Cyfoeth Naturiol Cymru
Natural Resources Wales

Environment Agency

Assessing new nuclear power station designs

Generic design assessment of Hitachi-GE's Advanced Boiling Water Reactor

Assessment report - AR03 Best available techniques

December 2017

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Published by:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH
Email: enquiries@environment-agency.gov.uk

Natural Resources Wales
Cambria House
29 Newport Road
Cardiff, CF24 0TP
Email:
enquiries@naturalresourceswales.gov.uk

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Email: enquiries@environment-agency.gov.uk.

or
Natural Resources Wales: 0300 065 3000
Email:
enquiries@naturalresourceswales.gov.uk

Executive summary

Protective status	This document contains no sensitive nuclear information or commercially confidential information.

Process and information document[1]	Relevant items from our Process and Information document (Environment Agency 2016a) include: Item 1: General information relating to the requesting party and the design – Include: 'a brief history of the design, identifying predecessor plant and the main design changes.' Item 2: A description of the requesting party's management arrangements and responsibilities for: – Include: 'establishing the methodology for identifying the 'best available techniques' (BAT) .... and ensuring their use in the design' Item 4: A detailed description of the radioactive waste management arrangements: You should describe your optimisation process and identify and justify the techniques you are proposing as BAT. Item 5: Quantification of radioactive waste disposals: 'infrequent but necessary aspects of operation, for example, plant wash-out; and the foreseeable, undesired deviations from planned operation (based on a fault analysis) consistent with the use of BAT, for example, occasional fuel pin failures.'

Radioactive Substances Regulation Environmental Principles[2]	The following principles are particularly relevant to this assessment: RSMDP3 – Use of BAT to minimise waste: The best available techniques should be used to ensure that production of radioactive waste is prevented and minimised where that is not practicable with regard to activity and quantity. RSMDP4 – Processes for identifying BAT: The best available techniques should be identified by a process that is timely, transparent, inclusive, based on good quality data, and properly documented.

[1] Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs, Version 2, Environment Agency, Mar 2013. http://webarchive.nationalarchives.gov.uk/20151009003754/https://www.gov.uk/government/publications/assessment-of-candidate-nuclear-power-plant-designs

Latest version is Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs, Version 3, Environment Agency, October 2016. https://www.gov.uk/government/publications/assessment-of-candidate-nuclear-power-plant-designs . Note - no material changes between revisions.

[2] Regulatory Guidance Series, No RSR 1: Radioactive Substances Regulation – Environmental Principles, Version 2), Environment Agency, April 2010. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296388/geho0709bqsb-e-e.pdf

	RSMDP7 – BAT to minimise environmental risk and impact: When making decisions about the management of radioactive substances, the best available techniques should be used to ensure that the resulting environmental risk and impact are minimised. RSMDP8 – Segregation of wastes: The best available techniques should be used to prevent the mixing of radioactive substances with other materials, including other radioactive substances, where such mixing which might compromise subsequent effective management or increase environmental impacts or risks.

Report author	Dr Paul Abraitis

This report presents the findings of the assessment of information relating to best available techniques (BAT) as proposed by Hitachi-GE for the UK Advanced Boiling Water Reactor (ABWR) design. This is based on our detailed consideration of the final case presented to the Environment Agency as part of the UK generic design assessment (GDA) process.

Our assessment covers the techniques used to prevent and minimise the creation of radioactive waste, minimise the discharges of gaseous and aqueous radioactive waste to the environment, and minimise the impact of those discharges. Using BAT for monitoring is not covered in this report and our assessment of this is provided elsewhere (Environment Agency, 2017a).

We conclude that, overall, the UK ABWR is consistent with the application of BAT in relation to radioactive substances, and that this has been demonstrated to a sufficient level that is in line with our expectations for GDA.

We have identified no GDA Issues.

We have identified a number of Assessment Findings that we will expect a future operator to address. These are:

- Assessment Finding 3: A future operator shall demonstrate that the UK ABWR will be operated in a manner that represents best available techniques, addressing in particular:
    - fuel selection
    - fuel and core management
    - avoidance of control rod failure in power suppression situations
    - consideration of all normal operational modes and stages of the reactor’s lifecycle
    - control of water chemistry
    - selection of demineraliser resins for liquid waste management systems
- Assessment Finding 4: A future operator shall review the practicability of techniques for abatement of carbon-14 prior to operation.
- Assessment Finding 5: A future operator shall assess the partitioning of carbon-14 between gaseous, aqueous and solid waste streams, during initial operations.

- Assessment Finding 6: A future operator shall address the 15 forward actions as identified by Hitachi-GE in the 'Demonstration of BAT' submission - GA91-9901-0023-00001 Rev. G, August 2017. (Hitachi-GE, 2017a)[3].

The basis and context of these assessment findings are described in this report.

[3] The 15 actions referred to in Assessment Finding 6 are reproduced in Appendix 5 of this document.

Contents

1. Introduction

This report provides our assessment of Hitachi-GE's process for identifying best available techniques (BAT) and how these are to be applied in the UK ABWR design for generic design assessment purposes. Our report considers the final relevant technical submissions provided by Hitachi-GE and has been informed by the outcomes of our consultation process.

Our assessment covers the techniques used to prevent and minimise the creation of radioactive waste, minimise the discharges of gaseous and aqueous radioactive waste to the environment, and minimise the impact of those discharges. Using BAT for monitoring is not covered in this report and our assessment of this is provided elsewhere (Environment Agency, 2017a).

Identifying BAT is the result of a process of optimisation, where minimising the generation and discharge of radioactive waste is balanced against the cost and benefits of further reductions. Applying the results of such a process leads to a design that is capable of meeting high environmental standards but where the cost of applying techniques is not grossly disproportionate in relation to the environmental protection they provide.

There is a requirement under Environmental Permitting Regulations 2016 (EPR16) (Defra, 2016) that we carry out our work to ensure that all exposures to ionising radiation of any member of the public and of the population as a whole resulting from the disposal of radioactive waste are kept as low as reasonably achievable (ALARA), taking into account economic and social factors. We do this by requiring designers and operators to use BAT.

We define best available techniques as the latest stage of development of processes, facilities or methods of operation that indicate the practical suitability of a particular measure for limiting discharges, emissions and waste. In determining whether a set of processes, facilities and methods of operation constitute the best available techniques in general or individual cases, special consideration is given to:

- comparable processes, facilities or methods of operation that have recently been successfully tried out
- technological advances and changes in scientific knowledge and understanding
- the economic feasibility of these techniques
- time limits for installation in both new and existing plant
- the nature and volume of the discharges and emissions concerned

'Techniques' include both the technology used and the way in which the installation is designed, built, maintained, operated and dismantled.

BAT is, therefore, a fundamental aspect of radioactive substances regulation, and we expect it to be identified by an appropriate process as described in our Radioactive Substances Regulation Environmental Principles (REPs) (Environment Agency, 2010) at principle RSMDP4 (methodology for identifying BAT). The process is not restricted to considering radioactive substances and their resulting doses, but also has regard to:

- safety considerations, for example, worker protection and security
- wider environmental considerations, for example, energy and other resource usage, the generation and disposal of conventional waste
- social and economic considerations, such as potential impacts on employment

2. Assessment

2.1. Assessment method

Our assessment method was to:

- consider the submission Hitachi-GE made, in particular the 'Demonstration of BAT' (Hitachi-GE, 2017a) and 'Approach to Optimisation' (Hitachi-GE, 2017b) reports and by sampling the supporting documents
- hold technical meetings with Hitachi-GE to clarify our understanding of the information presented and explain any concerns we had with that information
- raise Regulatory Queries (RQs), Regulatory Observations (ROs) and Regulatory Issues (RIs) as required, definitions for which are given in our decision document (Environment Agency, 2017g)
- assess the techniques Hitachi-GE proposed to prevent and minimise the creation of radioactive waste, minimise the discharges of gaseous and aqueous radioactive waste to the environment and minimise the impact of those discharges
- decide on any issues to carry forward from this stage of GDA in our statement of design acceptability (SoDA) as 'GDA Issues'
- identify any findings to carry forward from GDA and to be addressed by the future operators as 'Assessment Findings'

2.2. Assessment objectives

Our assessment objectives were to determine whether Hitachi-GE had provided the following with respect to the UK ABWR design and the supporting case for generic design assessment:

- Have the significant radionuclides present in waste been identified? These are those that contribute significantly to the amount of activity in waste disposals or to the potential doses to members of the public.
- Have the best available techniques been identified to prevent and minimise the creation of radioactive waste, minimise the discharges of gaseous and aqueous radioactive waste to the environment and minimise the impact of those discharges?
- Do the options chosen for the UK ABWR constitute BAT?

2.3. Hitachi-GE documentation

We referred to the following documents to produce this report (Table 1):

Table 1. Hitachi-GE documentation reviewed for this assessment

Document No.	Title
GA91-9901-0019-00001_Rev H	Summary of the generic environmental permit applications
GA91-9901-0022-00001_Rev H	Radioactive waste management arrangements
GA91-9901-0023-00001_Rev G	Demonstration of BAT
GA91-9901-0021-00001_Rev F	Approach to optimisation

Document No.	Title
GA91-9901-0028-00001_Rev F	Alignment with the Radioactive Substances Regulation Environmental Principles (REPs)
GA91-9101-0101-18000_Rev C	PCSR* Chapter 18 Radioactive waste management
GA91-9101-0101-09000_Rev C	PCSR* Chapter 9: General description of the unit (facility)
GA91-9201-0003-00976-Rev 1	End user source term methodology report
GA91-9201-0003-00941-Rev 2	Nuclide selection by end user requirement
GA91-9201-0001-00160-Rev 2	Topic report on discharge assessment during normal operation
GA91-9201-0003-00353-Rev 2	Methodology for expected event selection
GA91-9201-0003-00942-Rev 2	Source term manual general report
GA91-9201-0003-00945-Rev 3	Process source term supporting document

**PCSR = Pre-construction safety report*

Hitachi-GE provided its initial submission (Revision A) to GDA in December 2013. This was updated to include a separate section on regulatory context and consideration of the REPs for Revision B (14 March 2014) and Revision C was issued for web publication on 31 March 2014.

We carried out our Step 2 initial assessment on Revision D, which was issued on 6 August 2014. Our assessment for BAT consisted of an initial assessment of the contents against our requirements and was not an in-depth assessment of the discharges. Our initial assessment feedback (Environment Agency, 2014) noted that some further information would be needed to undertake the detailed assessment, specifically:

- appropriate and reliable evidence to support the estimates of liquid and gaseous discharges (see RO-ABWR-0006 below)
- details on the contribution that each phase of normal operations makes to discharges, for example, start-up, operation, maintenance and shut-down
- demonstration that expected discharges will not exceed those of comparable power stations across the world
- further information on the assessment of expected events under normal operations

The Hitachi-GE response to this feedback is reflected in subsequent issues of the GEP documentation (Revisions E, F and G) and supporting documents. Our views on the adequacy of this information is covered elsewhere in our assessment reports but some aspects are relevant to the demonstration of BAT.

Assessment and technical discussions resulted in RQs, RO and an RI that were relevant to best available techniques and source term aspects. We issued some of these, but we issued the majority jointly with ONR.

A table summarising these RQs, ROs and RIs is provided in Appendix 1. The table includes a brief summary of the topics that were covered in each.

2.4. Summary of the generation, minimisation and management of radioactive waste in the UK ABWR

A diagrammatic representation of the sources and routings of radioactive wastes within the UK ABWR is provided by Hitachi-GE (Figure 1). A summary of the main aspects for the most significant radionuclides contributing to discharges from the UK ABWR design is provided in tables in the appendices to this report (Appendix 2 & 3). A summary of the solid radioactive waste arisings from the UK ABWR design is provided in our assessment report relating to solid radioactive waste (Environment Agency, 2017b). Projected annual discharges (gaseous and aqueous) are discussed elsewhere (Environment Agency, 2017c, 2017d).

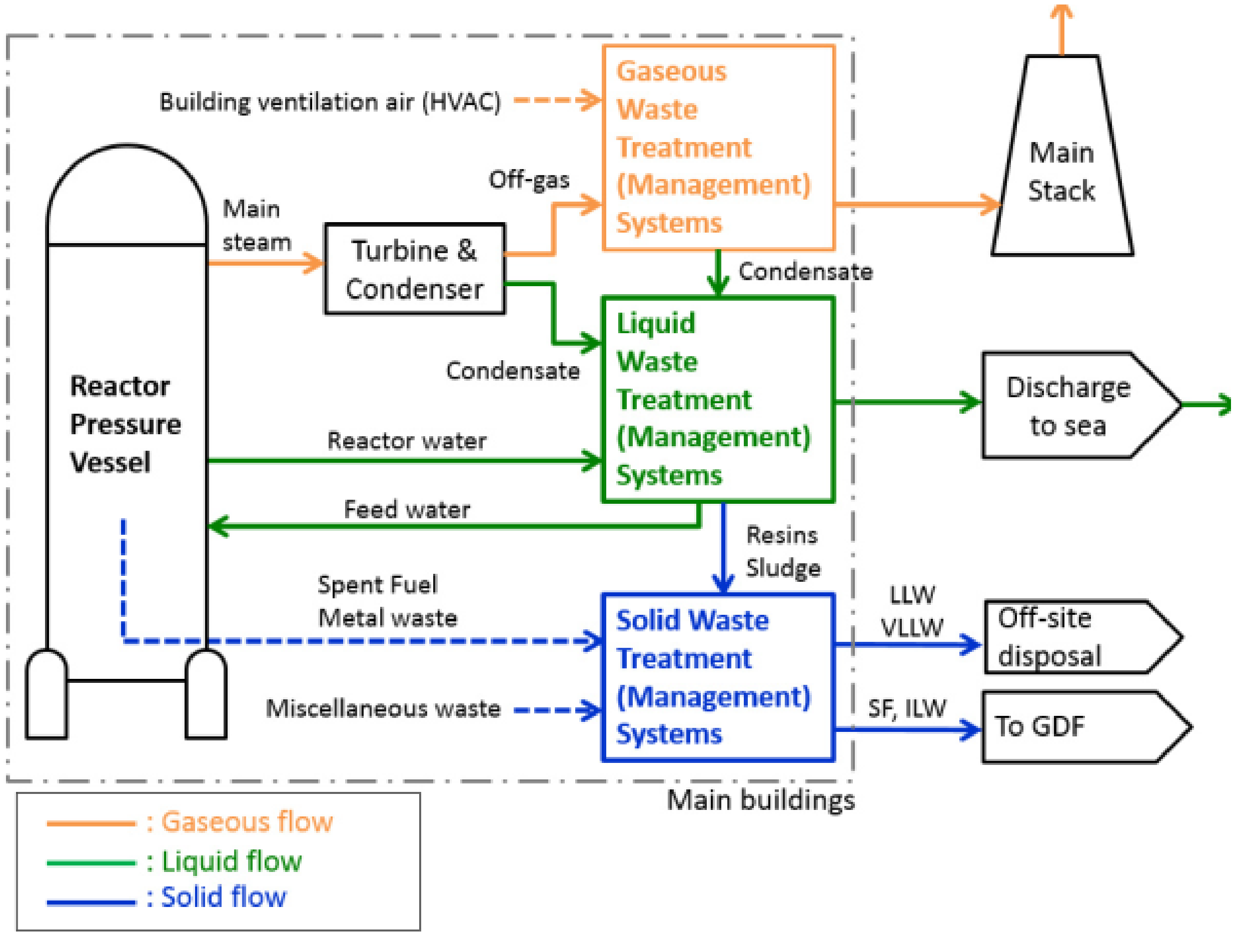

Figure 1: Diagrammatic representation of gaseous, liquid and solid waste arisings within the UK ABWR (Hitachi-GE, 2017c).

The origins of radioactivity within the UK ABWR are mainly as follows (Appendix 2 and 3):

(a) Activation of chemical species in the primary reactor coolant (water). Important radionuclides arising in this way are argon-41 and carbon-14, which transfer to the gaseous discharge stream. Other notable activation products include tritium (H-3) and cobalt-60.

(b) Fission products formed in the fuel. These may leak into the primary coolant through any defects in the fuel cladding. Soluble fission products that form ionic species are predominantly accumulated on ion exchange resins and filters and, therefore, arise ultimately as solid waste for disposal. There are very limited liquid discharges from the UK ABWR. Noble gases, including radionuclides of krypton, xenon and argon, are extensively retained on delay beds. Spent fuel is assumed to be waste for GDA purposes and this will contain the majority of radioactivity.

Activated and contaminated metals within the plant become solid waste for disposal. Corrosion products from the metal components of the reactor system are also a significant source of waste arisings. Corrosion products entrained within the reactor coolant are activated as they pass through the core of the reactor. In radioactivity terms, the most significant radionuclide arising in this way is cobalt-60. Corrosion products tend to accumulate on filters and ion exchange media within the liquid system and are largely associated with solid wastes for eventual disposal.

Tritium (H-3) arises via a number of mechanisms, including ternary fission in fuel, neutron reactions of boron-10 (a component of some control rods) and from activation of deuterium (H-2).

Based on the extensive documentation Hitachi-GE provided we conclude that, at this stage, Hitachi-GE has broadly identified the radionuclides that will contribute significantly to the amount of activity in waste disposals and will result in doses to members of the public. However, sources of radioactivity in the UK ABWR design has been subject to a joint Environment Agency/ONR RO (RO-ABWR-0006) and a subsequent RI (RI-ABWR-0001), 'Definition and justification for the radioactive source terms in UK ABWR during normal operations'.

Together with ONR we raised RO-ABWR-0006 on 28 April 2014. Two of the actions under the RO requested the definition and justification of the radiological source terms for the UK ABWR design. This was raised because the GDA submission from Hitachi-GE lacked information regarding radionuclides in the UK ABWR during normal operation. The submission also lacked evidence to support the gaseous and aqueous discharge estimates and proposed limits. We received a resolution plan for this RO on 15 July 2014 and we had regular meetings with Hitachi-GE between July and December 2014. Hitachi-GE submitted 2 reports to us in January 2015, which we and ONR assessed. These reports were intended to address the definition and justification of source terms for the UK ABWR. These reports did not meet our expectations, and together with ONR, we provided feedback to Hitachi-GE outlining shortfalls in the reports. We challenged the approach and methodology used to derive the UK ABWR source terms, the limited use of operation and experience (OPEX) data from other operating ABWRs and the evidence on which discharge estimates were based.

Together with ONR, we escalated the RO to an RI. A workshop was held on 19, 20 and 22 May 2015, at which we and ONR presented our requirements to Hitachi-GE and gave some examples of source terms that we have assessed for other nuclear power plants designers and operators. RI-ABWR-0001 was raised on 3 June 2015. Regular meetings were held between regulators and Hitachi-GE from June 2015 to date. Hitachi-GE has changed its approach to deriving and justifying source terms for the UK ABWR, using more OPEX data and providing more explanation of the methods used. Between November 2015 and February 2016 we received a number of reports documenting the derivation and justification of the UK ABWR source term. These provided information on the primary source term (radionuclides in the reactor water and steam), process source terms (radionuclides in different downstream systems within the plant) and end-user source terms (which included source term for gaseous and aqueous discharges).

Both RI-ABWR-0001 and RO-ABWR-0006 are now closed. We are content that Hitachi-GE has utilised an adequate approach and produced a justifiable source term for the UK ABWR for example, Hitachi-GE, 2016d.

2.5. Minimising waste in the UK ABWR

Hitachi-GE claims that the UK ABWR design eliminates or reduces the generation of radioactive waste. Claims, arguments and evidence in support of this are provided as part of the 'Demonstration of BAT' submission (Hitachi-GE, 2017a). The developed BAT arguments have been applied to specific radionuclides and, in particular, those that are significant constituents of gaseous and aqueous discharges (Appendix 2 & 3). The BAT related arguments Hitachi-GE presented and our associated conclusions are summarised below and in section 2.13 of this report 'Assessment of Hitachi-GE's claims, arguments and evidence in relation to best available techniques'.

