemented to deliver a complete, cogent and coherently developed modern standards safety case for the UK ABWR, which is consistent across all technical areas and takes cognisance of multiple relevant interfaces.	24/06/2015	

RO-ABWR-0035	Robust justification for the materials selected for UK ABWR	The choice of materials for a particular SSC of a nuclear reactor is influenced by many competing factors, including: • the functional requirements of the SSC; • the tolerance/degradation of the SSC in its operating 'environment', and/or: • the potential hazards and risks, which must be either eliminated, reduced or controlled. Considering the above factors, and potentially others, it is clear the justification of the most appropriate material selected for a particular SSC requires a balance to be struck which should include a robust demonstration that all of the relevant risks have been considered and reduced SFAIRP.		2.3
RO-ABWR-0036	Demonstration that the approach taken to radioactive waste management reduces risks SFAIRP	The approach taken to the management of liquid, solid and gaseous radioactive wastes can involve complex decisions. The chosen regimes must adequately balance the different benefits and detriments of the approach in order to demonstrate that this reduces risks So Far As Is Reasonably Practicable (SFAIRP).		
RO-ABWR-0037	Safety Case for Faults not Directly Related to the Reactor	Requires Hitachi-GE to demonstrate that it has identified all buildings, systems, processes and activities which could, in a fault condition, result in a person receiving a significant radiation dose or to the escape of a significant quantity of radioactive material, despite the reactor core being unaffected.	02/08/2017	
RO-ABWR-0045	UK ABWR – Operational Experience (OPEX)	The RP has not demonstrated sufficiently how it has considered and taken account of operational experience from BWR plants from around the world including Japan. ONR acknowledges that the ABWR is an evolutionary design, incorporating a number of engineered features, which are considered improvements to earlier designs. In addition, the ABWR itself has been operational for a number of years. This regulatory observation is cross-cutting and of interest to all assessment disciplines. Hitachi-GE is required to: 1. demonstrate adequate knowledge of all BWR and ABWR operational experience across the world; 2. demonstrate the adequacy and robustness of its ABWR technology; and 3. adequately consider operational experience to reduce risks So Far As is Reasonably Practicable (SFAIRP).	31/03/2017	
RO-ABWR-0054	UK ABWR – Chemical/Process Engineering Design approach	ONR's review has identified shortfalls in the Hitachi-GE proposal for the radioactive waste systems and their ultimate decommissioning relating to the J-ABWR use of embedded pipework and Hitachi-GE's approach	02/08/2017	

		to the implementation of the recommendations arising from the identification of hazards arising from the radioactive liquid waste systems. The objective of this Regulatory Observation (RO) is to: a) State ONR's expectations related to a Chemical/Process engineering design approach to systems, i.e. the principles, rules, considerations and selection criteria. b) Request Hitachi-GE shows how it will implement a design approach that meets ONR expectations for the design of the UK ABWR.		
RO-ABWR-0064	Design approach to identification and provision of both permanent and temporary features necessary for the adequate control of radioactive contamination across the full lifetime of UK ABWR	It has not been possible to clearly identify the approach that Hitachi-GE has taken to control radioactive contamination. ONR expects that the UK ABWR is designed such that permanent and temporary features required to manage and prevent the spread of radioactive contamination, from areas of high designation to those of lower designation are fully considered.	27/07/2017	
RO-ABWR-0065	Demonstration of adequate design and implementation…… whilst being cognisant of design requirements relating to other discipline areas	An important area for shielding design is the specification for management of through wall penetrations to minimise and or prevent - shine paths for radiations into areas of lower zone classification thereby increasing the general or local radiation dose rate in the adjacent area.	02/05/2017	
RO-ABWR-0071	Turbine Gland Steam System: Discharges and Optimisation	The Turbine Gland Steam System is a source of gaseous radioactive waste that is discharged to the environment. The Turbine Gland Steam System supplies steam to the turbine shaft seal parts and the major valve gland parts. The Turbine Gland Steam System is not fully considered in the Generic Environmental Permit submission and Pre-PCSR. There is a need to assess the BAT and ALARP aspects of this system and the impacts of its discharges.	02/11/2016	
RO-ABWR-0073	Robust demonstration that the design of the UK ABWR off-gas system reduces risks SFAIRP	The UK ABWR off-gas system is designed to control and mitigate a number of hazards arising during normal operations, including, the accumulation of radioactivity (predominately radioisotopes of xenon and krypton), and explosion hazards from hydrogen generated by radiolysis. By deliberately accumulating radioactivity the off-gas system allows it to decay to acceptably lower levels, prior to its discharge.	/09/2017	
RO-ABWR-0075	Robust demonstration that the design of the UK ABWR HVAC system has been adequately conceived and reduces risks SFAIRP	ONR has carried out a multi-disciplinary assessment of Hitachi-GE's BSC for the UK ABWR HVAC system which has revealed a number of gaps with regulatory expectations. Requests additional evidence in order to demonstrate that the design of the UK ABWR HVAC system is fit for purpose and reduces risks So Far As is Reasonably Practicable (SFAIRP).	03/07/2017	