Hitachi-GE claims that the UK ABWR design contains a range of features that help to eliminate or reduce radioactive waste. Hitachi-GE has identified the most significant of these features and objectives, as follows:

- design, manufacture and management of nuclear fuel to minimise the potential for a release of fission products (FP) from the fuel into the steam circuit or cooling pool water
- eliminating or reducing materials that are susceptible to activation at all stages of commissioning and operation
- selecting an appropriate reactor water chemistry regime
- reducing the volume of spent fuel (SF) and higher activity waste (HAW) generated for a given energy output
- reducing the generation of lower activity wastes for a given energy output
- promptly detecting and managing failed fuel
- introducing techniques to be used during commissioning, start-up and shutdown to reduce waste arisings

Hitachi-GE also claims that the UK ABWR design includes features that allow operational flexibility to minimise the radioactivity in radioactive waste disposed to the environment. Hitachi-GE identifies the most significant of these features and objectives, as follows:

- providing an off gas system (OG) that includes processes to reduce radioactivity of short-lived fission products in the gaseous phase prior to discharge to the environment
- providing a heating, ventilation and air conditioning (HVAC) system that prevents the uncontrolled discharge of radioactive substances
- treatment techniques for aqueous waste that minimise the discharge of radioactivity to the environment
- decay storage to minimise the radioactivity associated with wastes that require disposal

Hitachi-GE also claims that the UK ABWR design and operational flexibility includes features and objectives to minimise the volume of radioactive waste disposed to other premises. Hitachi-GE identifies the most significant of these, as follows:

- design changes that will minimise the volume of operational and decommissioning waste
- providing a number of features that will allow future operators to adopt an operating philosophy that will minimise the quantity of solid radioactive waste associated with routine operations and maintenance
- providing dedicated facilities for management, treatment and storage of solid radioactive waste
- reducing the quantity of solidified high chemical impurity waste (HCW) that is generated
- availability of a range of decontamination techniques during decommissioning

2.6. An overview of radioactive waste processing in the UK ABWR

Hitachi-GE has described how radioactive substances will be processed in the UK ABWR to ensure that waste is appropriately managed for disposal. We summarise the design features of the UK ABWR that are applicable to processing gaseous, liquid and solid wastes.

A diagrammatic representation of the sources and routings of radioactive wastes within the UK ABWR is provided by Hitachi-GE (Figure 1). A summary of the origin of the most significant radionuclides contributing to discharges from the UK ABWR is provided (Appendices 2 and 3). Our assessment report on radioactive waste provides a summary for solid wastes (Environment Agency, 2017b).

We note that detailed operational aspects of relevance to the BAT case are not provided in the Hitachi-GE documentation at this time, although broad operational aspects are discussed. The definition of ‘limits and conditions’ may provide some clarity on generic operational aspects for plant with an environmental protection function. We will expect further details as to how plant will be operated to ensure that BAT is applied in the site permitting phase. Operational aspects of specific relevance to the BAT case are identified as Assessment Findings.

2.7. Processing of gaseous wastes

The off-gas radioactive waste treatment system (OG) has 2 main functions: (i) to safely recombine flammable gases (hydrogen and oxygen) that are generated by radiolytic decomposition (radiolysis) of reactor cooling water; (ii) to minimise and control the release of small quantities of slightly radioactive gases into the atmosphere by delaying and filtering the OG waste process stream to adequately decay short-lived radioactive isotopes and filter out particulate matter, reducing the radioactivity in discharges.

Moisture in the main gas stream is first condensed and subsequently reused as reactor feed water. This includes tritiated water. The remaining non-condensable gases, principally air with a small amount of radioactive argon, krypton and xenon gas are extracted and passed through off-gas charcoal adsorber beds. These adsorbers are designed to provide adequate ‘hold-up’ or ‘delay’ to allow time for the radioactive gases to decay to lower activity levels before leaving the system.

Steam used in the turbine gland steam system (TGS) is derived from the condensate system and is one source of tritium discharge (see discussion of Argument 2e, below). This source is not shown in Figure 1. We raised a RO regarding discharges from the turbine gland steam system (RO-ABWR-0071, ‘Turbine Gland Steam System: Discharges and Optimisation’) and this has now been closed to our satisfaction (Hitachi-GE, 2016c).

Gaseous waste from the off-gas system (OG), the HVAC and the TGS is released to the environment through the main stack following in-line monitoring (Environment Agency, 2017a).

The HVAC system is identified as ‘building ventilation air’ in Figure 1. The functions of the HVAC system for managing gaseous radioactive wastes are limiting and containing the possible release of radioactive materials from plant and equipment in a room/area; and, where necessary, filtering contaminated air prior to its discharge into the atmosphere.

The buildings that are within the detailed design scope of GDA and which are identified with the potential to generate gaseous radioactive waste due to the inventories within them, are the reactor building, the turbine building and the radioactive waste building. Further buildings outside the ‘reactor island’ and not subject to detailed design in GDA, including the conceptual radioactive treatment and conditioning buildings (wet solid waste facilities and waste stores), are also likely to generate small quantities of gaseous radioactive waste.

Radiologically-controlled area HVAC systems will include high-efficiency particulate air (HEPA) filters on their discharge. The HVAC systems will discharge to the environment via the main stack, which will be designed to provide adequate dispersion and will be determined at the site-specific permitting stage. The HVAC system discharge from the main stack also includes the tank vents/extracts from the various tanks in the radioactive waste building that join the radioactive waste building HVAC system.

Hitachi-GE argues that design features of the UK ABWR ensure that the impacts of gaseous discharges are minimised. Relevant aspects are outlined in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a). The arguments relating to specific radionuclides are summarised in Appendix 2.

In broad terms, the UK ABWR design aims to avoid and reduce gaseous waste arisings, limit the concentration of radionuclides in gaseous wastes by using delay beds, and remove particulate material from gaseous waste using HEPA filtration. The main features of the design relevant to minimising the impact of gaseous discharges are as follows:

- the design, manufacture and management of nuclear fuel to minimise the potential for a release of fission products (FP) from the fuel into the steam circuit or fuel pool water
- the prompt detection and in core management of failed fuel by power suppression testing

- provision of an OG that includes processes to reduce radioactivity in the gaseous phase prior to discharge to the environment
- provision of a charcoal adsorber within the OG to abate short lived fission products
- provision of a HVAC system that prevents the uncontrolled discharge of radioactive substances

We observe the following:

- Using a modern fuel design and further measures to reduce fuel failure rates will help minimise gaseous waste arisings by limiting releases from fuel failure. Measures to detect and manage fuel failure within the core by power suppression testing should also prove effective in this regard. The regulators will seek to ensure that any future operators develop suitable arrangements to ensure that gaseous discharges are minimised by appropriate fuel management. We discuss the management of spent fuel further in our related assessment report (Environment Agency, 2017b).
- Using delay bed technology is effective at reducing discharges of noble gases, consistent with the application of BAT for such gases and consistent with approaches adopted in other light water reactors. Delay beds are also effective at reducing the concentration of short-lived iodine radionuclides. We conclude that Hitachi-GE has demonstrated that the quantity of charcoal to enable delay has been optimised in the UK ABWR design. As we went to consultation, aspects of the OG design were subject to further, specific ALARP considerations by the regulators under RO-ABWR-0073. This RO has now been closed without any impact on our preliminary conclusions as the design has remained unchanged.
- The UK ABWR design aims to discharge gases at height via a main stack and this will help to minimise the impacts of those discharges. The height and location of the stack are a site-specific matter for detailed design stage.
- Hitachi-GE conclude that no abatement of tritium or carbon-14 is practicable at this time. We agree with Hitachi-GE. However, we have included an Assessment Finding (Assessment Finding 4) that a future operator should consider if abatement of carbon-14 from gaseous discharges is appropriate in a site-specific context. We expect an operator to review carbon-14 abatement and implement any abatement if it considered as BAT.
- Assessment Finding 4: A future operator shall review the practicability of techniques for abatement of carbon-14 prior to operation.

Assessment of gaseous discharges to the environment is provided in our related assessment report (Environment Agency, 2017c).

2.8. Processing of liquid wastes

The liquid radioactive waste management system (LWMS) (shown in green in Figure 1) is designed to control, collect, segregate, process, handle, store, and dispose of radioactive waste water generated during operation of the UK ABWR reactor and turbine. All potentially radioactive waste waters are collected in sumps or drain tanks at various locations in the plant and transferred to collection tanks within the radioactive waste building.

The LWMS has been designed to recycle as much of the treated waste water back into the reactor cooling water system as possible. An exception is waste water that contains detergent from the laundry and showers, which are incompatible with the reactor and fuel pool water systems as they contain organic carbon compounds.

The LWMS is divided into several sub-systems: the high chemical impurity waste (HCW), the low chemical impurity waste (LCW), laundry drain (LD) and controlled area drain (CAD). These systems use a combination of filtration, adsorption (ion-exchange, charcoal) and evaporation technologies. The sub-systems segregate waste water with different characteristics that is the type of impurity or chemical content, allowing appropriate and efficient treatment prior to re-use or eventual disposal. In a situation where the quality of the waste water output from a treatment system cannot be reused or disposed of, the waste water treatment systems can cycle the waste water back through the treatment systems until the relevant reuse parameters or disposal limits are met. Essentially, the system is designed to maximise, opportunities to 'concentrate and contain' rather than 'dilute and disperse'.

Despite the aim to re-use the waste water, there may be times when liquid discharges are necessary if capacity limits for on-site storage of treated liquid waste are reached. Hitachi-GE argues that the frequency, volume and contaminant loading of such liquid discharges are reduced to a very low level. The LWMS normally operates on a batch basis. Provision is made for sampling and analysis at important process points and from the discharge tank to ensure that process parameters and discharge limits are met.

Detecting abnormal conditions and subsequent alarms as well as operational procedures protect against accidental discharge. System components such as tanks, processing equipment, pumps, valves, and instruments that may contain radioactivity are arranged in appropriately shielded, access-controlled containments to minimise radiation exposure of plant staff and to prevent or minimise radiation dose or release to the environment.

During operation, the LWMS will generate solid wastes that include waste termed as 'crud' or 'sludge', spent filters and spent ion exchange resins. The solid wastes will be treated and disposed of via the solid radioactive waste management system.

At decommissioning, the water within the reactor and fuel pool systems will be treated and discharged using the systems identified above as far as practicable. Redundant items of plant and equipment will be managed according to the solid radioactive waste management system.

Hitachi-GE argues that design features of the ABWR ensure that the impacts of aqueous discharges are minimised. Relevant aspects are outlined in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a). The arguments relating to specific radionuclides are summarised in Appendix 3.

In broad terms, the UK ABWR design aims to:

- avoid and reduce aqueous waste arisings
- ensure appropriate segregation, treatment and reuse of liquids
- enable optimised use of filter and demineraliser technology
- use an evaporator for liquids that require this treatment

The main features of the design relevant to minimising aqueous discharges are as follows:

- The design, manufacture and management of nuclear fuel to minimise the potential for a release of fission products (FP) from the fuel into the steam circuit or cooling pool water.
- The prompt detection and management of failed fuel
- Treatment techniques within a segregated liquid management system that allows liquid to be reused within the plant and helps to minimise the discharge of radioactivity to the environment. These technologies comprise filtration of solids, use of ion exchange (demineraliser) resins to remove ionic species, use of charcoal filters and an evaporator. These are used as appropriate on specific liquid systems.
- Decay storage to minimise the radioactivity associated with aqueous liquids that require eventual disposal. This is of particular relevance to liquids containing tritium that has a half-life of approximately 12 years. Some decay of tritium within the circuit is possible over the 60-year operational life as envisaged. This reflects the potential residence times within the system and claims of minimal liquid discharges during operations.
- The elimination or reduction of materials that are susceptible to activation at all stages of commissioning and operation. This prevents activation products forming that could contribute to liquid waste, or arise as components of solid waste.

We observe the following:

- Using a modern fuel design, and further measures to reduce fuel failure rates, will help minimise liquid waste by limiting releases from fuel failure. Measures to detect and manage fuel failure should also prove effective in this regard. The regulators will seek to ensure that a future operator develops suitable arrangements to ensure that aqueous discharges are minimised by appropriate fuel management.
- The UK ABWR design enables clean-up and reuse of liquids within the plant, therefore avoiding unnecessary discharges. We note the low volume of aqueous discharges that are associated with this design and the very low projected doses associated with these (Environment Agency, 2017d and 2017e).
- The UK ABWR uses filters, demineraliser, charcoal filters and evaporator technology to remove radioactivity from liquids. In our view, using these technologies is appropriately targeted at segregated liquids within the plant systems. This transfers the radioactivity to solid waste, consistent with a 'concentrate and contain' approach.
- No abatement of liquid tritium is practicable. We agree with Hitachi-GE that it would be grossly disproportionate to deploy techniques at this time to avoid aqueous disposals of tritium, given the very small dose impact (Environment Agency, 2017e).
- We note there is an assumption within the GDA source term that 100% of carbon-14 will partition to the gaseous waste stream. If this assumption is not valid, carbon-14 could enter the LWMS. We have therefore included an Assessment Finding (Assessment Finding 5) to ask that this assumptions is validated. If the assumption is not valid, we would expect an operator to review the BAT case and potential environmental impacts.
- Assessment Finding 5: A future operator shall assess the partitioning of carbon-14 between gaseous, aqueous and solid waste streams, during initial operations

We discuss aqueous discharges to the environment further in our related assessment report (Environment Agency, 2017d).

2.9. Processing of solid wastes

Solid radioactive wastes are produced during the operational and decommissioning phases of a power station's life cycle. The UK ABWR design has a waste management strategy and system based on available treatment technologies and current and assumed future disposal facilities. A summary of the approaches that are to be used to eliminate, reduce and minimise solid radioactive waste is provided in Appendix 4.

A solid radioactive waste management system (SWMS) is designed to control, segregate, collect, handle, process, package, and temporarily store wet and dry solid radioactive waste prior to dispatch for off-site disposal. Hitachi-GE describes facilities capable of treating, interim and decay storing, where appropriate, and managing the disposal of solid radioactive wastes in accordance with the chosen options for managing these wastes (Hitachi-GE, 2017a).

The nature of the solid wastes that will arise in the UK ABWR and our view on the proposed processing of these is described further in our assessment report on solid radioactive waste (Environment Agency, 2017b).

2.10. Process for identifying best available techniques

We consider Hitachi-GE's approach to optimisation to be a suitable basis from which to identify BAT for the ABWR for GDA purposes. The approach is documented in a dedicated 'Approach to Optimisation' report (Hitachi-GE, 2017b). Claims generated as part of this optimisation process are presented along with their accompanying arguments and evidence in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Hitachi-GE has suitably recognised the relevant principles of optimisation and sought to apply these in presenting the GDA case. The approach has also been guided by considering standard environmental permit conditions and P&ID requirements relating to optimisation (Environment Agency, 2013 and 2016a).

However, we note that there are operator choices to be considered in the future that may impact on BAT. Therefore we have included an Assessment Finding (Assessment Finding 3) to ensure that operator choices also reflect BAT and are appropriately optimised for both environment and safety.

- Assessment Finding 3: A future operator shall demonstrate that the UK ABWR will be operated in a manner that represents best available techniques, addressing in particular:
    - fuel selection
    - fuel and core management
    - avoidance of control rod failure in power suppression situations
    - consideration of all normal operational modes and stages of the reactor's lifecycle
    - control of water chemistry
    - selection of demineraliser resins for liquid waste management systems

Hitachi-GE has also carried out a number of optioneering exercises to identify optimal approaches to the UK ABWR for GDA purposes (see below).

Hitachi-GE's approach has been to set out claims, develop arguments in support of these, and to provide the relevant supporting evidence, where possible. A specific radionuclide route map is provided, which indicates how the developed BAT arguments apply to specific radionuclides and, in particular, those that are significant constituents of gaseous (Appendix 2), aqueous (Appendix 3) and solid disposals (Appendix 4).

The approach recognises that the UK ABWR is an evolution of earlier BWR technology and reflects on design improvements that are relevant to the BAT claims (as described by Hitachi-GE against specific BAT arguments, see below). We consider this to be a sensible approach and a suitable method by which to convey the 'BAT case' for generic design assessment of the UK ABWR.

Hitachi-GE has provided extensive evidence. This is reflected in more than 100 references that support the 'Demonstration of BAT' submission. We have sampled these references as part of our assessment. We have raised a large number of RQs in relation to BAT aspects, often jointly with ONR (Appendix 1). Hitachi-GE has responded to the RQs and, in many cases, the response has subsequently become a supporting reference.

Hitachi-GE's approach has also included identifying aspects relating to BAT that a future operator will need to action at the detailed design and permitting stage. These aspects have been identified as, 'Forward Actions' (Appendix 5). We consider this to be a useful approach and recognise the value of these forward actions, therefore we have included an Assessment Finding (Assessment Finding 6) to ensure that this forward action plan is implemented by a future operator.

- Assessment Finding 6: A future operator shall address the 15 forward actions as identified by Hitachi-GE in the 'Demonstration of BAT' submission - GA91-9901-0023-00001 Rev. G. August 2017 (Hitachi-GE, 2017a).

Overall, we conclude that Hitachi-GE has followed an appropriate process for identifying BAT in the design of the UK ABWR.

2.11. Optioneering

Hitachi-GE's approach to optimisation, as presented for GDA, has been based predominantly on demonstrating that the current design reflects progressive development and improvement of BWR technology. Therefore, the ‘Demonstration of BAT’ document (Hitachi-GE, 2017a) illustrates many examples of how design changes have led to perceived improvements, and aims to explain why these are beneficial.

As presented, the case provides limited reliance on conventional optioneering approaches based on directly comparing different options to a range of attributes as the design is a development of existing technology. However, such an optioneering approach has been used in relation to a number of aspects and where considered appropriate by Hitachi-GE. This has been applied largely to inform UK specific aspects of the design, for example solid waste considerations in relation to UK disposal routes, and in response to specific RQs or ROs, for example optioneering in relation to optimisation of the turbine gland seal system, as per RO-ABWR-0071).

We note the following as examples of optioneering exercises conducted by Hitachi-GE in support of the GDA case for the ABWR:

- ‘BAT Optioneering Report’ (Hitachi-GE, 2016a), which identifies preferred option(s) and describes initial concept designs for the radioactive waste treatment and storage facilities for the UK ABWR.
- ‘High Level Optioneering on Spent Fuel Interim Storage’ (Hitachi-GE, 2016b) describes optioneering to identify the best conceptual option for interim storage of spent fuel.
- ‘Turbine gland steam system: Demonstration of BAT’ (Hitachi-GE, 2016c) describes the outcomes of an optioneering exercise to identify the best option for management of turbine gland steam (this was produced as one response to RO-ABWR-0071).
- Options work on inclusion of evaporator in HCW. This includes some optioneering assessment work that supports using an evaporator in the HCW system and why this represents an optimised solution overall based on a life cycle analysis. The work was undertaken in response to RQ-ABWR-0668 (Hitachi-GE, 2017d).

Hitachi-GE’s optioneering method and process has varied in terms of the specific approaches to scoring and sensitivity analysis. We recognise that different approaches are possible and consider that the approaches Hitachi-GE adopted have been sensibly scoped and are in line with the GDA decision context. Overall, we conclude that Hitachi-GE has used optioneering approaches where appropriate, targeting those aspects that are relevant to the UK design and, where prompted, in response to specific regulatory considerations, for example to justify specific design configurations. Some of these optioneering aspects are discussed below in relation to our assessment of the relevant BAT arguments as presented by Hitachi-GE (Hitachi-GE, 2017a).

2.12. Consideration of BAT and ALARP in optimisation

Demonstrating that BAT has been applied to the design and operation of the UK ABWR means relevant factors, including safety aspects must be balanced. Therefore, optimisation must be based on an approach that considers both BAT and the requirement that safety risks must be ALARP (as low as reasonably practicable), where appropriate.

At the time of writing our consultation document (August 2016) we concluded that the UK ABWR design was consistent with BAT in so far as this has been demonstrated and to a level in line with our expectations for GDA. However, we could not make our final conclusion, as ALARP aspects of the design were yet to be fully demonstrated to ONR and a number of relevant ROs remained open. We concluded that BAT was adequately addressed in Hitachi-GE’s design development processes and therefore anticipated that any design changes that may result from on-going ALARP considerations would be appropriately assessed in terms of BAT. However, pending appropriate outcomes, we raised a potential GDA Issue that required Hitachi-GE to demonstrate that appropriate consideration has been given to both environmental and safety aspects, in order to achieve an optimised design.

ONR had raised a number of ROs ultimately relating to ALARP considerations for plant systems where BAT is also relevant (radioactive waste management systems). Of particular relevance are RO-ABWR-0036, 'Demonstration that the approach taken to radioactive waste management reduces risks so far as is reasonably practicable (SFAIRP)', RO-ABWR-0054, 'UK ABWR – Chemical/Process Engineering Design Approach' and subsequently, RO-ABWR-0073, 'Robust demonstration that the design of the UK ABWR off-gas system reduces risks SFAIRP', which was raised jointly with us.

These ROs have now been closed to the regulators satisfaction. Closure has not resulted in any significant design changes or impacts on the claims, arguments and evidence that Hitachi-GE has made in the demonstration of BAT document. We are therefore content that the UK ABWR design is consistent with BAT and suitably optimised in line with our expectations for GDA.

However, we note that the ONR has included an Assessment Finding (AF-ABWR-RW-02) in their safety assessment, related to the closure of RQ-ABWR-0036. This requires additional ALARP justification for some aspects of the radioactive waste management systems.

2.13. Assessment of Hitachi-GE's claims, arguments and evidence in relation to best available techniques

The 'Demonstration of BAT' submission (Hitachi-GE, 2017a) includes 5 claims and 32 arguments. We have assessed these and sampled the supporting evidence to reach our conclusions.

A large number of RQs were raised (Appendix 1) and in our view each of these has been satisfactorily responded to. We briefly discuss some of the more significant queries and the associated responses against the relevant arguments (below). Detailed aspects of each query and the related responses are traceable through the relevant RQ forms and the responses provided by Hitachi-GE in each case. These details are not repeated in this summary assessment report.

Our assessment of each claim is provided, in turn, below.

We note that at the outset Hitachi-GE has identified a number of aspects that future operators will need to consider. These are termed 'Forward Actions' and 15 of these are defined (Appendix 5). We agree that these are appropriate actions for future operators to address and have included an assessment finding to prompt the necessary future operator actions and follow-up.

Claim 1: Eliminate or reduce the generation of radioactive waste

We expect BAT to be used to ensure that production of radioactive waste is prevented, and where that is not practicable, minimised with regard to activity and quantity (consistent with RSMDP3 (Environment Agency, 2010)).

Hitachi-GE claims that the UK ABWR design will eliminate or reduce the generation of radioactive waste. This claim is supported by 10 arguments (1a-1j) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 1a. Design, manufacture and management of fuel (Table 1a)

We conclude that the ABWR is designed to implement a modern fuel design, to utilise fuel manufactured using appropriate techniques and can, ultimately, be suitably managed to prevent or minimise waste arisings as a result.

Fuel performance has important implications in terms of generating solid, liquid and gaseous wastes requiring disposal. It is anticipated that the vast majority of radioactivity will remain associated with spent fuel and will, therefore, be disposed of in solid form to a future geological disposal facility (GDF). However, the potential transfer of fission products (FPs) from the fuel to the steam circuit and the spent fuel pool generates radioactive waste.

Hitachi-GE has assumed a degree of fuel failure in defining the source term for the ABWR. Hitachi-GE argues that only a small number of fuel assemblies may experience failure during normal operations, and presents evidence of an overall downward trend in fuel failure rates.

Fuel failure is described as an ‘expected event’ in terms of estimating waste arisings. For GDA purposes, Hitachi-GE has assumed a low but non-zero failure rate, although it has been argued that this is a conservative assumption and is, therefore, tending to overestimate release rates and associated radioactive waste arisings. Evidence from reactor fleet operations has been provided that the total failure rate in modern BWR fuel, such as GE14 due to pellet cladding interaction (PCI) mechanisms (an important fuel failure mechanism) is less than 4 parts per million. We discuss this aspect further in our assessment report on spent fuel and radioactive waste (Environment Agency, 2017b).

Hitachi-GE provides evidence that design features in the GE14 fuel, such as debris filtration and zirconium cladding lining, should help to reduce the likelihood of fuel failure and, therefore, reduce the associated waste arisings. Debris filtration reduces the potential for degradation of cladding, as does introducing a zirconium cladding lining. Evidence has been provided in relation to reduced fuel failure rates through advances in fuel design and reactor operational regimes.

We note that the evidence provided on the basis of BWR fuel experience may not be fully transferable to the UK ABWR. This is due to differences in factors such as specific reactor chemistry, fuel burn-up and operational arrangements that may ultimately influence fuel failure rates. It is, however, indicative that low rates of fuel failure are possible and demonstrates an understanding of the underlying mechanisms and technological approaches to improve fuel performance. We anticipate that operational experience from the operational ABWR fleet will usefully inform decisions of future fuel use by UK ABWR operators.

Hitachi-GE recognises ‘Manufacturer's guidance on fuel use’ and argues that adopting these guidelines will help reduce fuel failure rates in support of the GDA case. We sought clarity on using manufacturer’s guidance in support of BAT arguments (RQ-ABWR-0370). Although future operators would ultimately be using this guidance, we see benefit in considering using it, where available.

We note that fuel technology will progressively improve. For example, an advanced fuel design known as GNF2 is currently being developed and progressively deployed in the BWR fleet. Detailed fuel design will need considering further at the site-specific permitting stage, as fuel may be available at that time that offers improved performance. In particular, any design improvements to minimise fuel failure during operation will need to be considered as this could help minimise waste. We, therefore, identify an assessment finding relating to the need for a future operator to consider fuel design further (Assessment Finding 3).

The detailed operational arrangements for fuel and core management, and how these will be optimised to minimise waste, will be considered in any site-specific permitting. We note that this is a particular aspect that needs further attention, including any learning from ABWR operational experience, and we identify this as an Assessment Finding (Assessment Finding 3).

Table 2a. Summary of evidence Hitachi-GE presented in support of Argument 1a in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 1a	Design, manufacture and management of fuel
Evidence	Analysis of recent fuel failures – provides a summary and analysis of fuel failure in BWR technology, including evidence of failure rates versus time. Evidence of the failure mechanisms is discussed.
	Debris removal – provides evidence that use of debris filtration technology has led to reduced fuel failure rates in BWR fuels. Also provides evidence of the performance of various debris removal technologies.
	Pellet-cladding interaction (PCI) reduction – provides evidence in relation to reduced fuel failure rates due to a lower incidence of PCI in BWR fuel.
	Manufacturing improvements – provides an overview of improved fuel manufacturing processes and how these are argued to contribute to reducing fuel failure.

Argument 1a	Design, manufacture and management of fuel
	Manufacturer's guidance of fuel use – fuel manufacturer's guidance will be available to future operators. Argues that adherence to this will add benefits in terms of fuel performance.
	Selection of fuel cladding materials – suggests that the chosen fuel cladding material benefits from design improvements, including the best features of earlier fuel design and improved manufacturing.
	Manufacturing and quality assurance (QA) processes to minimise tramp uranium – evidence of avoidance of 'tramp uranium' by improved manufacturing and quality assurance. Tramp uranium is “uranium or uranium dioxide dust that clings to the outside of the fuel elements and is insufficiently cleaned off during fabrication. Once in the reactor, it will undergo fission and its FPs readily enter the reactor coolant.”
	Fuel handing equipment - Operational experience and feedback – evidence that no fuel damage or collision of fuel during fuel handling operations has occurred using Hitachi-GE fuel handling machines (since 1974).

Argument 1b. Reactivity control (Table 1b)

The ABWR design enables a range of techniques for reactivity control. These include using hafnium and boron carbide control rods, using burnable poisons within the fuel, and controlling the flow of water through the core. As an intrinsic feature of the ABWR design, there is no requirement to use dissolved boron species in the reactor circuit (unlike PWR designs) and, therefore, the production of tritium via such routes is avoided. We conclude that the ABWR design appropriately enables reactivity control while having associated features that can contribute to minimising waste.

Hitachi-GE has demonstrated that the ABWR includes reactivity control design features that help to minimise associated waste arisings. We will expect any future operators to optimise reactivity control arrangements to make sure this happens.

We raised a number of RQs relating to using boron carbide control rods (RQ-ABWR-0245; RQ-ABWR-0469; RQ-ABWR-0565). These sought clarity on how control rod rupture would be avoided given that this can lead to, arguably small, increases in tritium arisings in the coolant circuit and, therefore, in waste generated. Overall, we concluded that the detailed arrangements for using and managing control rods in the reactor core will need to be fully defined by a future operator, although we have no reason to doubt that suitable arrangements are possible based on the case provided.

We queried whether irradiation of hafnium control rods would generate any problematic radionuclides in relation to the disposal inventory (RQ-ABWR-0222). The response indicates that this is not the case. We also queried the optimum balance between using boron carbide and hafnium control rods in relation to the associated solid waste arisings. The operational lifetime of boron carbide control rods is significantly less than that of the hafnium rods. Hitachi-GE explained that each type of control rod has different specific functions and provided arguments to suggest that the proposed balance was appropriate in relation to minimising solid waste arisings, which seems reasonable.

We also queried whether using gadolinium as a neutron poison would have any implications for the UK’s radioactive waste disposal inventory given its potential chemotoxicity (RQ-ABWR-0241). Only small quantities of residual gadolinium are anticipated in the spent fuel from the UK ABWR. The chemotoxic effects of gadolinium in the UK radioactive waste disposal inventory are yet to be specifically assessed. This is also true of several other potentially toxic components of the UK disposal inventory. As the disposability assessments continue, such matters will be considered and we are pursuing these matters with Radioactive Waste Management Ltd (RWM) (Environment Agency, 2016c).

Table 2b. Summary of evidence Hitachi-GE presented in support of Argument 1b in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1b	Reactivity control
Evidence	Recirculation flow control – comparison between the use of water flow rate to control the power output in the UK ABWR with the method used in PWRs. Using flow control in the UK ABWR allows regulation of reactor power output without needing to move the control rods.
	Gadolinia - description of the use of gadolinia as a burnable poison to additional control during certain parts of the operational cycle. This method has been used effectively since the 1970s. The evidence for why gadolinia has been chosen for the UK ABWR over alternative burnable poisons is presented.
	Introduction of hafnium control rods - provides evidence to support using a mix of hafnium and boron carbide control rods.
	Reactivity control – operational experience and feedback - using the above 3 methods removes the need to inject aqueous boron reagents to control radioactivity and, therefore, reduces the amount of tritium produced by the process.

Argument 1c: Efficiency of fuel use

We conclude that the ABWR design, together with optimised future reactor operations, should enable efficient fuel use and, in turn, minimise the volume and activity of spent fuel generated. The creation of spent fuel is inevitable, but we expect to see optimisation to ensure that spent fuel arisings are minimised.

Hitachi-GE argues that design features of the ABWR core and operational regimes based on 'spectral shift operation' minimises the amount of spent fuel created. Spectral shift operation involves exposing fuel to fast neutrons in the bubble-rich region of the core followed by subsequent burning out of any ingrown fissile plutonium in the core region where water-moderated, thermal neutrons predominate. Essentially this enables a quantity of fertile uranium-238 to be burnt. We queried the efficacy of this process and argument (RQ-ABWR-0367). 'Spectral shift' can result in around 2% fuel savings, therefore reducing spent fuel waste volumes accordingly (See Environment Agency, 2017b).

Evidence is provided of improvements in fuel efficiency. It is argued that BWR fuel bundles typically achieved discharge exposures of approximately 20 GWd/t during the 1970s, while more recent BWRs loaded with 10x10 fuel bundles, such as GE14 fuel, have achieved discharge exposures of 50 GWd/t. We note that Hitachi-GE is proposing average fuel burn-ups of between 50-60 GWd/t for the ABWR.

Table 2c. Summary of evidence Hitachi-GE presented in support of Argument 1c in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1c	Efficiency of fuel use
Evidence	Configuration and geometry of the reactor core - provides a description of how the fuel bundle design (10x10, N-lattice geometry) based on experience from other ABWRs provides higher performance, greater operational flexibility and better reliability.
	Efficiency of fuel use – operational experience - provides a summary of the operational and design techniques used to reduce the frequency of fuel replacement, and, therefore, the amount of radioactive waste generated

Argument 1d: Detection and Management of Failed Fuel

Hitachi-GE argues that the ABWR design includes features that allow failed fuel to be detected and action taken to isolate this fuel and, therefore, reduce any impacts from it. Hitachi-GE has provided evidence to demonstrate detection of fuel failure by in-line radiation monitoring and proposed arrangements for managing such events, should they arise.

Hitachi-GE argues that inserting control rods around a failed fuel assembly can effectively isolate any detrimental effects and allow operations to continue. This is known as 'suppression'. Suppression of failed fuel using boron-carbide control rods could potentially result in control rod rupture if not properly managed (we raised RQ-ABWR-0469 and RQ-ABWR-0565 on this subject). This is because boron-carbide control rods can swell when exposed to neutrons in the reactor at power. Any such 'failure' event would give rise to increased waste arisings, such as increased tritium concentrations in the reactor circuit. Hitachi-GE argues that operational controls during suppression can minimise these failures.

We will expect a future operator to define appropriate, optimised arrangements and controls to avoid such failures in power suppression situations. This would also prompt a future operator to define appropriate, optimised arrangements for failed fuel detection and management. These will need to be included in detailed specifications, which define the extent of permitted fuel failure in an operational core, together with any operational timeframes and other limits that may be appropriate before shutdown is required. We, therefore, identify an Assessment Finding (Assessment Finding 3) relating to the need for a future operator to define appropriate, optimised arrangements and controls to manage failed fuel and to avoid control rod rupture in power suppression situations.

Table 2d. Summary of evidence Hitachi-GE presented in support of Argument 1d in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1d	Detection and Management of Failed Fuel
Evidence	Detection system in gaseous waste treatment system - specifies the radionuclides that, if detected, in the off-gas monitoring system would indicate fuel failures or cladding defects. Reference is made to the sampling techniques and the 'Approach to sampling and monitoring' submission.
	Procedures for locating fuel failure in reactor core - describes using increased monitoring, power suppression testing (PST) or plant shutdown to respond to the detection of increased levels of radioactivity and locate the position of failed fuel in the core.
	Management of failed fuel - description of the techniques used to manage and store failed fuel rods once they have been removed from the core.

Argument 1e. Commissioning, start-up, shutdown and outage procedures

Hitachi-GE describe processes that could potentially occur during commissioning, start-up, shutdown and reactor outage that could increase the amount of radioactive waste generated. These are mobilisation of corrosion products (CP) that can become activated, and increased incidence of stress corrosion cracking, subsequently requiring component replacement and, therefore, increase waste arisings. Hitachi-GE describe approaches to reduce these processes by chemical treatments such as controls on iron concentration in the reactor circuit, oxygen and zinc injection, and through operational arrangements (Hitachi-GE, 2017a).

We conclude that these measures are likely to be effective in reducing waste arisings when appropriately used within an optimised operational regime. We will expect a future operator to develop optimised arrangements to ensure that wastes are minimised using these approaches and, as appropriate, during all aspects of operations. We have identified an assessment finding to prompt this (Assessment Finding 3).

Table 2e. Summary of evidence Hitachi-GE presented in support of Argument 1e in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1e	Commissioning, start-up, shutdown and outage procedures
Evidence	Alkali pre-filming technique - provides a description of the technique to produce an oxide film layer on carbon steel pipes in a non-radiological environment in order to prevent oxide film layers developing once reactor operation commences. Using the technique reduces operator dose and ILW arisings.
	Hydrazine, oxalic acid, potassium permanganate (HOP) decontamination process - provides a description of using chemicals to clean pipework by removing radioactivity from surfaces during outages. The chemicals decompose after use.
	Water conditioning - provides a description of the techniques used and reasons for water conditioning during start-up, shutdown and outages.
	Low temperature residual heat removal (RHR) shutdown cooling method - provides a comparison with the soft shutdown method that has been used previously. The comparative benefits from using low temperature RHR are described in terms of reduced waste and direct dose to workers.

Argument 1f. Water chemistry

Chemical conditions within the reactor plant have important implications for waste generation. For example, this can affect the mobility of radionuclides and the extent to which corrosion products are produced and ultimately arise as waste. Hitachi-GE describes a range of techniques that are possible to ensure that reactor water chemistry is optimised, which is important in terms of minimising waste arisings. These techniques include the potential for injection of specific reagents and the inclusion of filtration and demineralisation technology.

Hitachi-GE proposes operating the ABWR with hydrogen water chemistry (HWC) and noble metal chemical addition. This is intended to ensure a reducing chemical environment, which is considered appropriate in terms of minimising corrosion rates. This is in contrast to early BWRs, which used normal water chemistry (NWC) with no reagent additions. The current Japanese ABWR fleet uses normal water chemistry.

The selection of water chemistry has been subject to a regulatory observation (RO-ABWR-0022, 'Demonstration that the primary cooling system operating chemistry reduces risks SFAIRP', which was closed in October 2015).

We note that the ABWR design appears to offer flexibility in terms of water chemistry control. We will expect a future operator to ensure optimised water chemistry regimes consistent with the relevant GDA results, as this is an important aspect in terms of reducing waste generation. We identify this as an Assessment Finding (Assessment Finding 3).

Table 2f. Summary of evidence Hitachi-GE presented in support of Argument 1f in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1f	Water chemistry
Evidence	Hydrogen water chemistry with noble metal chemical addition - provides a description of how injecting hydrogen into the reactor water reduces stress corrosion cracking. The negative aspects of hydrogen injection are increased radioactive discharges and worker dose but mitigated to an extent by the noble metal chemical addition.
	Zinc injection - provides evidence that zinc injection into the feed water system reduces the build-up of cobalt-60 in the oxide films that build up

Argument 1f	Water chemistry
	inside pipework and vessels. This, in turn, reduces radiological dose to operators.
	Iron concentration control - provides evidence that controlling the iron concentration in the feed water adequately reduces radioactivity concentration in the reactor water.
	Oxygen injection - provides evidence of using oxygen injection to reduce flow accelerated corrosion (FAC) and crud formation of carbon steel in the feed water and condensate system.
	Fuel integrity - provides evidence of how water chemistry controls have reduced the number of fuel failure events since the 1970s.
	Condensate clean-up system and reactor clean-up system to remove corrosion products - summarises the importance of effectively removing corrosion products from the feed water and condensate system by using filters and demineralisers.

Argument 1g. Specification of materials

Hitachi-GE describe its intention to use low cobalt steels and to reduce its use of high cobalt alloys (stellites®) in the ABWR design. Using corrosion resistant alloys is also described, which is intended to reduce waste arising from activated corrosion products. It is argued that these measures will reduce waste arisings from activation.

We recognise using low cobalt alloys and corrosion resistant steel is beneficial in reducing waste, and we will expect an operator to demonstrate that it has selected and used appropriate choices of low cobalt and/or corrosion resistant alloys, as available at that time.

Table 2g. Summary of evidence Hitachi-GE presented in support of Argument 1g in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1g	Specification of materials
Evidence	Specification of low cobalt materials - provides evidence for using alternatives to reduce the amount of cobalt-based alloys used in the design.
	Substitution of Stellites® - provides a description of where cobalt-based alloys such as Stellites® are currently used within the design and that they will be replaced by cobalt-free materials with sufficient material characteristics. Previous designs have had cobalt content as high as 45 to 64%, whereas the UK ABWR will have no more than 1% cobalt content in the design.
	Introduction of low corrosion materials - describes using low alloy steel and stainless steel in pipework to reduce corrosion.
	Specification of materials – operational experience and feedback - provides evidence on how using alternative materials with reduced cobalt content has led to a lower amount of cobalt-60 activated in the core.

Argument 1h. Recycling of water to prevent discharges

Hitachi-GE describes design features of the ABWR that allow water to be recycled in plant systems, including the steam circuit, suppression pool and fuel pool. It is also argued that liquid effluent will be reused during decommissioning activities, for example where used in aqueous decontamination processes, therefore avoiding generating further liquid waste at that time. The only proposed liquid discharges from the UK ABWR are from the laundry drain (LD) and occasionally the HCW, as discussed further in another assessment report (Environment Agency, 2017d).