Annex 5
Management of Radioactive Wastes Regulatory Queries

RQ Ref	RQ Title	Description
RQ-ABWR-0193	Off Gas Charcoal Adsorber Efficiency for 60 years of Operation	In light of the UK ABWR having an operational lifetime of 60 years, longer than other ABWR's currently operating, ONR requested clarification of whether the charcoal adsorbers will remain fit-for-purpose over the full 60 year operational lifetime.
RQ-ABWR-0240	Delay Beds (Argument 2b)	Requested clarification of how iodine abatement had been considered during optimisation of the UK ABWR.
RQ-ABWR-0244	Off-Gas Treatment System BAT Considerations	Requested further evidence in support of the specific aspects of the Off Gas system design and associated impacts on environmental protection.
RQ-ABWR-0668	Justification for revised design of the HCW LWMS	Requested further justification of the incorporation of either filtration and ion exchange, or evaporation and re-use, as the operational basis of the HCW system.
RQ-ABWR-0781	Off Gas System Design – Adequate ALARP Demonstration	Challenged several elements of the Off Gas system design (e.g. configuration of guard beds, hold up times and potential guard bed provision) and asked for further justification on grounds of ALARP
RQ-ABWR-0782	Off Gas System Design – Adsorber Safety Functions, Classification and Performance Margins	Required information to clarify Hitachi-GE's treatment of the adsorber safety functions, classifications and demonstration of adequate performance margins and operational limits.
RQ-ABWR-0784	Off-gas System Design – Recombiner Safety Functions, Classification and Performance Margins	Required information to clarify Hitachi-GE's treatment of the recombiner safety functions, classifications and demonstration of adequate performance margins and operational limits
RQ-ABWR-0875	Maintenance Strategy for the SWMS	Noted that maintenance schedules for Japanese ABWRs are based on a 'time based maintenance' strategy, whereas a maintenance schedule based on a combination of 'time based maintenance' and 'reliability centred maintenance' will be developed for the UK ABWR. ONR therefore highlighted the expectation that maintenance requirements will be considered within the design itself in order that risks are reduced ALARP.
RQ-ABWR-0877	LWMS, Breakthrough of Concrete Cell Walls	Noted Hitachi-GE's apparent intention to enable personnel access into cells housing process vessels containing ILW, via the break-through of concrete shield walls in pre-specified areas designed for the purpose, and highlighted ONR's relevant expectations in relation to containment and IRR99.
RQ-ABWR-0908	Tank Capacities	Noted that Hitachi-GE had not provided adequate justification for the relationship between the working and design capacity of various tanks in the LWMS and sought a demonstration of compliance with Safety Assessment Principles ECV.1 – ECV.10.
RQ-ABWR-0909	Decay Storage of Bead Activated Carbon	Sought an improved demonstration of compliance with SAPs RW2 and RW5 in relation to Hitachi-GE's proposals for decay storage of combustible dewatered LLW Bead Activated Carbon (BAC).
RQ-ABWR-0910	Demonstration of ALARP for the SWMS	Requested Hitachi-GE to provide further evidence that the design of the SWMS will reduce risks

		ALARP, including a clear link between the original design basis, risk identification, consideration of RGP, optioneering and incorporation of design features leading to reduced risk.
RQ-ABWR-0911	Review of Relevant Good Practice in SWMS	Noted that Hitachi-GE's quoted "examples of good practice" focused on the production of the end waste product without addressing the full life cycle phases of waste management (i.e. retrieval, handling, segregation, treatment/conditioning and final packaging for consignment off site or interim storage on-site). ONR highlighted its expectation for a systematic review of RGP to identify techniques, features and processes that could be incorporated into the ABWR design to reduce
RQ-ABWR-0938	Progressing the design of the Liquid Waste Management System (LWMS)	Noted outstanding design work associated with aspects of the LWMS, highlighted relevant ONR expectations and sought clarification of Hitachi-GE's strategy and plan to demonstrate how the LWMS design will be taken to a suitable state of maturity within GDA.
RQ-ABWR-0959	Definition of 'Concept Design' as applied to UK ABWR Systems for Management of Radioactive Wastes in GDA	Asked Hitachi-GE to explain its practical definition of 'Concept Design' in the context of GDA for the UK ABWR systems for Management of Radioactive Wastes and to demonstrate how this aligned with regulatory advice.
RQ-ABWR-1043	LWMS Observations	Highlighted a range of ONR expectations in relation to the LWMS, including; a consideration of the impact of the UK ABWR change to operating chemistry; the waste hierarchy, with preference in the first instance for avoidance, and; the need for ALARP considerations to be recognised alongside BAT.
RQ-ABWR-1189	Control and Instrumentation in the LWMS	Raised a range of questions concerning; the standards used for Categorisation and Classification of LWMS systems; the meaning of "fully adopted" and "partially adopted" in the context of the LWMS considerations within GDA; use of hardwired interlocks; the potential to automate safety functions, and; use of smart devices.
RQ-ABWR-1198	Chemistry Monitoring and Sampling Queries 2	Requested a confirmation of where, within the UK ABWR safety case, the adequacy of the design of the UK ABWR with respect to sampling non-primary reactor water systems will be demonstrated whilst highlighting ONR's expectations in respect of the sampling philosophy, potential for the sampled liquid to be recycled and the need for representative sampling.
RQ-ABWR-1218	LWMS Design Justification	Challenged Hitachi-GE's justification for several elements of the LWMS design and operations, while highlighting ONR's expectation for a justification proportionate to the nuclear safety significance of the LWMS. Specifically: The number, type, capacity and layout of filters and demineralisers in the design; Adequate and representative sampling to support safe operations; Controls to prevent spurious transfers to the CST; Provisions for acid/alkali dosing to the HCW system; Allocation of safety claims, and; Identification of LCOs.
RQ-ABWR-1219	LWMS ALARP Design Considerations	Sought a range of supporting references in order to establish that the design of the LWMS was based on a robust consideration of all practicable options and further demonstrated that the option chosen is reasonably practicable and has reduced the risk SFAIRP.
RQ-ABWR-1220	LWMS Effluent Sampling Process	Asked Hitachi-GE to clarify its broad objectives of the sampling regime and the principles set down to define at the detailed design level how the system will be managed, with a demonstration that the sampling system will be able to accommodate the timescales and volumes anticipated during normal