Recycling water clearly avoids the need to discharge contaminated effluent and, therefore, can potentially reduce environmental impacts. This is consistent with a ‘concentrate and contain’ approach, which is aligned with policy for the UK (Defra, 2009a and 2009b).

The ABWR design allows recycling by using demineraliser technology, which transfers the majority of activity to ion exchange material for eventual disposal as solid waste. Therefore, using demineralisers generates solid waste, while reducing the radioactivity disposed in liquid waste discharges. We comment further in a specific assessment report on the use of demineralisers and the implications in terms of solid waste arisings and disposal routes (Environment Agency, 2017b).

Detailed design of the demineraliser systems will depend on operator choices and is considered a matter for site-specific permitting. Hitachi-GE has provided us with arguments to demonstrate the levels of decontamination that are possible based on typical types of ion exchange media used in nuclear applications (in response to RQ-ABWR-0239). Selecting appropriate demineraliser resins to minimise waste generated needs to be considered further with a future operator, and we identify this as an Assessment Finding (Assessment Finding 3).

The assumption that no carbon-14 enters the liquid waste streams and, therefore, cannot adsorb onto the demineraliser resins or be discharged is not a conservative assumption for liquid discharges and may need considering further in the future or validating in early operations. We have identified an Assessment Finding relating to this aspect (Assessment Finding 5).

Table 2h. Summary of evidence Hitachi-GE presented in support of Argument 1h in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 1h	Recycling of water to prevent discharges
Evidence	Condensate water clean-up system - provides evidence to demonstrate how using demineralisers (ion removal) and filters (crud removal) reduces worker dose and the radioactivity of wastes generated.
	Reactor water clean-up (CUW) system - provides a description of how and why the CUW system removes impurities from the reactor water. Evidence of the effectiveness of the CUW system is also presented.
	Fuel pool cooling/clean-up system and the suppression pool clean-up system - provides a description of the system and evidence to support the importance of water chemistry management.
	Low chemical impurities waste (LCW) treatment system - provides a summary of the assessment of the different treatment technologies available for LCW. The conclusion was that using demineralisers and filters provide the best option.
	Nuclear industry application – demineralisers - provides evidence that the techniques proposed for aqueous waste streams in the UK ABWR represent BAT.
	Demineraliser media - provides a summary of the considerations in determining which ion exchange media are appropriate for the UK ABWR. The flexibility offered to future operators on choice of media is considered to represent BAT.
	Recycling of water within steam circuit – operational experience and feedback - provides a summary of how recycling water following treatment within the system reduces the need to make discharges of aqueous waste.

Argument 1h	Recycling of water to prevent discharges
	Reuse of liquid effluent during decommissioning activities - describes the benefits of retaining water from the operational phase to use in decommissioning activities.

Argument 1i. Secondary neutron sources

Hitachi-GE has proposed using californium-252 sources in stainless-steel cladding as secondary neutron sources in the ABWR design. An advantage of this type of source is that it avoids producing additional tritium relative to certain alternatives, such as sources based on antimony-beryllium. Hitachi-GE suggests that there is considerable operational experience to support the use of californium-252 sources.

Table 2i. Summary of evidence Hitachi-GE presented in support of Argument 1i in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1i	Secondary neutron sources
Evidence	Selection of neutron source materials - provides evidence that using californium-252 in the neutron source assemblies eliminates the production of tritium.
	Selection of neutron source cladding - provides evidence for using palladium/californium wires in welded stainless steel capsules.
	Secondary neutron sources – operational experience and feedback - provides background and history of using californium-252 as a neutron source since the 1970s.

Argument 1j. Leak tightness of liquid, gas and mixed phase systems

Hitachi-GE argues that the design of the UK ABWR includes a range of provisions to help ensure that radioactive substances that are unavoidably created during operations are contained within designated facilities.

Relevant measures to ensure leak tightness, as described by Hitachi-GE, include rationalising the amount of pipework associated with plant operations; improving the performance of welds, seals and connections; including level alarms; including bunding and application of impermeable coatings to the floor and walls in areas where leakage is possible. Hitachi-GE has also defined 'Design policies and principles' that seek to reduce or eliminate leakage, which have been considered in the design of the ABWR. Specific policies are described for various components of the plant, specifically the liquid waste system, the OG, the containment vessel, the HVAC system and the fuel pool.

We note that ONR's 'Chemical/process engineering design approach' RO (RO-ABWR-0054) is now closed with no impact on our preliminary conclusions. We consider the measures for ensuring leak tightness as defined by Hitachi-GE to be consistent with use of BAT.

Table 2j. Summary of evidence Hitachi-GE presented in support of Argument 1j in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 1j	Leak tightness of liquid, gas and mixed phase systems
Evidence	Application of design features for leak tightness - provides a description of the design features that reduce leakage and the release of radioactive material.
	Design policies and principles for leak tightness in the liquid waste system – describes the items that are considered when designing the system for

	treating liquid waste to prevent leakage. Consideration is given to materials and joints, valves, leak detection, secondary containment and alarms.
	Design policies and principles for leak tightness in the OG - briefly describes using the off-gas charcoal absorber under negative pressure to prevent off-gas leaking into other parts of the nuclear power plant.
	Design policies and principles for leak tightness in the containment vessel - provides a brief description of the principles of materials selection and connection types.
	Design policies and principles for leak tightness in HVAC System - provides a description of using negative pressure within buildings to ensure that air flows from areas of low radioactive contamination to areas of higher radioactive contamination. Air tight seals will be used on hatches, doors and pipe penetrations between rooms.
	Design policies and principles for leak tightness in fuel pool - provides a description of how the fuel pool has been designed to prevent leakage. The design incorporates leak detection, level alarms and has an absence of outlets.
	Design policies to prevent atmospheric argon leaking into the coolant system - provides a brief statement that the design will minimise the amount of argon-40 that can leak into the main condenser.
	Leak detection and isolation system - specifies the reactor systems that will incorporate leak detection and isolation systems. A description of what the leak detection and isolation system consists of is also provided.
	Improvements to leak tightness - provides a summary of the design improvements to the main steam isolation valves that have been incorporated into the UK ABWR design to prevent leaks.
	Improvements in turbine gland seal design - provides a comparison between the previous design (steam seal regulator) and the current separate steam seal system.

Claim 2: Minimise the radioactivity in radioactive waste disposed to the environment

We expect best available techniques to be used to prevent and/or minimise releases of radioactive substances to the environment.

Hitachi-GE claims that the UK ABWR design will minimise the radioactivity in radioactive waste disposed to the environment. This claim is supported by 10 arguments (2a-2j) and extensive evidence. We summarise each argument below and provide our conclusions at this time.

Argument 2a. Off-gas waste treatment system (OG)

The major radionuclides in the off-gas stream that are anticipated in gaseous discharges are the noble gases, carbon-14, tritium and iodine radionuclides. The design of the UK ABWR includes an OG, which collects, conveys, treats and discharges gaseous radioactive waste from the condenser. This gaseous radioactive waste includes radionuclides that are transported with steam but are not condensed along with water in the condenser. The ABWR also includes filtration technology to remove particulate species from the off-gas stream.

The OG includes columns of activated charcoal to adsorb radioactive species and, therefore, delay discharge in the off-gas flow. During this delay period, short-lived radionuclides decay in-situ and, therefore, do not contribute to the radioactivity in the discharge. The term ‘delay beds’ is used to describe this abatement approach and this is common practice in light water reactor technology and recognised as BAT for such applications in international literature. Systems based broadly on the same technology are in operation at Sizewell B and are proposed in both the EPR and UK ABWR reactor designs.

Hitachi-GE has provided arguments and evidence that the design of the OG will be effective in removing short-lived radionuclides that are amenable to delay (most noble gases and short-lived radionuclides, including those of iodine).

Hitachi-GE argues that there are no practicable techniques to abate tritium and carbon-14 in the gaseous waste streams at this time. This view is supported by a review of international practice and a range of options that have been considered against recent IAEA guidance (IAEA, 2014). We prompted further consideration of such aspects via RQ-ABWR-0244.

Abating carbon-14 via the OG would require development work on alkaline scrubbing treatment techniques, which would also entail the disposal of secondary solid wastes resulting from the scrubbing process. Hitachi-GE argues that the development costs would be substantial and any benefits marginal in terms of overall impacts. Hitachi-GE has concluded that not abating carbon-14 in the OG is BAT at the GDA stage, but identify this as an aspect that is suitable for a future operator to consider further. We agree with Hitachi-GE’s view and will expect a future operator to review the practicability of techniques for abating carbon-14 at the site-specific permitting stage. We have raised an Assessment Finding to this effect (Assessment Finding 4).

Table 3a. Summary of evidence Hitachi-GE presented in support of Argument 2a in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 2a	Off-gas waste treatment system (OG)
Evidence	Configuration of the OG - provides a statement that the design of the OG in the UK ABWR takes into account relevant good practice from the BWR fleet in Japan and across the nuclear industry. A description of the OG is provided, which includes alternative treatment options that have been considered.
	Off-gas waste treatment system – operational philosophy - the OG will be run continuously while the UK ABWR is in operation. If the OG goes outside specified limits, then the reactor will be shut down so the causes can be investigated.
	Assessment of gaseous treatment techniques for tritium and carbon-14 - The delay beds used in the UK ABWR OG are not effective in treating carbon-14 and tritium. This section provides evidence of treatment options and concludes that the UK ABWR will minimise at source and use dispersion from the stack rather than use a specific treatment technology.
	In-process monitoring to support demonstrating the application of BAT - provides a brief statement to say that monitoring the OG is carried out as well as temperature of the delay beds. The temperature of the delay beds can affect their performance so must be kept within specified parameters.

Argument 2b. Delay beds for noble gases and iodine

Hitachi-GE argues that the delays beds that are part of the OG are suitably configured to enable significant delay of noble gases and iodine radionuclides. Supporting evidence is provided to substantiate the quantity of charcoal required to achieve optimised ‘delay’. It is also argued that there are benefits in terms of abating iodine radionuclides. We sought clarity on the basis of the delay calculations and related aspects (RQ-ABWR-0240) that Hitachi-GE presented.

Hitachi-GE argues that the proposed delay beds are designed for 60 years of operation without needing to replace the charcoal. This is based on operational experience from 20 operational nuclear power plants.

Argon-41 is a noble gas radionuclide with a relatively long half-life of 1.8 hours. It is not formed from nuclear fission but results from neutron activation of argon-40 (present in air and entrained in the reactor circuit). The delay bed design in the UK ABWR would result in a significant reduction in argon-41 gaseous discharges (by a concentration factor of 14, it is argued). However, argon-41 abatement is not as extensive as the reduction in other noble gas radionuclides, which will effectively decay in-situ within the OG. Hitachi-GE has identified a number of additional approaches that could be used to further abate argon-41, but argues that each would be prohibitively expensive compared to the potential benefit and given that argon-41 only contributes a small amount to projected doses to the public. Hitachi-GE concludes, based on a qualitative analysis, that it is likely to prove grossly disproportionate to abate argon-41 further.

We agree with Hitachi-GE that using delay bed technology in the UK ABWR design is consistent with the application of BAT.

Table 3b. Summary of evidence Hitachi-GE presented in support of Argument 2b in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 2b	Delay beds for noble gases and iodine
Evidence	Configuration of delay beds - provides a description of the design and configuration of the charcoal delay beds. Designed for 60 year operational life with no media replacement needed.
	Use of delay beds - provides a statement with supporting evidence that delay beds for short-lived radionuclides represents best practice.
	Calculations to support delay bed size for xenon and krypton - provides evidence, with calculations for the sizing of the delay beds.
	Calculations to support abatement of iodine - presents evidence to demonstrate that the discharges of iodine and methyl iodine from the OG will be ‘very low’.
	Delay beds for krypton, xenon and iodine – Design Improvements – provides a summary of the changes from delay tanks to charcoal delay beds introduced in the 1970s and 1980s to improve the performance of the OG.
	Delay beds for radioactive decay of argon - provides a description, including alternative options considered, to reduce the amount of argon-40 that becomes activated to argon-41 and the subsequent abatement of argon-41 in the OG.

Argument 2c. Heating, ventilation and air conditioning (HVAC) system

The ABWR design includes a HVAC system that aims to maintain environmental conditions within the reactor plant and provide a cascade air flow from areas of low contamination to areas of higher contamination. All HVAC systems discharge gaseous waste via outlets that will require permitting. Other than filtration, there is no abatement on HVAC discharges. Flow through the HVAC system helps to dilute discharges from the OG. The HVAC system for the ABWR is segregated into sub-systems according to the main areas.

HEPA filtration within the HVAC systems aims to ensure that the concentration of particulate matter within the gaseous radioactive waste stream is minimised during normal and accident conditions. The extent of filtration, in terms of the number of filter banks, has been designed to ensure appropriate efficiency based on demands from those plant areas. Hitachi-GE observe that each system will include safe change HEPA filters that comply with relevant industry standards. Hitachi-GE has introduced increased HVAC flow rates to the UK ABWR design, mainly to ensure appropriate radiological protection for workers.

Hitachi-GE propose that HEPA filters will be changed, where practicable, based on performance criteria, such as decontamination factor and differential pressures, that is the relative pressures upstream and downstream of the filtration. Hitachi-GE notes that under these arrangements filters will be used to their design capacity and not changed at a predefined frequency. This approach can prevent unnecessary volumes of solid waste being generated and needing to be disposed of. However, the actual change frequency has not been declared by Hitachi-GE as this will be operator choice to be defined at the site-specific stage.

We queried the ability to abate iodine in the HVAC system (RQ-ABWR-0424). The response argues that it would be less than optimal and disproportionate from a normal operations, public dose perspective to instigate further abatement. It is noted that iodine radionuclides are a low contributor to total dose. This is a reasonable argument and we also note that should higher activity levels be detected in the HVAC, for example in the case of an accident, there is the possibility to switch flow through a standby gas treatment system (with charcoal abatement).

Table 3c. Summary of evidence Hitachi-GE presented in support of Argument 2c in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2c	Heating, ventilation and air conditioning system
Evidence	Configuration of HVAC System - provides a description of the design and configuration of the HVAC system. Appropriate abatement is used before discharge to the environment.
	HVAC discharges - provides a consideration of dose rates to conclude that the use of HEPA filters provides little benefit, but they will be used in the HVAC system of the UK ABWR anyway. A statement is also made that the cost of abating iodine from the HVAC system would be disproportionately high.
	In-process monitoring to support demonstrating the application of BAT in the HVAC system – provides a summary of the in-process monitoring carried out to ensure the HVAC system is operating correctly.

Argument 2d. Filtration of airborne particulate matter

Hitachi-GE argues that the UK ABWR will use appropriate filtration techniques to ensure that the concentration of particulate matter within the gaseous radioactive waste stream is minimised during normal and accident conditions. Hitachi-GE argues that the UK ABWR has been subject to considerable optimisation, so that the amount of particulate matter that could potentially become mobilised within the building areas served by the HVAC systems has been minimised. Overall, Hitachi-GE argues that the performance of the filters will exceed that required for normal operations.

We raised RQ-ABWR-0840 to seek clarity on filtration of the TGS and mechanical vacuum pump (MVP). We noted that the TGS and MVP lines could provide potential sources of particulate matter that could then adsorb activity within the system prior to discharge, therefore, providing a particulate source term in gaseous discharges. The response indicates that Hitachi-GE will install HEPA filtration into the TGS and MVP lines. The benefits in terms of monitoring arrangements are also recognised (see Environment Agency, 2017a).

We recognise that demands on the filtration systems for airborne particulate matter extend beyond normal operations. This aspect was subject to separate consideration via RO-ABWR-0017, which is now closed to the satisfaction of ONR.

Table 3d. Summary of evidence Hitachi-GE presented in support of Argument 2d in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2d	Filtration of airborne particulate matter
Evidence	Application of filtration in the nuclear industry - re-iterates the evidence provided under Argument 2c regarding the fact that HEPA filters will be included in the design despite the little benefit they offer in relation to normal

	operations (that is, the predominant role relates to demand in accident scenarios where particulate source terms may be significant). A description of the HEPA filtration system is provided.
	The basis for filter selection - provides a brief statement on where the HEPA filters will be located and their use.
	Filtration of airborne particulate matter – air flow rate - presents evidence to show how increased flow-rates, although creating more solid waste, provide a higher degree of safety.

Argument 2e. Optimisation of the turbine gland seal

Water is extracted from the condensate storage tank (CST) to produce steam that is used in the turbine gland seal. Hitachi-GE argues that following use in the turbine gland, 98% of the steam is condensed, along with the associated tritiated water, and is subsequently returned to the main condenser and is made available to be used.

Steam used in the turbine gland seal represents a source of tritium gaseous discharge and this was not considered in early source term work. A RO (RO-ABWR-0071, 'Turbine gland steam system: discharges and optimisation') was raised in June 2016 because the TGS was not fully considered in the generic environmental permit (GEP) submission (Rev E) and pre-construction safety report (PCSR). The RO is now closed and we agree that the TGS system has been demonstrated to use BAT based on the following:

- Hitachi-GE argues that using CST water as the supply for the gland steam evaporator, rather than purified water, allows the operator to manage the water balance of the plant without having to make additional discharges of aqueous radioactive waste. It concludes that small gaseous discharges of tritium are preferable, overall, to further liquid discharges and other associated impacts, including cost and additional decommissioning waste.
- An options assessment has been provided (as outlined in Hitachi-GE, 2017a). The assessment explored opportunities to further optimise the turbine gland seal. It concluded that the costs, in terms of time, effort and financial cost are grossly disproportionate to the benefits in terms of dose reduction.

Table 3e. Summary of evidence Hitachi-GE presented in support of Argument 2e in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2e	Optimisation of the turbine gland seal
Evidence	TGS impact on gaseous discharges – provides a quantification of the gaseous source term provided by the turbine gland seal steam and compares this with other sources.
	TGS options assessment – outlines the results of an options assessment process to explore opportunities to further optimise the turbine gland seal.

Argument 2f. Configuration of the liquid management system:

The design of the UK ABWR includes a liquid management system. This has a series of segregated drains, which segregate wastes of broadly similar characteristics for subsequent treatment, where practicable. In-process monitoring is used to confirm the relevant characteristics of the liquid wastes and to ensure suitability for onward treatment, reuse or disposal. Aqueous radioactive waste is treated prior to it being discharged. Treatment techniques include filtration, demineralisation and evaporation that aim to remove radionuclides, and certain other species, to ensure compatibility for reuse and/or to meet discharge criteria (Hitachi-GE, 2017a).

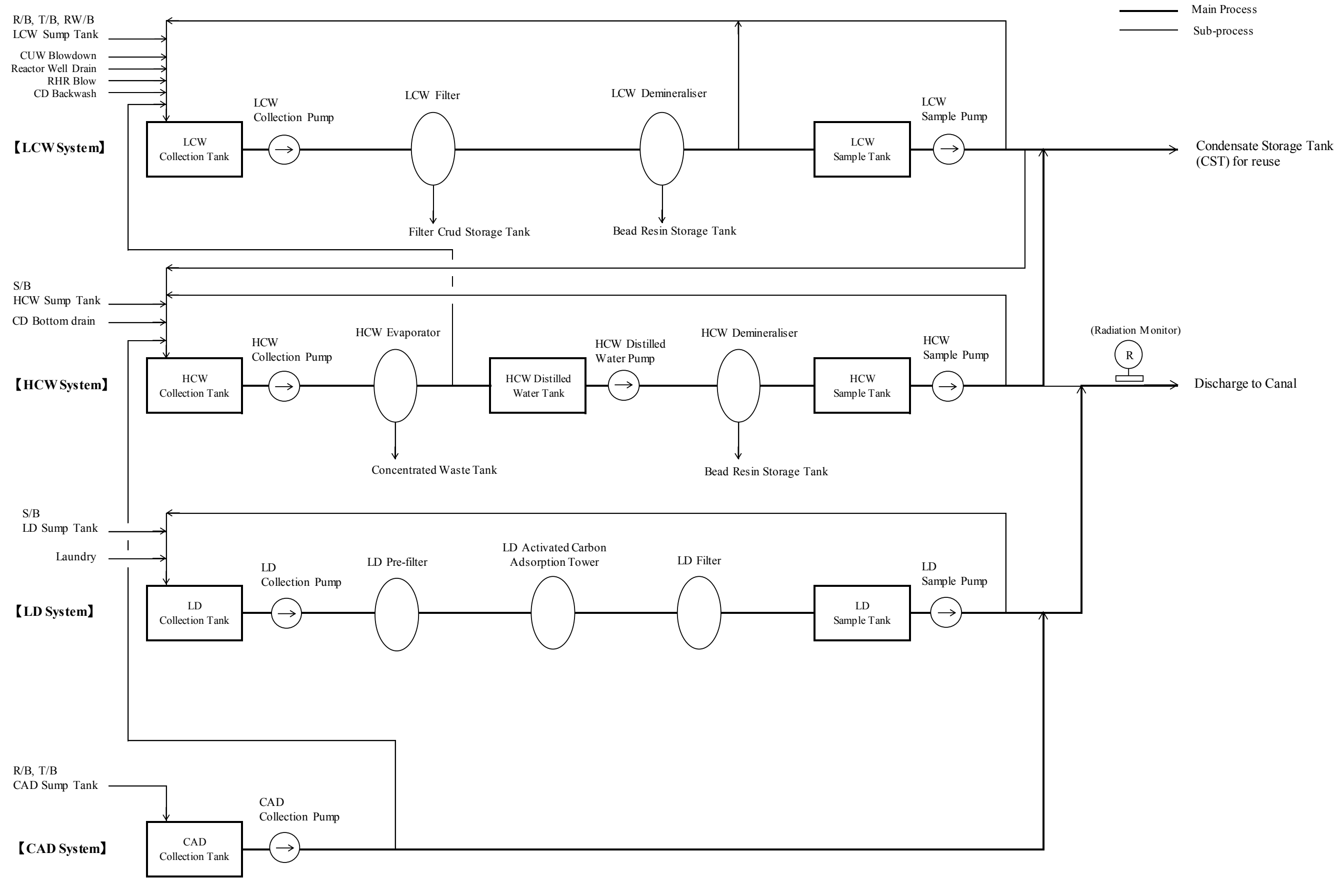

Figure 2: Diagrammatic representation of the configuration of the liquid management system (Hitachi-GE, 2017a).

The LCW consists of filters for removing particulates, demineralisers for removing ionic species, and sampling pools. Treated liquids are returned to the CST so they can be recycled rather than discharged.

The HCW includes an evaporator for removing a range of impurities and a demineraliser for removing residual ionic species from the condensate. Treated HCW liquids are either transferred to the CST to be reused or, in limited circumstances, disposed of into the environment following reassurance monitoring to ensure compliance with permitted limits.

LD waste water streams contain detergent, suspended solids and organic material and low levels of radioactivity, largely as particulate crud. The treatment system comprises collection tanks and filters (LD pre-filter, LD activated carbon adsorption tower and LD filter). Treated waste is disposed of following monitoring to ensure compliance with permitted limits.

The CAD system contains a range of liquid wastes generated in the ABWR facility's controlled areas, which are not otherwise captured by the HCW and LCW systems. This includes liquid derived from air-conditioning units and, therefore, the quantity of CAD generation depends on the temperature and humidity in the building. Wastes from the CAD are discharged into the environment following monitoring to ensure compliance with permitted limits. CAD liquid is treated through the HCW system if any significant radiological contamination is detected.

Hitachi-GE argues that the liquid management systems have been developed based on a set of design policies to prevent leakage of liquid radioactive substances and to prevent their uncontrolled discharge. The LWMS will be designed so that it can be centrally monitored and controlled in the radioactive waste building control room.

Hitachi-GE argues that liquid tritium discharges for the ABWR design will be very low and the design allows considerable containment of this radionuclide within the reactor water system, including the main steam/condensate circuit and the condensate storage tank. Some tritiated water will be discharged via evaporation, for example via the HVAC and the TGS steam route. Tritiated water will also be discharged via HCW discharges to maintain the water balance of the plant.

The residence time of water in the condensation system circuit will lead to benefits in terms of decay storage. Hitachi-GE observes that discharges of reactor water will not occur until 60 to 80 years after start of operation. The tritium concentration will reach an equilibrium value during the operational phase of the reactor and will start to decay when operations have ceased. The period between the end of operations and discharge may be up to 20 years which potentially allows for an appreciable decay of tritium within the plant.

Hitachi-GE suggests that there are no practicable abatement techniques for liquid tritium and that the low discharge rates and associated impacts do not warrant further development and deployment.

It is notable that liquid radioactive discharges from the ABWR are low, in terms of volume, activity and the associated projected dose (Environment Agency, 2017e). Our comparison of relevant reactor discharge data supports this view (Environment Agency, 2017d).

ONR has issued a number of ROs with potential implications for the design of the liquid waste management system, including RO-ABWR-0054 (‘Chemical/process engineering design approach’) and RO-ABWR-0036 (‘Demonstration that the approach taken to radioactive waste management reduces risks SFAIRP’). These ROs are now closed, the design has not been changed and therefore, we have not changed our preliminary conclusions relating to BAT.

The ABWR design benefits from inherent features that allow liquid to be reused and this is helped by applying appropriate techniques to concentrate and contain waste, where practicable. Overall, we conclude that the design of the ABWR liquid waste management system is consistent with the application of BAT at the GDA stage.

Table 3f. Summary of evidence Hitachi-GE presented in support of Argument 2f in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 2f	Configuration of liquid management system
Evidence	Configuration of liquid waste treatment system - provides a description of the design and configuration of the LWMS. The LWMS comprises 4 systems: a dedicated treatment system for low chemical impurities waste, dedicated treatment system for high chemical impurities waste, laundry and hot shower drain waste and controlled area drain system.
	Design policies for the liquid waste treatment system - provides a summary of the design policies for the LWMS and confirmation that they have been used for the UK ABWR design.
	Assessment of liquid treatment techniques for tritium – considers the treatment options for tritium before presenting evidence to support recirculating tritiated water rather than discharging it.
	Key parameters for water balance - provides evidence to support reusing treated water within the primary circuit to minimise discharges and how this is managed. Where discharge to the environment is necessary, the monitoring that the effluent is subjected to is described.
	In-process monitoring to support demonstrating the application of BAT - provides a summary of the in-process monitoring techniques used for the LWMS.

Argument 2g. Sizing of tanks, vessels and liquid containment systems

The UK ABWR design includes tanks to manage the liquid wastes from the segregated drain systems. Hitachi-GE argues that these tanks have been designed to provide sufficient capacity to store the effluent during treatment and prior to discharge. We queried the definition of these capacities and specifically the definition of the associated margins (RQ-ABWR-0246).

It is argued that the size of the tanks ensures that operators will have enough time to carry out sampling and analysis of wastes prior to making any decisions to discharge effluent to the environment, or to subject it to additional treatment. All tanks are to be fitted with a series of volume level alarms and with secondary containment in the form of bunding.

We conclude that the approach to sizing of tanks, vessels and liquid containment systems is consistent with the application of BAT at the GDA stage.

Table 3g. Summary of evidence Hitachi-GE presented in support of Argument 2g in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2g	Sizing of tanks, vessels and liquid containment systems
Evidence	Capacity of tanks and vessels - provides details of the method used to calculate tank capacity.
	Secondary containment of tanks and vessels - provides a brief statement that secondary containment will be appropriately sized and constructed.

Argument 2h. Demineralisers for distillates from the high chemical impurities waste evaporator

The ABWR design includes an evaporator in the HCW system, which is effective at concentrating and containing the majority of the radioactivity from the HCW liquid. It is argued that evaporator liquor is accumulated in a form suitable for conditioning and solid waste disposal.

Some of the volatile radionuclides are carried over with the distillate during evaporation and further treatment of the distillate by demineraliser resin is performed. This 'polishing' step further minimises radioactivity in the liquid before the waste is reused, where possible. Where reuse criteria are not met, the liquid would be routed back to the HCW collection tank and treated again.

Hitachi-GE has provided evidence of design improvements for treatment of HCW liquids relative to earlier BWR designs. The evaporator has benefited from significant design improvements in relation to operability, and recent practice has seen greater throughput treatment and reuse of the floor drain liquid waste arisings.

Overall, we conclude that using an evaporator is consistent with a concentrate and contain approach given that a large proportion of the radioactive substances in the HCW stream is concentrated into a solid waste stream. It is also consistent with the waste management hierarchy, in terms of potentially enabling reuse of liquids that would otherwise need discharging.

Table 3h. Summary of evidence Hitachi-GE presented in support of Argument 2h in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2h	Demineralisers for distillates from the high chemical impurities waste evaporator
Evidence	Configuration of the demineraliser provided in the HCW - provides a brief overview of the demineraliser process in the high chemical impurities waste system.

Argument 2i. Evaporation of high chemical impurities waste (HCW)

Hitachi-GE has included an evaporator in the design of the UK ABWR specifically to treat liquids arising in the HCW system. This liquid waste is collected in the chemical drain and may contain substances that interfere with waste treatment systems and can cause corrosion of process equipment. Without further treatment this type of waste could not be reused and would, therefore, require discharging (disposing of). Residue from the evaporator will contain the majority of the radioactivity. Hitachi-GE proposes that this is converted to and disposed of as solid radioactive waste.

We challenged a potential revised design of the HCW liquid waste management system, which would have resulted in removing the evaporator from the design (RQ-ABWR-0668). Following further consideration, Hitachi-GE opted to reinstate the evaporator.

Unlike other components of the liquid waste management system the HCW system is linked to a liquid discharge route. The UK ABWR design means that a future operator will only discharge liquid waste to the environment from the HCW route if there is a need to reduce the water holdings of the plant (that is to maintain water balance) and only where sampling and analysis indicate that the waste meets discharge criteria. Any such discharges would be of very low activity (Environment Agency, 2017d).

We agree with Hitachi-GE that the proposed low frequency of discharges, combined with applying reliable treatment technologies, are consistent with the application of BAT for the UK ABWR design.

Table 3i. Summary of evidence Hitachi-GE presented in support of Argument 2i in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2i	Evaporation of high chemical impurities waste
Evidence	Nuclear industry application – evaporators - provides a summary of the evaporation process that is used widely in the nuclear industry for treating radioactive liquid wastes. The decision making process Hitachi-GE carried out has concluded that evaporators are the appropriate technology for the UK ABWR.
	Configuration of evaporation system - provides a brief overview of the evaporation system to demonstrate how the system is configured.
	HCW sampling and monitoring - provides a description of the monitoring (locations and parameters) carried out on the HCW system.
	Evaporation system – design improvements - provides a summary of the design improvements that have reduced the amount of radioactivity released to the environment and increased the amount of water available that can be re-used. Improvements include using evaporators for floor drain waste, adopting forced circulation evaporators and pH adjustment.

Argument 2j. Radioactive decay of solid and liquid wastes

Hitachi-GE observe that decay storage is a recognised practice in the nuclear industry and is particularly useful in managing short-lived radionuclides. Hitachi-GE argues that there are benefits from decay storage of both solid waste and liquid waste and that the design of the ABWR and the proposed waste management strategy enables these benefits to be realised.

The design of the UK ABWR includes storage of solid higher activity wastes. Hitachi-GE has assumed storage timescales of up to 100 years pending timescales of future GDF availability. Notably, Hitachi-GE argues that storage of CUW resins and FPC resins will enable significant decay in storage. Early conditioning of operational waste arisings is proposed and, therefore, storage in a solidified waste form is envisaged. Hitachi-GE has not identified storage capacities for waste that may benefit from decay storage and proposes that a future operator will need to consider this.

Hitachi-GE argues that storage timescales will be sufficient to enable decay heat dissipation such that package heat outputs would not hinder disposal to a future GDF. We note, however, that RWM has questioned if certain package types Hitachi-GE proposed are optimal with regards to package thermal outputs (Environment Agency, 2017b).

Hitachi-GE propose using 3m^3 boxes with the same handling features, handling configuration, and transport over-pack as the 3m^3 drum used for wet ILW waste. The design of the vault will be considered in future studies.

We recognise that decay storage can minimise the quantities of waste that need disposing of, and that this is a particularly useful approach for radionuclides with short-half lives. We also support plans for early waste conditioning, where appropriate, as immobilisation helps to ensure containment and reduce future burdens where it is shown that robust and disposable products can be produced.

Table 3j. Summary of evidence Hitachi-GE presented in support of Argument 2j in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 2j	Radioactive decay of solid and liquid wastes
Evidence	Nuclear industry application – decay storage - provides the justification for using decay storage for solid and liquid waste in the UK ABWR.
	Storage of solid ILW - provides an overview of the process that involves 5 years in the spent fuel pools followed by buffer storage to allow further decay prior to size reduction and packaging pending disposal in a GDF.
	Radioactive decay of sludge and spent resin waste - provides a brief description of the decay storage of waste sludge and spent resin. Both waste streams are expected to be stored for 5 years.
	Storage period of reactor water clean-up system (CUW) and fuel pool cooling and clean-up system (FPC) resins - provides evidence that decay storage of immobilised CUW and FPC resins may facilitate appreciable decay.
	Decay storage of concentrated liquid waste - provides evidence to support the conclusion that a decay storage period of 1 year is needed to allow halogenous nuclides to decay.
	Decay storage of ILW during decommissioning - describes the time periods for a number of stages of decay storage from decommissioning to final disposal in a GDF.
	Tank vent treatment system - provides evidence to show that the higher activity waste tanks vent system provides a continuous flow of air and is fitted with a filter system prior to discharge from the main stack.

Claim 3: Minimise the volume of radioactive waste disposed to other premises

This claim is supported by 5 arguments (3a-3e) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 3a. Design to minimise the volumes of operational and decommissioning waste arisings

Hitachi-GE argues that the design of the UK ABWR has evolved to reduce the quantities of solid radioactive waste that will be generated relative to earlier BWR designs. Arguments and evidence of this design evolution is provided in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a). Main aspects include using internal reactor pumps that avoid additional pipework, improved reactor pressure vessel design reducing size and eventual waste arisings, reductions in stress corrosion cracking leading to lower replacement frequencies, using hollow fibre filters reducing filter waste arisings and 10 further minor design changes that are beneficial.

Hitachi-GE identifies only one design change that has increased waste arisings (responding to RQ-ABWR-0232). That is the introduction of moisture separator reheaters. It is argued that the benefits of this change exceed the implications of a small quantity of additional waste through improved thermal efficiency.

Table 4a. Summary of evidence Hitachi-GE presented in support of Argument 3a in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 3a	Design to Minimise the Volumes of Operational and Decommissioning Waste Arisings
Evidence	Introduction of reactor internal pumps (RIP) - presents the evolution of reactor water re-circulation methods from BWR-1 to the UK ABWR design. The UK ABWR will be fitted with reactor internal pumps that provide the benefits of a reduction in decommissioning waste, a reduction in the size of the primary containment vessel (PCV) required, decrease in operational exposure to workers, increase in safety and a reduced power consumption.
	Evolution of the primary containment vessel - provides a brief description of the improvements made in the design of the primary containment vessel.
	Design of the primary containment vessel - presents detail on the reduction in size of the primary containment vessel and how this has been achieved.
	Techniques to reduce stress corrosion cracking - the techniques of material selection, fabrication process and improved operating environment (for example, injection of hydrogen) are described in relation to how they reduce stress corrosion cracking.
	Replacement of pre-coated filters - the benefits of replacing pre-coated filters with hollow fibre filters on the condensate and LCW systems are described in terms of water quality and waste reduction.
	Review of further design changes - a range of design changes are described that help to minimise the volume of radioactive waste.

Argument 3b. Selection of methods to minimise solid waste generation

Hitachi-GE argues that the design of the UK ABWR includes a number of features that will allow a future operator to adopt an operating philosophy that will minimise the quantity of solid radioactive waste associated with routine operations and maintenance. The main aspects are ensuring available space for operations in designated areas to allow waste to be segregated, avoiding unnecessary 'office work' in controlled areas and adopting a flexible maintenance philosophy allowing appropriate items to be replaced as needed rather than on a pre-defined schedule.

We recognise these aspects as good practice consistent with the application of BAT.

Table 4b. Summary of evidence Hitachi-GE presented in support of Argument 3b in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 3b	Selection of methods to minimise solid waste generation
Evidence	Segregation of wastes - describes how the design of the UK ABWR allows future operators the flexibility to segregate, collect, store and process waste using BAT.
	Locate offices outside of controlled areas - the majority of office accommodation will be located outside the radiological controlled area.

	Storage facilities for tools and other maintenance equipment - provides a description of how the management of maintenance equipment, tools, spares, consumables and protective clothing for use inside the radiological controlled area reduces the amount of radioactive waste for disposal.
	Maintenance philosophy - presents an example of replacement of HEPA filters and filter demineraliser elements being based on performance monitoring rather than fixed timescales. This is expected to reduce the amount of radioactive waste produced throughout the life of the site.

Argument 3c. Application of volume reduction processes for solid waste

Hitachi-GE observes that making efficient use of space in waste containers has the combined effect of reducing the size of storage facilities, decreasing the number of vehicle movements during transportation and minimising the demand on disposal capacity. Appropriate size reduction of used control rods, using 'off-site' incineration facilities, shredding and low force compaction as the preferred processing methods for LLW filters and combustible waste are consistent with this approach.

We recognise these aspects as relevant good practice consistent with the application of BAT. We will seek to ensure that a future operator makes appropriate use of such approaches and provisions.

Table 4c. Summary of evidence Hitachi-GE presented in support of Argument 3c in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 3c	Application of volume reduction processes for solid waste
Evidence	Size reduction of control rods - presents the results of an assessment Hitachi-GE carried out on managing control rods when they reach the end of their useful life. The conclusion is that they will undergo decay storage before being cut up (size reduced) prior to disposal. The justification for this decision is also presented.
	Incineration - provides evidence to support the use of incineration as the preferred management route for combustible waste streams. The preferred option is off-site incineration.
	Solid waste compaction - provides evidence to support the use of shredding and low force compaction for 'soft' LLW.

Argument 3d. Minimising the quantity of solidified high chemical impurities waste (HCW)

Hitachi-GE argues that HCW is best treated by a combination of evaporator and demineraliser technology. The evaporator helps to remove impurities that increase the risk of corrosion and the associated generation of corrosion products. These include organic carbon impurities that are difficult to remove by demineralisation approaches. Using evaporation technology helps to allow liquids to be reused in the condensate circuit, therefore avoiding liquid effluent discharge where reuse is possible. Residues from the evaporation process are to be conditioned for eventual disposal.

We conclude that using evaporation technology allows a 'concentrate and contain' approach and could potentially reduce the quantity of overall conditioned waste relative to other approaches. It also enables (greater) reuse of liquids within the plant system, therefore avoiding discharge (as per argument 2h). This is consistent with the application of BAT.

Table 4d. Summary of evidence Hitachi-GE presented in support of Argument 3d in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 3d	Minimising the quantity of solidified high chemical impurities waste (HCW)
Evidence	Solidification of concentrated high chemical impurities waste - presents the results of an assessment Hitachi-GE carried out on managing HCW liquors. The preferred option is solidification using an in-line cement immobilisation process.

Argument 3e. Application of decommissioning techniques to reduce the activity and volume of decommissioning waste

Significant quantities of waste will be generated in decommissioning a UK ABWR. We note that waste arisings are likely to be comparable to other light water reactor designs, based on the projected waste arisings (Environment Agency, 2017b).

Hitachi-GE observes that it will be the future operator's responsibility to decommission the UK ABWR and to select techniques to do this. Hitachi-GE, therefore, focuses on demonstrating for GDA that adequate techniques are available to carry out this task, based on current technologies. The aspects Hitachi-GE highlighted are those relating to system decontamination during decommissioning and approaches to decontamination after dismantling.

We recognise that these approaches, as outlined for GDA, are potentially applicable and effective. We will expect, however, that a future operator develops an optimised and integrated decommissioning plan, which makes sure that waste will be appropriately minimised and routed. The development of the decommissioning plan will form part of normal regulatory business.