		operation.
RQ-ABWR-1229	LCW Filter Packaging	Requested Hitachi-GE to clarify its description of the LCW Filter Packaging Room and the intended operations within it, including; the extent of manual operations in changing the LCW filter banks; how loaded 500litre drums will be lifted over the dwarf wall; how the drip hazard from the filters will be minimised; containment arrangements, and; the potential for airborne contamination.
RQ-ABWR-1253	LWMS and Fault Conditions	Sought a resolution of apparent inconsistencies between the Basis of Safety Case on Liquid Waste Processing in the Radioactive Waste Building, Rev.6 (GA91-9201-0002-00053), the Topic Report on Design Basis Analysis Rev. 10 (GA91-9201-0001-00023), Attachment-L Dose Evaluation for Non-Reactor Faults, and the Topic Report on Fault Assessment (GA91-9201-0001-00022).
RQ-ABWR-1353	LWMS – Effluent Make-Up, Design Justification and Operating Rules	Requested further information to allow ONR to form judgements on the adequacy of the chemical performance and engineered design of the LCW and HCW systems, including: Characteristics of the LCW and HCW untreated effluent; Justification of the LCW and HCW capacities, vessel arrangements and filtration provisions; Justification of the choice of HCW corrosion inhibitor; Identification of any operating rules (limits and conditions) for the LWMS which are necessary in the interests of safety.
RQ-ABWR-1408	Queries Arising from Assessment of GA91-9201-0003-01707, 'Topic Report: High Level Waste ALARP Assessment'	Requested further information from Hitachi-GE to objectively underpin the proposed UK ABWR strategy and design provisions for managing solid High Level Wastes.
RQ-ABWR-1425	Off Gas System Basis of Safety Case queries	Raised a range of questions that arose from ONR's assessment of Revision 4 of the Off-Gas System Basis of Safety Case (GA91-9201-0002-00054) in relation to hydrogen monitoring, DSEAR compliance, fault detection and fault response times.
RQ-ABWR-1473	Reactor Building Solid ILW Inventory	Identified that the generic case for the SWMS had not accommodated solid ILW from the Reactor Building as a contributory waste stream during the UK ABWR's 60 year life and asked for clarification of how Hitachi-GE would intend to manage such a waste stream should it arise.

Annex 6
Assessment Findings

Assessment Finding Number	Assessment Finding	Report Section Reference
AF-ABWR-RW-01	Hitachi-GE's generic safety case did not clearly define the full range of effluent feeds (in terms of the physical, chemical and radiological properties) that it anticipated would need to be received and processed by the Low Chemical Impurity Waste (LCW) system. In addition, Hitachi-GE was unable to present a consistent and coherent set of parameters against which the LCW output will be sentenced, either to the primary circuit via the Condensate Storage Tank (CST), recycled back through the LCW, transferred to the High Chemical Impurity Waste (HCW) system for additional treatment or potential discharge to the environment under permission. A number of these options are inter-linked with reactor operations and thus of a much higher importance than routine effluent treatment. Therefore the licensee shall demonstrate for the site specific situation that: a) It has an adequate understanding of the full range of anticipated feeds to the LCW from: • All stages of the reactor operational lifecycle (start-up, at power operations, shutdown and outage) • Normal operations and reasonably foreseeable deviations, including all design basis faults • Commissioning and decommissioning b) It has defined or established the criteria for routing the LCW discharge during the operational phases discussed above, including recycling through the LCW, further additional treatment, dispatch back to the primary circuit or potential discharge under permission. c) It has defined the performance requirements of the LCW unit operations and that this is consistently reproduced across all the LCW safety case and design documents. d) It has established that the operating life of the LCW is encompassed by the generic case and can be substantiated and justified. e) It has established that prior LCW optioneering has resulted in a solution that will deliver the requirements of parts a), b),and c) above as well as a suitably justified and substantiated solution that will demonstrably reduce	4.2.3 – Liquid Waste Management System, LCW System