Table 4e. Summary of evidence Hitachi-GE presented in support of Argument 3e in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 3e	Application of decommissioning techniques to reduce the activity and volume of decommissioning waste
Evidence	System Decontamination During Decommissioning - provides a description of the techniques used to remove radioactivity from the inner surfaces of pipes by using chemicals.
	Decontamination after dismantling - provides an outline of the techniques available to future operators and the factors they should consider when choosing an appropriate technique.

Claim 4: Selecting the optimal disposal routes for wastes transferred to other premises

This claim is supported by 5 arguments (4a-4e) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 4a. Provision of waste management facilities

Hitachi-GE argues that the design of the UK ABWR's radioactive waste building includes the space and services that are required to install the equipment necessary to characterise, treat and store waste. This, it is argued, will allow a future operator to implement the optimal waste disposal route for radioactive solid waste. Therefore, for GDA, Hitachi-GE has aimed to demonstrate that waste could be disposed of to appropriate routes based on currently established practice and national plans. Future site operators would need to select the actual disposal routes.

Hitachi-GE argues that characterisation, sorting, treatment and storage provisions will allow consignment to appropriately permitted routes, including those provided by waste management service providers. To support the GDA arguments, Hitachi-GE has provided evidence of agreement in principle for the disposal of lower activity waste that will arise during the lifetime of the UK ABWR. Hitachi-GE has also provided disposability assessments for higher activity waste based on advice received from RWM (Environment Agency, 2016c).

Overall, we recognise that the design does not constrain future operators and conclude that Hitachi-GE has provided a sufficient case in this respect for GDA.

Table 5a. Summary of evidence Hitachi-GE presented in support of Argument 4a in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 4a	Provision of waste management facilities
Evidence	Waste characterisation and assessment facilities - provides evidence to support the conclusion that providing sufficient space in the design will allow the future operator to characterise waste using BAT.
	Segregation and sorting facilities - provides evidence to support the conclusion that providing sufficient space in the design will allow the future operator to segregate and sort waste using BAT.
	Waste treatment facilities - Optioneering for GDA has concluded that the design will include a radioactive waste building for solid waste and a combined wet ILW and LLW treatment facility. Sufficient space has been included in the design to accommodate this. However, future operators do have the flexibility to re-configure the layout and types of techniques to increase the efficiency of operations.
	Waste storage capacity - provides evidence to support the conclusion that sufficient space has been provided for the future operator to optimise storage of LLW, ILW and spent fuel.

Argument 4b. Optimal disposal route selection

Hitachi-GE argues that waste arising from a UK ABWR will be compatible for disposal via existing disposal routes and those envisaged to be available in the future, such as a GDF. Evidence is provided to support the potential use of a range of selected waste management techniques to enable routing of appropriate wastes via a range of routes (see also Environment Agency, 2017b).

We consider the level of detailed provided in GDA to be appropriate in this regard. Hitachi-GE has recognised that the high level assessment to support this argument will require further assessment by a future operator.

Table 5b. Summary of evidence Hitachi-GE presented in support of Argument 4b in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 4b	Optimal disposal route selection
Evidence	Waste treatment techniques and disposal routes - presents the conclusions from the 'Hitachi-GE waste treatment BAT assessment'. The preferred waste management techniques for solid & wet LLW and solid & wet ILW treatment are summarised.

Argument 4c. Agreement in principle for waste routes - lower activity wastes

Hitachi-GE has engaged with the suppliers of waste management services for solid and non-aqueous radioactive waste in the UK. Agreement in principle has been obtained for compatible wastes against the following routes: metallic waste for physical decontamination and recycling; combustible waste for volume reduction by incineration; VLLW for disposal at appropriately permitted commercial landfills; super compaction of compressible lower activity waste followed by disposal in the national LLWR; and disposal of non-compressible lower activity waste in the national LLWR.

We consider this ‘agreement in principle’ to provide a suitable demonstration of waste compatibility with current disposal routes. This is at a level in line with GDA, and is based on high level descriptions of waste inventory and characteristics. A future operator would clearly be expected to confirm future compatibility by more detailed assessment against waste acceptance criteria at that time, and, therefore, to ensure permit compliance (see also Environment Agency, 2017b). Hitachi-GE has also identified forward actions (for a future operator) that prompt site-specific consideration of such aspects.

Table 5c. Summary of evidence Hitachi-GE presented in support of Argument 4c in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 4c	Agreement in principle for waste routes - lower activity wastes
Evidence	Agreement in principle - provides justification for the assumption that LLWR will provide all waste services via a waste service contract.

Argument 4d. Disposability Assessments for Higher Activity Wastes

Hitachi-GE has obtained disposability advice from RWM and responded to that advice as part of GDA.

We consider the level of development of the disposability case for higher activity waste (and spent fuel) to be in line with GDA expectations. We consider that this fulfils the relevant requirement of the P&ID. This is discussed further in a separate report (Environment Agency, 2017b).

Table 5d. Summary of evidence Hitachi-GE presented in support of Argument 4d in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 4d	Disposability assessments for higher activity wastes
Evidence	Disposability assessment – spent fuel - provides a summary of the considerations of the disposability assessment for spent fuel. The conclusion is that dry cask storage system is included in the design for GDA but with the flexibility for the future operator to choose an alternative technique that represents BAT at the time.
	Disposability assessment – intermediate level waste - provides a summary of the current conclusion of cement encapsulation (for solid items) and solidification (for wet/slurry wastes) as the appropriate options for ILW. However, the future operator will have the flexibility to choose alternative techniques at the time in order to satisfy BAT.

Argument 4e. Compatibility of existing UK waste BAT studies

Hitachi-GE has carried out assessments to determine the degree to which the findings of the Nuclear Decommissioning Authority (NDA) led UK waste BAT studies apply to the lower activity waste that will be generated by the UK ABWR. Assessments have considered metallic waste (NDA, 2006), combustible waste (LLWR, 2008) and waste with very low levels of radioactivity (LLWR, 2009).

The conclusions suggest that the UK BAT studies apply to the anticipated UK ABWR lower activity waste and, therefore, that BAT is demonstrated at a strategic level. We agree that this is a reasonable conclusion at this stage (see also Environment Agency, 2017b). Hitachi-GE has defined a forward action to prompt further consideration of such strategic aspects. We have also captured this as an assessment finding, which will expect an operator to address the forward actions Hitachi-GE identified in GDA.

Table 5e. Summary of evidence Hitachi-GE presented in support of Argument 4e in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Argument 4e	Compatibility of existing UK waste BAT studies
Evidence	Review of LLWR metallic waste strategic BAT assessment - provides a brief summary of the LLWR strategic BAT assessment for managing metallic waste. Hitachi-GE has concluded that metal waste will be consigned for recycling but the future operator has the flexibility to choose an alternative option.
	Review of LLWR combustible waste strategic BAT assessment - provides a brief summary of the LLWR strategic BAT assessment for managing combustible LLW. The LLWR assessment conclusions are the same as Hitachi-GE's strategy to utilise off-site incineration. The choice of the specific incineration facility will be for the future operator.
	Review of LLWR VLLW strategic BAT assessment - provides a summary of the LLWR BAT assessment and confirms that it is consistent with Hitachi-GE's strategy.

Claim 5: Minimise the impacts on the environment and members of the public from radioactive waste that is disposed of to the environment

This claim is supported by 2 arguments (5a-5b) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 5a. Gaseous discharge system - main stack

Hitachi-GE argues that the location, height and dilution of gaseous discharges in the main stack will help to minimise the dose to members of the public and the environment. Arguments are presented to suggest a generic location of the stack. It is also argued that gaseous waste from the OG, after sampling, will be significantly diluted prior to discharge by the much higher flow rates from the HVAC system, which is likely to contain very low levels of gaseous radioactivity.

Hitachi-GE recognises that determination of the specific stack height will be a site-specific activity for a future operator. We agree that appropriate location of the main stack is an aspect requiring further consideration in relation to minimising public doses. This is a matter to be progressed at the site-specific stage.

Table 6a. Summary of evidence Hitachi-GE presented in support of Argument 5a in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 5a	Gaseous discharge system – main stack
Evidence	Main stack - location - provides evidence to determine the location and height of the main stack. Sampling and monitoring provisions will be determined by the future operator.
	Stack height determination – main stack - briefly describes the benefits of the main stack being located on the roof of the reactor building.
	Gaseous discharge – dilution factor - presents the methods used to determine the dilution factor for the gaseous discharge from the main stack.

Argument 5b. Liquid effluent system

Hitachi-GE argues that the design of the UK ABWR's liquid effluent management system allows the timing and location of effluent discharges to be controlled.

The UK ABWR's liquid effluent management system also includes sampling arrangements. These are designed to enable confirmation of the characteristics of the waste and to demonstrate conformance with any specific limitations and conditions as may be imposed by permitting (Environment Agency, 2017a).

We observe that the timing and location of effluent discharges is a matter to be progressed with any future operators at the site-specific stage. We also note that design features enabling controlled discharges and suitable characterisation of liquid effluents are consistent with the application of BAT (see also Environment Agency, 2017a).

Table 6b. Summary of evidence Hitachi-GE presented in support of Argument 5b in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).

Argument 5b	Liquid effluent system
Evidence	Cooling water discharge location - the location of the cooling water discharge point to sea will be determined by the future operator at the site-specific stage.
	Liquid effluent discharges – dilution - provides evidence that the level of dilution provided for radioactive aqueous waste will be adequate.
	Control and management of aqueous discharges - briefly summarises the factors that the future operator will take into account when determining their management techniques.
	GDA dose modelling - provides an outline of the use of initial radiological assessment tool (IRAT) for calculating public doses. The results show that discharges from the UK ABWR at the generic site would not threaten any dose limits or constraints.

3. Compliance with Environment Agency requirements

Table 7. Compliance with Environment Agency requirements

P&ID Table 1 Section or REP	Comments
P&I Table 1	The correct part of the P&ID is identified
Principle RSMDP3 – Use of BAT to minimise waste	BAT arguments are presented to show that the design of the UK ABWR will ensure that the production and disposal of radioactive substances will be minimised. The details of the optimisation process are shown in the 'Approach to Optimisation' document of the GEP submission (Hitachi-GE, 2017b), with the results shown in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).
Principle RSMDP4 – Processes for identifying BAT	The method for identifying BAT is provided in the 'Approach to Optimisation' document (Hitachi-GE, 2017b).
Principle RSMDP7 – BAT to minimise environmental risk and impact	All decision-making regarding the management of radioactive substances for the UK ABWR will comply with the process outlined in the 'Approach to Optimisation' document (Hitachi-GE, 2017b) to ensure that any resulting environmental risk and impact are minimised, with the results provided in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a).
RSMDP8 – Segregation of wastes	The design of the UK ABWR takes into account the needs of appropriate waste management techniques, such as maintaining separation of waste streams where appropriate. The RWMA document (Hitachi-GE, 2017e) demonstrates the philosophy supporting waste management arrangements, including appropriate emphasis on the waste hierarchy. The 'Approach to Optimisation' document (Hitachi-GE, 2017b) demonstrates how the most suitable equipment and management techniques are assessed and applied. Systems descriptions are provided in PCSR Chapter 18: Radioactive Waste Management.

4. Public comments

Hitachi-GE received 2 public comments up to 15 August 2017 concerned directly with BAT.

On 2 March 2016, Hitachi-GE received a comment which essentially welcomed the 'Approach to Optimisation' and commented that it represents *"a clear and very well informed description of the optimisation process that is required to be pursued within the nuclear industry through declarations presented by the UK regulatory community."* This essentially aligns with our view. However, we note as per the potential GDA issue that there is a need to ensure that the demonstration of BAT for the UK ABWR is also consistent with a demonstration of ALARP and, therefore, that the UK ABWR is suitably optimised to a level consistent with the expectations of GDA. This potential GDA Issue has now been removed because the ALARP case has been made for GDA and it did not result in any changes to the BAT case.

On 11 March 2016, Hitachi-GE received a comment relating to the order in which the claims, arguments and evidence are developed in the approach to optimisation. Hitachi-GE responded to say that in practice the process is not as linear as the diagrammatic representation may suggest. Claims are developed first and the arguments and evidence developed in a more iterative manner. It is important to focus on evidence based decision making. During early stages of developing the claims, existing evidence is reviewed and used to develop the arguments. Gaps and uncertainties are then addressed to the further development of the arguments and to augment the evidence base. This process is then used to further develop arguments and evidence and to challenge the design as required. An important aspect is that arguments and decisions are evidence based and BAT is an integral part of the process.

We received consultation responses directly related to BAT and these are discussed below. We focus here particularly on responses to our consultation question that asked, "Please tell us if you have any comments on our preliminary conclusions on the process for identifying best available techniques (BAT)". Our other assessment reports, including those related to solid, aqueous and gaseous wastes, respond to other consultation responses in these particular areas of assessment. Responses to all comments received during the consultation are provided in our decision document (Environment Agency, 2017g). We have carefully considered the responses, although we judge that none of them impact or conflict with our conclusions as set out in this report.

The response from Nuclear Free Local Authorities (ABWR-03) asked about potential breaches of the spent fuel pool (SFP) leading to coolant losses with escape to the environment. We note that the design of the SFP is such as to minimise leakage and escape of liquid coolant in normal operations. Hitachi-GE has excluded any exhaust ports and the design includes water leakage detectors and water-level alarm devices to monitor any possible leakage of the fuel pool water [Hitachi-GE, 2017a, see 5.1.10.6.Evidence: Design policies and principles for leak tightness in fuel pool]. No liquid discharge from the SPF is anticipated in normal operations and there are no direct liquid discharge routes to the environment from the pool. As there are no liquid discharges from the SFP we will not have assessed radioactivity of the SFP water. We would not ask for monitoring of radionuclides to be undertaken where there are no discharges. We have considered the activity on the SFP clean-up resins and their final activity and volume for waste disposal. We also considered the BAT aspects of SFP management that could impact on resin activity, SF integrity or disposability, such as pH and temperatures. Routine monitoring of the SFP will be undertaken for reasons such as worker dose, but as this is outside our legal responsibilities we have not assessed it. We have, however, passed this consultation response on to ONR for its consideration. Monitoring of any liquid waste arisings in accident scenarios is not within the scope of our assessment in GDA, which considers only 'normal operations' as defined in our P&ID (Environment Agency, 2016a). Gaseous discharges via the SFP are anticipated in normal operations via evaporation of coolant and entrainment the HVAC system. A source term of volatile radionuclides from the SFP has been considered in our assessment.

In response to Q3 (BAT) the response from Berkeley Site Stakeholder Group (ABWR-05) asked, *"whether any proposal would only be acceptable if it gave an acceptable outcome?"* We seek evidence that a design is optimised and that all practicable measures have been taken to minimise waste arisings and any resulting environmental impacts. An acceptable outcome is one that not only meets relevant dose constraints but also demonstrates optimisation (public dose as low as reasonably achievable) via the application of BAT.

Berkeley Site Stakeholder Group (ABWR-05) also asked about the reliability of the fuel proposed for use in the UK ABWR. We noted that the proposed fuel, GE-14, is deployed in other BWR reactor types and therefore has been the subject of progressive development and optimisation. In its submissions Hitachi-GE has provided evidence of features which should reduce the likelihood of fuel failures. Furthermore, in recognition, of future improvements in fuel technology we have identified an Assessment Finding that will require a future operator to demonstrate that a UK ABWR reactor will be operated in a manner which represents BAT, including the choice and operation of fuel.The response from Anglesey County Council (ABWR-15) supported, *"the conclusions on the process used to identify BAT to minimise waste and discharges".*

A response to our question on (BAT) from an individual (ABWR-28) observed that, "Far too many compromises. In most cases, truly safe technology and/or systems are not yet available, (if they ever will be) or would render the project even more uneconomic." We observe that practicable technology cannot totally preclude radioactive waste arisings and associated discharges. In terms of environmental protection, we are content that the UK ABWR design for GDA will ensure that public dose constraints are met, that BAT is being used to minimise both waste arisings and any associated environmental impacts in normal operations. We have worked closely with ONR to ensure that the design meets appropriate standards in terms of safety and environment.

We also received a comment relating to BAT from Oldbury-on-Severn Parish Council (ABWR-09) asking *"Is Hitachi-GE or any public organisation known to be actively researching or funding development work for abatement of both tritium and carbon-14?"* We have assessed this and conclude that ongoing research in these areas appears to be limited. We consider tritium and carbon-14 abatement further in Argument 2a.

Oldbury-on-Severn Parish Council (ABWR-09) also asked whether *"all relevant data for similar BWR's in Japan has been obtained and has every effort been made to test the assumptions of fuel pin failure for the UK ABWR?"* We discuss this in Argument 1a and acknowledge that fuel technology will progressively improve. We have raised Assessment Finding 3 to ensure further consideration of any design improvements that would minimise fuel failure during operation.

5. Conclusion

We conclude that Hitachi-GE has followed an appropriate process for identifying BAT in the design of the UK ABWR. We also conclude that BAT has been demonstrated in the design of the UK ABWR to a level that is in line with the expectations of GDA. We have identified a number of Assessment Findings in relation to this assessment area. These are as follows:

Assessment Finding 3: A future operator shall demonstrate that the UKABWR will be operated in a manner that represents best available techniques, addressing in particular:

- **fuel selection**
- **fuel and core management**
- **avoidance of control rod failure in power suppression situations**
- **consideration of all normal operational modes and stages of the reactor's lifecycle**
- **control of water chemistry**
- **selection of demineraliser resins for liquid waste management systems**

Assessment Finding 4: A future operator shall review the practicability of techniques for abatement of carbon-14 prior to operation.

Assessment Finding 5: A future operator shall assess the partitioning of carbon-14 between gaseous, aqueous and solid waste streams, during initial operations.

Assessment Finding 6: A future operator shall address the 15 forward actions as identified by Hitachi-GE in the 'Demonstration of best available techniques' submission - GA91-9901-0023-00001 Rev. G (August 2017).

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List of abbreviations

Abbreviation	Details
ABWR	Advanced Boiling Water Reactor
ALARP	As low as reasonably practicable
BAT	Best available techniques
BWR	Boiling water reactor
CAD	Controlled area drain
CP	Corrosion product
CST	Condensate storage tank
CUW	Reactor water clean-up system
DF	Decontamination factor
EPA 90	Environmental Protection Act 1990
EPR 16	Environmental Permitting (England and Wales) Regulations 2016
EPRI	Electrical Power Research Institute – an independent USA organisation
FAPs	Fission and activation products
FPs	Fission products
FPC	Fuel pool cooling and clean-up system
GDA	Generic design assessment
GDF	Geological disposal facility
HCW	High chemical impurity waste
HEPA	High efficiency particulate air
HLW	High level waste
HVAC	Heating, ventilation and air conditioning system

Abbreviation	Details
IAEA	International Atomic Energy Agency
ILW	Intermediate level waste
iSoDA	Interim statement of design acceptability
JPO	Joint Programme Office
LCW	Low chemical impurity waste
LD	Laundry drain
LLW	Low level waste
LLWR	Low level waste repository
MVP	Mechanical vacuum pump
NDA	Nuclear Decommissioning Authority
NMCA	Noble metal chemical addition
NPS EN-6	National policy statement for nuclear power generation
NRW	Natural Resources Wales
OG	Off-gas system
ONR	Office for Nuclear Regulation
P&ID	Process and information document
PCI	Pellet-cladding interaction
PCER	Pre-construction environmental report
PCSR	Pre-construction safety report
PPC	Pollution prevention and control
POCO	Post operational clean out
PWR	Pressurised water reactor

Abbreviation	Details
REPs	Radioactive substances environmental principles
RI	Regulatory Issue
RIP	Reactor internal pumps
RO	Regulatory Observation
RQ	Regulatory Query
RWM	Radioactive Waste Management Ltd
SF	Spent fuel
SFAIRP	So far as is reasonably practicable
SoDA	Statement of design acceptability
TGS	Turbine gland steam
VLLW	Very low level waste
WAC	Waste acceptance criteria

Appendix 1: Summary table of Regulatory Queries, Observations and Issues relating to the demonstration of BAT

The following table summarises the Regulatory Queries (RQs), Observations (ROs) and Issues (RIs) that are most relevant to the application of BAT for the UK ABWR. Many of these have been raised jointly with ONR. In the case of some ONR ROs**,** the relevance to generic environmental permitting, and, therefore, Environment Agency interests, are recognised as a 'related technical area'**.** Revision G of the 'Demonstration of BAT' document (Hitachi-GE, 2017a) and supporting documents will consider the result of addressing these RQ, RO and RI.

Note that RO and RI are published on the ONR website, along with resolution plans. RQ information is not routinely published, but all RQs and subsequent responses are available to the regulators through the Joint Programme Office (JPO). Progress against each has been discussed at technical level meetings with the requesting party.

Table A1. Summary of RQs, ROs and RIs relating to BAT

RQ/RO/RI	Date issued	Title and summary
Regulatory Queries		
RQ-ABWR-0193	22-Jul-14	Charcoal adsorber efficiency for 60 years of operation Hitachi-GE was asked to provide further information on: • the efficiency of the OG charcoal adsorbers over the operational lifetime of the plant
RQ-ABWR-0247	03-Oct-14	Temperature within fuel pool Hitachi-GE was asked to provide further information on: • the expected actual pool temperature • the relationship between pool temperature and the amount of gaseous radioactive waste produced • what factors have been considered in determining the proposed limit of 52ºC
RQ-ABWR-0246	03-Oct-14	Sizing of tanks, vessels and liquid containment systems Hitachi-GE was asked to provide further information on: • what is meant by 'free board margin' and how the factors of 1.2 (process margin) and 1.1 (free board margin) have been derived
RQ-ABWR-0245	03-Oct-14	Potential for failure/rupture of boron carbide control rods Hitachi-GE was asked to provide further information on:

RQ/RO/RI	Date issued	Title and summary
		• detail of any OPEX relating to failures of boron carbide control rods, with particular reference to implications for waste arisings • the limits and conditions of operation that are appropriate to minimise release of activity from the control rods
RQ-ABWR-0244	03-Oct-14	Off-gas waste treatment system (OG) BAT considerations Hitachi-GE was asked to: • show how any recent advances in gaseous abatement technology have been factored into the arguments provided in the 'Demonstration of BAT' submission • substantiate the argument for lack of tritium abatement • show results from the document 'The Hitachi-GE Study' in relation to tritium and carbon-14 abatement • clarify the operational regime for the OG in terms of demands for abatement during operational transients (start-up, shut-down, reactor trips) • show how 'Other measures (which) can be used to minimise carbon-14 and tritium production at source' could contribute to the BAT case for tritium and carbon-14 • clarify why selecting the 'in-process monitoring' for the OG is no longer part of the BAT case (Rev. D of 'Demonstration of BAT' - GA91-9901-0023-00001)
RQ-ABWR-0243	03-Oct-14	HVAC radionuclide concentrations Hitachi-GE was asked to provide further information on: • the extent of operational data on radionuclide concentrations in HVAC routes • how estimates of gaseous waste arisings have been derived • clarification on why evidence relating to in-process monitoring provided in an earlier version of the submission has been changed in Rev. D
RQ-ABWR-0242	03-Oct-14	HVAC optimisation aspects Hitachi-GE was asked to provide further information on: • the aspects of the HVAC design that are to be considered outside GDA and those that are for later development • the measures that will be used to trigger a filter change • how the modifications to the HVAC design represent an optimised result
RQ-ABWR-0241	03-Oct-14	Environmental impacts of gadolinia Hitachi-GE was asked to provide further information on: • the likely inventory of gadolina and the potential impacts following disposal • how the benefits from using gadolina as a burnable poison outweigh any disbenefits

RQ/RO/RI	Date issued	Title and summary
RQ-ABWR-0240	03-Oct-14	Delay beds (Argument 2b) Hitachi-GE was asked to provide further information on: • the delay calculations • the source of the initial radioactivity concentrations used in the delay calculations and why they are considered to be representative • how the hold-up times for xenon and krypton relate to charcoal column numbers and loadings • alternative/additional technologies considered for the abatement of iodine species • the extent to which reactor chemistry decisions may alter the efficacy of iodine abatement • evidence that the delay bed performance can be maintained over the operational lifetime of the plant
RQ-ABWR-0237	03-Oct-14	Clarifications on aspects of storage timescales for solid and liquid wastes Hitachi-GE was asked to provide further information on: • the basis for the 2-year storage capacity (buffer) for LLW • which waste streams would benefit from decay storage • detail of the radionuclide components of the inventories and compare with the current (Oct 14) LLWR WAC
RQ-ABWR-0236	03-Oct-14	BAT aspects of provision of waste management facilities Hitachi-GE was asked to provide further information on: • the ‘UK Codes and Standards’ that have informed the design • justification to support arguments regarding BAT being achieved on the basis that the arrangements allow flexibility for the future • how the timing of batch waste conditioning campaigns will be determined • radioactive waste packaging for storage • the likely schedule of waste package disposals following storage
RQ-ABWR-0235	03-Oct-14	BAT aspects of solidified HCW Hitachi-GE was asked to provide further information on: • the source, and anticipated quantities, of activated carbon that will arise as concentrated liquid waste • when further assessment of BAT before the generation of resin wastes will be carried out
RQ-ABWR-0234	03-Oct-14	BAT aspects of selecting methods to minimise solid waste generation (Argument 3b) Hitachi-GE was asked to provide further information on: • how BAT will be applied to the management and disposal of waste in the future

RQ/RO/RI	Date issued	Title and summary
RQ-ABWR-0232	03-Oct-14	BAT aspects of Argument 3a. Hitachi-GE was asked to provide further information on: • any features of the UK ABWR design that may not be considered optimal in terms of minimising waste • quantifying the advantages for using reactor internal pumps • quantifying the implications of the PCV design optimisation in terms of comparative waste arisings in addition to comparative volumes of the RAC • the proposed hydrogen injection and noble metal chemical addition (NMCA) in relation to the reactor chemistry decision basis • further substantiation that measures to reduce SCC have been effective in maintenance and reducing the replacement of reactor component parts • the advantages, in terms of waste arisings, of a combination of equipment drain and floor drain • quantifying the implications of the design changes in terms of waste volumes
RQ-ABWR-0231	03-Oct-14	BAT aspects of application of volume reduction processes for solid waste (Argument 3c) Hitachi-GE was asked to provide further information on: • when decisions on treatment of control rods will be made • further evidence on compliance with LLWR waste acceptance criteria • the reasons why resins and activated carbon are described as liquid waste • waste conditioning practices • clarifying how the concept design and corresponding safety case link to the ‘Demonstration of BAT’ submission
RQ-ABWR-0230	03-Oct-14	Waste routes (LAW) (Argument 4c) Hitachi-GE was asked to provide further information on: • waste enquiry forms
RQ-ABWR-0229	03-Oct-14	Waste BAT studies (Argument 4e) Hitachi-GE was asked to provide further information on: • the request for a copy of ‘Hitachi-GE’s waste treatment assessment’ • the specific metallic waste streams that will be recycled • the strategy for the management of combustible waste
RQ-ABWR-0227	03-Oct-14	Argument 1g: Specification of materials Hitachi-GE was asked to provide further information on: • the scheduling of the relevant ‘design review process’ • the rationale behind why the 0.05% specification represents the minimal achievable cobalt content

RQ/RO/RI	Date issued	Title and summary
RQ-ABWR-0225	03-Oct-14	Gaseous discharge system (Argument 5a) Hitachi-GE was asked to provide further information on: • the timing of gaseous discharges in relation to their impact • the reasons why stack height determination is not possible at the GDA stage • the consistency of data provided to support dose estimates resulting from gaseous discharges
RQ-ABWR-0224	03-Oct-14	Disposal route selection (Argument 4b) Hitachi-GE was asked to provide further information on: • the request for the latest version of the 'Hitachi-GE waste treatment BAT assessment' • plans for conditioning waste following decay storage • uncertainties in relation to options for LLW conditioning routes • The BAT assessment for ILW conditioning routes • waste conditioning practices used at existing ABWRs worldwide and their applicability to the UK ABWR
RQ-ABWR-0223	03-Oct-14	Disposability of HAW (Argument 4d). Hitachi-GE was asked to provide further information on: • the influence of reactor chemistry and materials selection decisions on HAW inventory • the description of spent fuel options in the BAT document
RQ-ABWR-0222	03-Oct-14	Use of hafnium control rods Hitachi-GE was asked to provide further information on: • the lower waste arisings from the use of hafnium control rods • optimised ratio of hafnium control rods to boron carbide control rods in terms of waste arisings through all routes
RQ-ABWR-0359	16-Jan-15	Update of GEP following resolution of RO-ABWR036 Hitachi-GE was asked to provide further information on: • the request that the generic environmental permit submission is updated to reflect the resolution of RO-ABWR-0036
RQ-ABWR-0364	28-Jan-15	Application of BAT ALARP during decommissioning Hitachi-GE was asked to provide further information on: • the specific decontamination techniques that are considered BAT and ALARP during decommissioning • post operational clean out (POCO) strategy in relation to demonstration of BAT during decommissioning • the relevance of fault studies assessment to 'normal operations
RQ-ABWR-0365	28-Jan-15	BAT waste management hierarchy

RQ/RO/RI	Date issued	Title and summary
		Hitachi-GE was asked to provide further information on: • applying the waste hierarchy to the contamination, separation and segregation techniques for the UK ABWR waste streams • benefits of applying the techniques for minimising radioactive waste
RQ-ABWR-0366	28-Jan-15	Replacement frequency of plant items and associated waste generation Hitachi-GE was asked to provide further information on: • the plant items that have a lifetime of less than 60 years that are expected to arise as waste • the assumed replacement frequency for the plant items identified above
RQ-ABWR-0367	28-Jan-15	Spectral shift operational regime: uranium saving Hitachi-GE was asked to provide further information on: • the amount of spent fuel that can be avoided by the applying a 'spectral shift operational system' • the differences in the radionuclide inventory from the applying spectral shift operations • evidence that spectral shift operations represent an optimised operational system
RQ-ABWR-0424	27-Feb-15	Iodine from the HVAC Hitachi-GE was asked to provide further information on: • abatement of iodine from the HVAC system
RQ-ABWR-0469	25-Mar-15	Design basis for boron carbide control rod lifetimes Hitachi-GE was asked to provide further information on: • control rod lifetimes • control rod management system • further explanation of whether an average 25% boron-10 depletion limit represents an optimised system • implications of control rod containment failure/leakage in terms of carbon-14 discharges and waste arisings
RQ-ABWR-0522	15-May-15	GEP considerations and resolution of RO-ABWR-0054 Hitachi-GE was asked to provide further information on: • how BAT will be applied to the resolution of RO-ABWR-0054 • the impact of the resolution of RO-ABWR-0054 on the generic environmental permit (GEP) submission
RQ-ABWR-0541	02-Jun-15	Prevention of contamination from laydown Hitachi-GE was asked to provide further information on: • procedures for decontaminating equipment and the prevention/minimisation of secondary waste generation

RQ/RO/RI	Date issued	Title and summary
		and the spread of radioactive contamination during laydown operations
RQ-ABWR-0564	15-Jul-15	BAT route map for solid waste Hitachi-GE was asked to provide further information on: • including a BAT route map in the 'Demonstration of BAT' submission • scope for a BAT route map and timescale for inclusion in the 'Demonstration of BAT' submission
RQ-ABWR-0565	20-Jul-15	Control rod management during power suppression Hitachi-GE was asked to provide further information on: • deploying boron carbide control rods for power suppression and the additional measures that may be required • boron carbide control rod failure during power suppression of failed fuel, is this an expected event in normal operation
RQ-ABWR-0825	24-Mar-16	Optimisation of future commitments Hitachi-GE was asked to provide further information on: • how the design of the pools (for size reduction of reactor internal items) will enable and not preclude future management options for size reduction of the RPV • how early transfer of the final batch of spent fuel will be facilitated
RQ-ABWR-0833	01-Apr-16	Optimisation in decommissioning Hitachi-GE was asked to provide further information on: • how the design and techniques have been challenged to ensure optimisation of decommissioning • identifying relevant good practice for decommissioning
RQ-ABWR-0840	08-APR-16	Filtration of TGS and MVP discharges and effect on monitoring Hitachi-GE was asked to provide further information on: • the claim that particles from the TGS and MPV will have negligibly low activity • the effects of the particles on the waste stream and the monitoring system, considering whether larger particles can be removed from the waste streams
RQ-ABWR-0226	01-Oct-14	BAT aspects of recycling and clean-up of aqueous liquids Hitachi-GE was asked to provide further information on: • the operational circumstances that would result in treated waste falling outside required parameters • the option selection process for filters and demineralisers • the scope of flexibility offered to the operator through selecting demineraliser media and potential impact on solids waste inventory
RQ-ABWR-0233	03-Oct-14	BAT aspects of evaporation of high conductivity liquids

RQ/RO/RI	Date issued	Title and summary
		Hitachi-GE was asked to provide further information on: • discharge frequency from the HCW system • decision basis for demineraliser media replacement
RQ-ABWR-0238	03-Oct-14	BAT aspects of configuration of liquid management systems Hitachi-GE was asked to provide further information on: • options available if waste falls outside the reuse criteria and discharge criteria • consideration of heavy metals in the liquid waste inventories • design review schedule in relation to the GEP GDA • the reviews on which conclusions regarding tritium and carbon-14 abatement are based • the approach in water balance management to minimise discharges • the provision for in-process monitoring of liquid waste
RQ-ABWR-0239	03-Oct-14	Decontamination factors (DFs) for HCW system demineralisers Hitachi-GE was asked to provide further information on: • the likely DFs for the demineralisers • supporting evidence for liquid waste volumes and activities • the monitoring arrangements for HCW • how the HCW volume estimates inform the activity estimates
RQ-ABWR-0355	07-Jan-15	Discharges and waste arisings: comparison with other power stations Hitachi-GE was asked to provide further information on: • how the discharges and waste arising compare with those of comparable stations worldwide
RQ-ABWR-0363	28-Jan-15	Reagent addition (BAT aspects) Hitachi-GE was asked to provide further information on: • the reference supporting the selected oxygen concentration in primary circuit water • the oxygen monitoring regime in primary circuit water • the water chemistry system basis for the data presented • the iron concentration control options
RQ-ABWR-0369	28-Jan-15	Discharges - frequency, magnitude and temporal variability Hitachi-GE was asked to provide further information on: • how discharges vary with operational phase and power fluctuations • management of discharges during pool maintenance to minimise discharges
RQ-ABWR-0370	28-Jan-15	Operator guidance relating to BAT

RQ/RO/RI	Date issued	Title and summary
		Hitachi-GE was asked to provide further information on: • what guidance to operators will be provided to ensure operation is BAT
RQ-ABWR-0593	25-Aug-15	Draining of the reactor pressure vessel and liquid discharges Hitachi-GE was asked to provide further information on: • whether the reactor is drained via the bottom drain line during normal operations and if there are any contributions to liquid discharges
RQ-ABWR-0668	03-Nov-15	Justification for revised design of the HCW LWMS Hitachi-GE was asked to provide further information on: • the option selection for the HCW evaporator and other options considered
RQ-ABWR-0722	15-Jan-16	Related to the nuclide selection document • Hitachi-GE was asked to provide clarity regarding the nuclide selection method.
Regulatory Observations		
RO-ABWR-0006	28-Apr-14	Source terms Hitachi-GE was asked to provide information on the development, definition and justification of the source term for operational states that is appropriate to use in all technical areas. Hitachi-GE should demonstrate the application of BAT and that risks have been reduced so far as is reasonable practical (SFAIRP).
RO-ABWR-0017	16-Sept-14	Nuclear ventilation codes and standards ONR has requested that Hitachi-GE demonstrates consistency with relevant UK good practice, as essentially defined in the following: • NVP/DG001 ‘Nuclear industry guidance an aid to the design of ventilation of radioactive areas’ • ISO 17873:2004 ‘Nuclear facilities - Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors’ • ISO 26802:2010 ‘Nuclear facilities - Criteria for the design and operation of containment and ventilation systems for nuclear reactors’
RO-ABWR-0035	16-Dec-14	Robust justification for the materials selected for UK ABWR Hitachi-GE was asked to: make materials selection and safety justifications for all UK ABWR structure, system or components (SSCs) that are proportionate to the significance of identified SSCs in maintaining nuclear safety; in doing so, consider the nature, severity and likelihood of materials degradation in UK ABWR; make a robust demonstration, showing that risks relating to materials degradation for UK ABWR are reduced so far as is reasonably practicable (SFAIRP).

RQ/RO/RI	Date issued	Title and summary
RO-ABWR-0036	16-Jan-15	Demonstration that the approach taken to radioactive waste management reduces risks SFAIRP Hitachi-GE was asked to take due account of the principles and guidance set out in the RO when preparing its ALARP demonstration for the radioactive waste safety case and approach taken to managing liquid, solid and gaseous radioactive waste for UK ABWR. A series of specific aspects were outlined, including proper balancing of all risks and being aware of all relevant legislation, including the need to apply BAT to discharges and disposals of radioactive waste.
RO-ABWR-0054	15-May-15	Chemical/process engineering design approach ONR highlighted what were considered shortfalls regarding the chemical/process engineering design approach and the ALARP demonstration in support of the UK ABWR. A series of actions to address any shortfalls were placed, including demonstration of a chemical/process engineering design approach as input to demonstration of risks to SFAIRP.
RO-ABWR-0071	6-June-16	Turbine gland steam system: discharges and optimisation The turbine gland steam system was found not to be fully considered in the generic environmental permit (GEP) submission (Rev E) and pre-construction safety report (PCSR). We and ONR, therefore, requested appropriate information on BAT and ALARP aspects, radioactive waste discharges (and any associated disposals) and radiological impacts arising from the operation of the TGS system. Particularly relevant is an action to demonstrate that the design and operation of the TGS system is consistent with the application of BAT.
RO-ABWR-0073	15-August-16	Robust demonstration that the design of the UK ABWR off-gas system reduces risks SFAIRP This Regulatory Observation (RO) identified regulatory expectations with respect to Hitachi-GE producing a robust demonstration that the design of the UK ABWR off-gas system reduces risks so far as is reasonably practicable (SFAIRP). ONR's multi-disciplinary assessment of the off-gas system revealed a number of gaps between Hitachi-GE's submissions and regulatory expectations. This RO was raised to ensure regulatory expectations are clearly understood. The regulators (ONR and the Environment Agency) required Hitachi-GE to provide a robust demonstration that the design of the UK ABWR off-gas system has been optimised and is appropriately balanced, when taking account of the legislative requirements to reduce risks to ALARP and minimise discharges of radioactive waste to the environment, by applying BAT.
Regulatory Issues		
RI-ABWR-0001	02-Jun-15	Definition and justification for the radioactive source terms in the UK ABWR during normal operations

RQ/RO/RI	Date issued	Title and summary
		Hitachi-GE was asked to provide further information on the definition and justification of the source term for operational states that is appropriate to use in all technical areas.

Appendix 2: Gaseous discharges - approaches and techniques to minimise radionuclide quantities and impacts

Summary of the major radionuclides in gaseous discharges, approaches and techniques to minimise quantities and impacts. Reproduced from Table 6.1 in the ‘Demonstration of BAT’ submission.

Table A2-1. Gaseous discharges - approaches and techniques to minimise radionuclide quantities and impacts

Radionuclide	Sources	Approach and techniques to minimise quantities and impacts
Argon-41	Activation of entrained atmospheric argon-40 in coolant.	Minimisation of leaks (Argument 1j) and the air leakage into the main condenser. OG charcoal delay beds (Argument 2a and 2b). Discharge at height via main stack (Argument 5a).
Noble gases	FPs from fuel and structural uranium. Radioactive noble gases are formed by fission. They are usually confined within the fuel but in the event of fuel leaks, they can pass into the coolant via defects in the fuel cladding. Their presence in the coolant is also due to the occurrence of traces of uranium (‘tramp’ uranium) on the surface of fuel assemblies following the manufacturing process.	Minimise fuel cladding failures (grid-to-rod fretting, corrosion and crud, debris, PCI and manufacturing QA) (Argument 1a). High standards of fuel design and fabrication (Argument 1a). Minimise ‘tramp uranium’ (Argument 1a). Minimisation of crud formation and optimal water chemistry (Argument 1f). An efficient anti-debris device is provided for fuel assemblies (Argument 1a). The fuel performance - minimising the number of fuel assemblies used minimises the probability for cladding leakage of FPs into the coolant (Argument 1c). Identifying and isolating fuel leaks (Argument 1d). Minimise leaks (Argument 1j). OG and charcoal delay beds (Argument 2a and 2b). Discharge at height via main stack (Argument 5a).