	risks as low as reasonably practicable (ALARP), or amend it to deliver them. f) It has ensured that for all reasonably foreseeable operational events there is sufficient capability in the system to ensure that it can achieve the desired duty and integrate where necessary with the other parts of the Liquid Waste Management System (LWMS) or that the capability can be adequately adapted to deliver the required duty. g) It has ensured that the significant unexplained variation between the radionuclides content of the LCW discharge stream and the HCW system discharge stream when compared to the activity in the CST within the GDA case is reviewed and explained to ensure a consistent and coherent position is presented.	
AF-ABWR-RW-02	Although Hitachi-GE demonstrated that the treatment techniques deployed within the High Chemical Impurity Waste (HCW) system could adequately meet environmental protection requirements, the generic safety case did not meet ONR's expectations with respect to the optimisation of safety. The licensee shall therefore revisit the consideration of treatment options for the HCW system, to provide a suitably justified and substantiated safety solution that will demonstrably reduce on-site risks as low as reasonably practicable (ALARP) whilst also delivering the permitted environmental protection.	4.2.3 – Liquid Waste Management System, HCW System
AF-ABWR-RW-03	The Hitachi-GE generic safety case incorporates a recombiner stage within the Off-Gas system. However, the case failed to clearly and adequately substantiate a range of design aspects that are fundamental to recombiner safety and reliability in service. As a consequence it could not be determined whether the risks related to hydrogen ignition will be reduced So Far As Is Reasonably Practicable for all reasonably foreseeable events that the recombiners will be exposed to. The most important aspects are the claims regarding: a) The safety classification (and thus reliability) b) Operating Life c) Method of Operation and monitoring regime d) In-service performance including exposure to post accident atmospheres and catalyst degradation which	4.2.4 – Systems to Manage Gaseous Radioactive Wastes, Off Gas System

	relate to the potential hazard and risk profile Therefore the licensee shall: a) Establish the appropriate safety classification for all elements of the recombiner to demonstrably reduce risks as low as reasonably practicable (ALARP) at all points during the plant's anticipated operational life (i.e. 60 years). b) Adequately substantiate the operating regime for the recombiner system during normal operations and all reasonably foreseeable events by establishing - The in-service performance characteristics of the catalyst - The method by which this performance will be maintained, utilising appropriate system cycling and duty / standby configurations (including switchover)	
AF-ABWR-RW-04	Hitachi-GE's generic safety case associated with the Off-Gas system did not adequately address the following areas: a) Consideration of the integrity of the Off-Gas system pipework and equipment, in terms of their mountings and fixings, in the event of a hydrogen explosion inside the system. b) Composition of the main condenser feed gas to the first Steam Jet Air Ejector (SJAE) for the entire range of reasonably foreseeable conditions in the design basis. c) A suitably comprehensive and robust justification against the requirements of the Dangerous Substances and Explosive Atmosphere Regulations (DSEAR) for all sections of the Off-Gas system Therefore the licensee shall a) Suitably substantiate and justify the reactor off-gas pipework, equipment fixings and mountings, to ensure that the system integrity is maintained in the event of a hydrogen explosion within the Off-Gas system. b) Provide a comprehensive and objective consideration of the feed gas into the reactor Off-Gas system to ensure that a suitable DSEAR justification can be formulated. c) Review the Off-Gas system design and justify compliance of the system with the requirements of DSEAR.	4.2.4 – Systems to Manage Gaseous Radioactive Wastes, Off Gas System
AF-ABWR-RW-05	Hitachi-GE's generic safety case associated with the	4.2.4 –

	hydrogen hazard in the Off–Gas system failed to adequately address the following areas: a) The use of hydrogen explosion and ignition data. b) The consideration of early full or partial hydrogen hazard reduction in the Off-Gas system c) The basis of the containment integrity and hydrogen monitoring system to maintain adequate safety d) The use of post-trip purging to dilute any potential high hydrogen explosive atmosphere in the Off-Gas system. Therefore, the licensee shall: a) Provide suitably substantiated hydrogen ignition and explosion information relevant to the operating conditions of the Off-Gas system. b) Consider options to implement early hydrogen hazard reduction (full or partial) between the first Steam Jet Air Ejector (SJAE) and the second SJAE to reduce hydrogen hazard as low as reasonably practicable. c) Justify and substantiate the containment boundary and hydrogen monitoring system to ensure adequate safety during a fault condition. d) Provide a detailed understanding of any purge of the Off Gas system that may be required as part of a high hydrogen shutdown (typically as a result of recombiner failure), justify what gases (inert or air) are used in the purge and the required flowrates recognising the potential demands on the charcoal beds.	Systems to Manage Gaseous Radioactive Wastes, Off Gas System
AF-ABWR-RW-06	While ONR was satisfied by Hitachi-GE's evidence to the effect that the postulated fault (an Off Gas system leak) will not give rise to a flammable atmosphere in manned areas and rooms owing to the ventilation system, the case did not adequately address the potential for radioactive species to also migrate and present a hazard to people in the vicinity. Therefore the licensee shall suitably justify and substantiate: a) The consequence analysis for the postulated fault (which Hitachi-GE defined as a 'small leak' in the generic safety case). b) The Systems, Structures and Components that will be used to inform operators that the postulated fault has taken place and to minimise the subsequent doses.	4.2.4 – Systems to Manage Gaseous Radioactive Wastes, Off Gas System
AF-ABWR-RW-07	Hitachi-GE's considered that faults regarding moisture ingress to the charcoal beds were bounded by the total	4.2.4 – Systems to Manage Gaseous Radioactive Wastes, Off

	failure of the Off Gas system condenser. However, its estimates for moisture ingress in this scenario were not adequately underpinned and in addition would suggest that an additional fault of pressurisation of the Off Gas system upstream of the charcoal beds and thus problems with reactor operation would occur. Therefore the licensee shall consider all design basis faults that could provide acute moisture ingress into the charcoal beds and justify and substantiate the safety position.	Gas System
AF-ABWR-RW-08	Hitachi-GE's generic safety case associated with the Tank Vent Treatment System (TVTS) did not provide an adequate position with regard to the following: a) The derived hydrogen generation rate and thus the time to reach a flammable condition in the tanks following a ventilation failure could not be verified and thus could not be judged as conservative. b) The argument presented regarding the avoidance of stratification of hydrogen during a ventilation fault and thus the creation of a flammable gas zone earlier than expected. c) There is no consideration of gas hold-up in the waste sludges and how this will be managed in the event of sudden gas release during operation. d) The alternative hazard management strategy of draining the free liquid from the waste tanks in the event of a ventilation fault did not indicate where the waste liquors will be transferred to and whether this is reasonably practicable. e) There was no substantiation to the claim that the civil structure containing the waste tanks will provide containment in the event of a hydrogen deflagration/detonation in a waste tank. Therefore the licensee shall: a) Justify and substantiate the hydrogen generation rate for the waste and thus that the time to create a flammable gas in the event of a fault is suitably conservative. b) Justify and substantiate the flammable hydrogen condition taking into account potential localised high hydrogen concentrations in line with tank geometry and the understanding of hydrogen buoyancy behaviour in a static air condition.	4.2.4 – Systems to Manage Gaseous Radioactive Wastes, Tank Vent Treatment System

	c) Justify and substantiate the hold-up of gas within the sludge waste beds and how any sudden gas release into the tank ullage space will be managed to control the flammable hazard so far as is reasonably practicable. d) Justify and substantiate the liquid drainage hazard management strategy in terms of how it would be enacted and whether it is reasonably practicable to do so and its importance in the hierarchy of response to the initiating fault. e) Define what is meant by the civil structure providing 'bulk contamination containment performance' in the event of an explosion and substantiate how the civil structure will achieve this requirement.	
AF-ABWR-RW-09	Hitachi-GE's generic case for the Solid Waste Management System (SWMS) assumed that no solid Intermediate Level Waste (ILW) will be generated from maintenance of the UK ABWR during the site's operational life, primarily due to the adoption of a 60 year design life for the primary circuit Systems, Structures and Components. While there is a low probability of the UK ABWR giving rise to significant volumes of solid ILW during the operational phase, there is clear potential for maintenance wastes, failed components (such as valves, pump components or instruments) and equipment upgrades to result in items of ILW that may give rise to waste management challenges. The licensee shall demonstrate that the UK ABWR is capable of safely managing any miscellaneous items of solid ILW that may arise during the site's operational phase from plant breakdowns or replacements.	4.2.5 – Solid Waste Management System

Annex 7
Minor Shortfall

Minor Shortfall Number	Minor Shortfall	Report Section Reference
MS-ABWR-D-01	The licensee should address the reported findings of RWM Ltd and ensure the disposability of operational HAW and spent fuel at the UK's planned GDF is addressed within its choices on detailed design and operation of the UK ABWR.	4.2.2 Disposability of the UK ABWR Higher Activity Wastes