Radionuclide	Sources	Approach and techniques to minimise quantities and impacts
Iodine-131	FPs from fuel, structural uranium. Iodine isotopes are formed in the fuel by fission and can escape into the reactor coolant water via fuel defects. Also, like other FPs, small quantities are produced from uranium contamination on fuel surface (‘tramp’ uranium) within the reactor, which can also be found in the coolant.	Migration into reactor water (direct or through pin fracture) → Partial migration into steam → Separation at condenser → Discharge via stack via the OG (negligible). Discharge of volatile iodine in aqueous stream via HVAC system. Minimise fuel cladding failures (grid-to-rod fretting, corrosion and crud, debris, PCI, and manufacturing defects) (Argument 1a). High standards of fuel design and fabrication (Argument 1a). Minimise ‘tramp uranium’ (Argument 1a). Minimisation of crud formation and optimal water chemistry (Argument 1f). An efficient anti-debris device is implemented for fuel assemblies (Argument 1a). The fuel performance - minimising the number of fuel assemblies used minimises the probability for cladding leakage of FPs into the coolant (Argument 1c). Identifying and isolating fuel leaks (Argument 1d). Minimise leaks (Argument 1j).
Strontium-90 Strontium-89	FPs from fuel, structural uranium. Isotopes of strontium are formed as a result of fission. They are usually confined in the fuel but, in the event of fuel leaks, they can pass into the coolant via defects in the fuel cladding. Their presence in the coolant is also due to the occurrence of traces of uranium (‘tramp’ uranium) that can never be completely removed on new fuel assemblies following the manufacturing process.	Minimise fuel cladding failures (grid-to-rod fretting, corrosion and crud, debris, PCI, and manufacturing defects) (Argument 1a). High standards of fuel design and fabrication (Argument 1a). Minimise ‘tramp uranium’ (Argument 1a). Minimisation crud formation and optimal water chemistry (Argument 1f). An efficient anti-debris device is implemented for fuel assemblies (Argument 1a). The fuel performance - minimising the number of fuel assemblies used minimises the probability for cladding leakage of FPs into the coolant (Argument 1c). Identifying and isolating fuel leaks (Argument 1d). Minimise leaks (Argument 1j). Filters to remove particulate material (Argument 2d).

Radionuclide	Sources	Approach and techniques to minimise quantities and impacts
		Discharge at height via main stack (Argument 5a).
Caesium-137	FPs from fuel, structural uranium.	As for strontium-89 and strontium-90.
Cobalt-60	Cobalt-59 (n,g), cobalt-60. Activation of reactor components. Activation of insoluble and soluble metal crud and particulate in reactor water.	Minimisation of crud formation and optimal water chemistry (Argument 1f). Specification of low cobalt content materials (Argument 1g). Minimise leaks (Argument 1j). Filters to remove particulate material (including filters on the HVAC) (Argument 2d). Discharge at height via main stack (Argument 5a).
Tritium	Ternary fission in fuel. Boron-10 (n,2a), tritium from boron in control rods. Hydrogen-2 (n,g), tritium from hydrogen-2 in reactor water.	No boron usage in the water chemistry (Argument 1b). Use of hafnium control rods (Argument 1b). Use of gadolinium as a burnable poison rather than boron (Argument 1b). Minimise fuel cladding failures (grid-to-rod fretting, corrosion and crud, debris, PCI, and manufacturing defects) (Argument 1a). High standards of fuel design and fabrication (Argument 1a). Minimisation of crud formation and optimal water chemistry (Argument 1f). An efficient anti-debris device is implemented for fuel assemblies (Argument 1a). The fuel performance - minimising the number of fuel assemblies used minimises the probability for cladding leakage of FPs into the coolant (Argument 1c). Identifying and isolating fuel leaks (Argument 1d). Minimise leaks (Argument 1j). Gaseous tritium present within the OG is removed by the OG recombiner and OG condenser. The OG recombiner recombines hydrogen and oxygen and the OG condenser cools and condenses the hydrogen depleted off-gas to separate any moisture and return it to the main condenser.

Radionuclide	Sources	Approach and techniques to minimise quantities and impacts
		Following treatment by these 2 components of the OG the hydrogen concentration is minimised in the OG. As tritium is a hydrogen compound, the performance of the OG recombiner and OG condenser, therefore, also removes tritium from the off-gas. The hydrogen and, therefore, any tritium is converted to water and is returned to the CST where it is reused within the plant (Argument 2a). Discharge at height via main stack (Argument 5a).
Carbon-14	Neutron activation of nitrogen-14 and oxygen-17 results in carbon-14 both from fuel and reactor water. Another minor mechanism contributing to carbon-14 is the reaction carbon-13 (n, γ) -> carbon-14, which occurs due to the presence of dissolved carbon in the coolant.	None. The main source of carbon-14 is the thermal neutron reaction with oxygen-17 in the reactor coolant water (H_2O). Therefore, there are no measures for reducing carbon-14.

Appendix 3: Aqueous discharges - approaches and techniques to minimise radionuclide quantities and impacts

Summary of the major radionuclides in aqueous discharges, approaches and techniques to minimise quantities and impacts. Reproduced from Table 6.2 in the ‘Demonstration of BAT’ submission (Hitachi-GE, 2017a).

Table A3-1 Gaseous discharges - approaches and techniques to minimise radionuclide quantities and impacts

Radionuclide	Sources and amounts	Approach and techniques to minimise quantities and impacts
Strontium-90, strontium-89	FPs from fuel, structural uranium. Isotopes of strontium are formed as a result of fission. They are usually confined in the fuel but, in the event of fuel leaks, they can pass into the coolant via defects in the fuel cladding. Their presence in the coolant is also due to the occurrence of traces of uranium (‘tramp’ uranium) that can never be completely removed on new fuel assemblies following the manufacturing process.	Minimise fuel cladding failures (grid-to-rod fretting, corrosion and crud, debris, PCI, and manufacturing defects) (Argument 1a). High standards of fuel design and fabrication (Argument 1a). Minimise ‘tramp uranium’ (Argument 1a). Minimisation of crud formation and optimal water chemistry (Argument 1f). An efficient anti-debris device is implemented for fuel assemblies (Argument 1a). The fuel performance - minimising the number of fuel assemblies used minimises the probability for cladding leakage of FPs into the coolant (Argument 1c). Identifying and isolating fuel leaks (Argument 1d). Minimise leaks (Argument 1j). CUW system (Argument 1h). LD pre-filter LD activated carbon adsorption tower activated charcoal LD filter HCW evaporator HCW demineraliser (Argument 2e, Argument 2g and 2h).

Radionuclide	Sources and amounts	Approach and techniques to minimise quantities and impacts
Iodine-131	FPs from fuel, structural uranium. Iodine isotopes are formed in the fuel by fission and can escape into the reactor coolant water via fuel defects. Also, like other FPs, small quantities are produced from uranium contamination on fuel surface (‘tramp’ uranium) within the reactor, which can also be found in the coolant.	As for strontium-89 and strontium-90.
Caesium-137	FPs from fuel, structural uranium.	As for strontium-89 and strontium-90.
Cobalt-60	Cobalt-59 (n,g), cobalt-60. Activation of reactor components. Activation of insoluble and soluble metal crud and particulate in reactor water.	Minimisation of crud formation and optimal water chemistry (Argument 1f). Specification of low cobalt content materials (Argument 1g). Minimise leaks (Argument 1j). CUW system (Argument 1h) LD pre-filter LD filter LD activated carbon adsorption tower HCW evaporator HCW demineraliser (Arguments 2e, 2g and 2h).
Tritium	Ternary fission in fuel Boron-10 (n,2a), tritium from boron in control rods. Hydrogen-2 (n,g), tritium from hydrogen-2 in reactor water.	No boron usage in the water chemistry (Argument 1b). Use of hafnium control rods (Argument 1b). Use of gadolinium as a burnable poison rather than boron (Argument 1b). Minimise fuel cladding failures (grid-to-rod fretting, corrosion and crud, debris, PCI and manufacturing defects) (Argument 1a). High standards of fuel design and fabrication (Argument 1a). Minimisation of crud formation and optimal water chemistry (Argument 1f). An efficient anti-debris device is implemented for fuel assemblies (Argument 1a).

Radionuclide	Sources and amounts	Approach and techniques to minimise quantities and impacts
		The fuel performance - minimising the number of fuel elements used minimises the probability for cladding leakage of FPs into the coolant (Argument 1c). Identifying and isolating fuel leaks (Argument 1d). Minimise leaks (Argument 1j). No abatement (Argument 2e)

Appendix 4: Summary table of solid waste arisings

Summary of the techniques to eliminate, reduce and minimise impacts from solid radioactive waste. Reproduced from Table 6.3 in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a). Note that 'Argument' and 'Evidence' refer to the titles of the relevant sections in the 'Demonstration of BAT' submission (Hitachi-GE, 2017a) where more detail is provided.

Table A4-1 Summary of solid waste arisings

Waste category	Technique to eliminate or reduce the generation at source	Technique to minimise the impacts of disposal on the environment (Claims 2-5)	Waste management route
VLLW	Prevent or reduce the generation of FPs, activation products and CPs that subsequently lead to the generation of combustible and non-combustible VLLW during maintenance activities (Claim 1: Eliminate or reduce the generation of radioactive waste).	Segregating waste to ensure the optimised treatment, storage and disposal option is selected (Evidence: Segregation of waste). Minimising the number of operator visits into radiation controlled areas (RCAs) and reducing the volume of consumables that are taken into RCAs reduces the potential to generate maintenance waste (Evidence: Locate offices outside of controlled areas). Minimising the amount of maintenance equipment and tools that are taken into RCA (Evidence: Storage facilities for tools and other maintenance equipment). Providing facilities to characterise, sort, treat and store waste before consignment to an appropriately permitted waste management service supplier (Argument 4a: Provision of waste management facilities). Effective preventative maintenance schedules; predict, prepare and avoid (where practicable) leaks and spillages and associated clean-up	Incineration (Evidence: Incineration and waste treatment techniques and disposal routes).

Waste category	Technique to eliminate or reduce the generation at source	Technique to minimise the impacts of disposal on the environment (Claims 2-5)	Waste management route
		activities (Evidence: Maintenance philosophy). Volume reduction treatment processes (Evidence: Incineration and solid waste compaction). Decontamination where practicable to reduce waste classification and/or aid onward treatment and disposal.	
Dry-Solid LLW	Prevent or reduce the generation of FPs, activation products and CPs that could then be filtered by the HVAC system leading to the contamination of HVAC filters (Claim 1: Eliminate or reduce the generation of radioactive waste).	HEPA filters will be changed, where practicable, based on performance determined using continuous measurement of differential pressures or as a result of manufacturer's guidance (Argument 2d: Filtration of airborne particulate matter and Evidence: Maintenance philosophy). HVAC filters will be segregated from other waste streams to ensure appropriate maintenance (Evidence: Segregation of waste). Volume reduction treatment processes (Evidence: Incineration and Evidence: Solid waste compaction).	Incineration (Evidence: Waste treatment techniques and disposal routes and BAT options assessment report).
	Prevent or reduce the generation of FPs, activation products and CPs that subsequently lead to the generation of combustible LLW during maintenance activities (Claim 1: Eliminate or reduce the generation of radioactive waste).	See VLLW. 2 to 3 years decay storage of bead activated carbon from LD system (Argument 2i: Radioactive decay of solid and liquid wastes).	Incineration (Evidence: Waste treatment techniques and disposal routes and BAT options assessment report).

Waste category	Technique to eliminate or reduce the generation at source	Technique to minimise the impacts of disposal on the environment (Claims 2-5)	Waste management route
	Prevent or reduce the generation of FPs, activation products and CPs that subsequently lead to the generation of metal LLW during maintenance activities (Claim 1: Eliminate or reduce the generation of radioactive waste)	See VLLW.	Off-site recycling (Evidence: Waste treatment techniques and disposal routes and BAT options assessment report)
	Prevent or reduce the generation of FPs, activation products and CPs that subsequently lead to the generation of non-combustible LLW during maintenance activities (Claim 1: Eliminate or reduce the generation of radioactive waste).	See VLLW.	Disposal at an appropriately permitted site (Evidence: Waste treatment techniques and disposal routes). For example LLWR (BAT options assessment report).
Wet-solid LLW	Prevent or reduce the generation of FPs, activation products and CPs that subsequently enter liquid systems and require treatment leading to the generation of resin, sludge and granular activated carbon waste (Claim 1: Eliminate or reduce the generation of radioactive waste). Before start-up, removing crud prior to activation reduces the radioactivity deposited on the demineraliser resins (Evidence: Water Conditioning).	Segregated between source systems (Argument 2e: Configuration of liquid management systems). Segregating waste to ensure the optimised treatment, storage and disposal option is selected (Evidence: Segregation of waste). Cementation, in batch campaigns, prior to disposal (Evidence: Waste treatment facilities). Replacement of pre-coated filters with HFF or pleated filters (Evidence: Replacement of pre-coated filters). During an outage the CD is isolated and is stored in demineralised water to prevent degradation of the resin (Evidence: Water conditioning). Selection of resin media that can be suitably disposed (Evidence: Demineraliser media).	Disposal at an appropriately permitted site (Evidence: Waste treatment techniques and disposal routes). For example, LLWR (BAT options assessment report).

Waste category	Technique to eliminate or reduce the generation at source	Technique to minimise the impacts of disposal on the environment (Claims 2-5)	Waste management route
		Allowing solid and liquid radioactive waste to undergo radioactive decay before disposing of it to the environment or another premises will reduce the amount of radioactivity that is disposed of in the waste (Argument 2j: Radioactive decay of solid and liquid wastes).	

Waste category	Technique to eliminate or reduce the generation at source	Technique to minimise the impacts of disposal on the environment (Claims 2-5)	Waste management route
Dry-solid ILW	The design of the UK ABWR has evolved to reduce the quantities of solid radioactive waste that will be generated during its life cycle (Design to minimise the volumes of operational and decommissioning waste arisings). Use of hafnium control rods that have a longer operational life and, therefore, require less frequent disposal (Argument 1b: Reactivity control). Implementation of commissioning, start-up, shutdown and outage processes to prevent the deposition of radioactivity on reactor components that will become waste during maintenance and decommissioning (Argument 1e: Commissioning, start-up, shutdown and outage procedures). Selecting materials and water chemistry to reduce the activation of metals (Argument 1f: Water chemistry and Argument 1g: Specification of materials).	Segregating waste at source and separation (LLW: ILW) after decay storage (Evidence: Segregation of waste and Evidence: Segregation and sorting facilities). Providing a dedicated facility to process and treat dry-solid ILW (Argument 4a: Provision of waste management facilities). Decay storage in dry casks to reduce activity levels (Argument 2j: Radioactive decay of solid and liquid wastes). Size reduction in order to aid optimal disposal (Evidence: Size reduction of control rods). Optimised disposal (Argument 4b: Optimal disposal route selection, Argument 4d: Disposability assessments for higher activity wastes and Argument 4e: Compatibility of existing UK waste BAT studies).	Disposal at GDF (Evidence: Disposability assessment – Intermediate level waste and options for the management of dry solid ILW).

Waste category	Technique to eliminate or reduce the generation at source	Technique to minimise the impacts of disposal on the environment (Claims 2-5)	Waste management route
Wet-solid ILW	Prevent or reduce the generation of FPs, activation products and CPs that subsequently enter liquid systems and require treatment, leading to the generation of resin, sludge and granular activated carbon waste (Claim 1: Eliminate or reduce the generation of radioactive waste). Before start-up, removing crud prior to activation reduces the radioactivity deposited on the demineraliser resins (Evidence: Water conditioning).	See wet-solid LLW.	Disposal at GDF (Evidence: Disposability assessment – intermediate level waste).
Fuel	The efficiency with which the nuclear fuel is used in the UK ABWR and the frequency with which it is changed will influence the amount of SF and HAW that is generated during operations (Argument 1c: Efficiency of fuel use). The generation of fuel waste is inevitable, however there are a number of practices that ensure subsequent optimal handling, treatment and disposal (Argument 1a: Design, manufacture and management of fuel).	Segregation of fuel from other waste streams (5.3.2.1. Evidence: Segregation of waste). Decay storage in SFP followed by dry cask storage in SFIS.	Disposal at GDF (Evidence: Disposability assessment – spent nuclear fuel).

Appendix 5: Hitachi-GE's 'Forward action plan' in the 'Demonstration of BAT' submission

Forward actions defined by Hitachi-GE (Hitachi-GE, 2017a). These record a gap in 'Demonstration of BAT' as a forward action (FA) to be addressed at a later, more appropriate stage of the project. The actions identify when it is appropriate to address these in the 'delivery phase (that is, by an operator). In each case, these are identified as actions for an operator rather than relevant to the GDA case.

Table A5-1 A copy of the Hitachi-GE Forward action plan for BAT (Hitachi-GE, 2017a, Table 7-1)

No.	Section Reference	Action	Delivery phase
1	5.1.8	To support the demonstration that (from 5.1.8 Argument 1h: Recycling of water within steam circuit) performance of systems deemed to be BAT perform as expected and have, therefore, been optimised, a future operator shall undertake performance monitoring of the following systems during commissioning: • Condensate water clean-up system • CUW • FPC and SPCU • LCW	Commissioning
2	5.1.8	An assessment shall be undertaken to determine BAT for the selection of demineraliser resins to support the full substantiation of argument 5.1.8 Argument 1h: Recycling of water within steam circuit.	Future operator
3	5.2.1.3	Undertake a BAT assessment of carbon-14 abatement techniques including alkaline scrubbing (for example, determine if available evidence challenges the argument that the development and implementation of an abatement technique is grossly disproportionate).	Future operator
4	5.2.2.1	Commissioning data shall be provided to support the design basis calculations currently being used to substantiate the argument that the delay period provided by the off-gas delay beds is BAT (5.2.2 Argument 2b: Delay beds for noble gases and iodine).	Commissioning
5	5.3.4	Undertake a BAT assessment of waste management techniques post-GDA, taking	Future operator

		into account site-specific factors, including the proximity principle.	
6	5.4.1 5.4.2 5.4.2.1	Undertake BAT assessments to support the specification and selection of equipment to be used in the radioactive waste management building (5.4.1.3 Evidence: Waste treatment facilities).	Future operator
7	5.4.2 5.4.3.1 5.4.5.1	Undertake a BAT assessment of waste management routes, taking into account site-specific factors, including the proximity principle and other relevant factors to fully substantiate 5.4.2 Argument 4b: Optimal disposal route selection.	Future operator
8	5.3.4.1 5.4.1.1 5.4.1.3 5.4.3 5.4.4	The management of waste, the final waste route and the quantity of waste to be consigned will be determined through the application of BAT by the future operator.	Future operator
9	5.5.1 5.5.2	A future operator shall select the techniques for environmental sampling and determine the environmental monitoring programme.	Future operator
10	5.1.7.1	A future operator shall assess the cobalt content of steels based on availability and cost from available suppliers.	Future operator
11	5.4.1.4 5.4.4.1	A future operator shall demonstrate BAT when selecting their plans for packaging, storage and disposal of SF.	Future operator
12	5.5.1.2	A future operator shall determine the optimal stack height.	Future operator
13	5.5.2 5.5.2.1 5.5.2.3	A future operator shall determine the management and arrangements for aqueous discharges.	Future operator
14	5.2.9.2	A future operator shall assess and define the decay storage timescales.	Future operator
15	**Error! Reference source not found..Error! Reference source not found.**	Management arrangements will be developed to ensure that BAT is considered through the life cycle of the project; from design to decommissioning.	Future operator

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