Assessing new nuclear power station designs

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

Assessment report - AR06 Solid waste and spent fuel

December 2017

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

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

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

Executive summary

Protective status	This document contains no sensitive nuclear information. This document does refer to commercially confidential information. This information was provided in responses to Regulatory Queries (RQs), Regulatory Observations (ROs) and Regulatory Issues (RIs) written by Hitachi-GE and labelled as 'HGNE COMMERCIAL'. This information does NOT appear in the main submissions of the generic environmental permit (GEP).

Process and information document[1]	The following section of Table 1 in our process and Information document (P&ID) is relevant to this assessment (only relevant text is included here): Item 4: A detailed description of the radioactive waste management arrangements. A description of how radioactive waste and spent fuel will arise throughout the facility's life cycle, including decommissioning and your plans for how they will be managed and disposed of, to encompass • sources of radioactivity and matters that affect waste arising • gaseous, liquid and other waste In justifying techniques as best available techniques (BAT) you should address the following, in respect of waste arising throughout the lifetime of the facility: • minimising, in terms of mass/volume, solid and non-aqueous liquid radioactive wastes and spent fuel • the suitability for disposal of any waste and spent fuel for which there is no currently available disposal route and how it will be managed in the interim so as not to prejudice its ultimate disposal. (You should obtain a view from the Nuclear Decommissioning Authority, as the UK authoritative source in providing such advice, on the disposability of such wastes and spent fuel). Item 5: Quantification of radioactive waste disposals. Provide quantitative estimates for normal operation of: • arisings of other radioactive waste (by category and disposal route (if any)) and spent fuel

Radioactive Substances Regulation	The following principles are relevant to this assessment: Principle RSMDP1 – Radioactive Substances Strategy A strategy should be produced for the management of all radioactive substances.

[1] Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs, Version 2, Environment Agency, March 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.

Environmental Principles[2]	Principle 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 compromise subsequent effective management or increase environmental impacts or risks. Principle RSMDP9 – Characterisation Radioactive substances should be characterised using the best available techniques so as to facilitate their subsequent management, including waste disposal. Principle RSMDP10 – Storage Radioactive substances should be stored using the best available techniques so that their environmental risk and environmental impact are minimised and that subsequent management, including disposal is facilitated. Principle RSMPD15 – Requirements and conditions for disposal of wastes Requirements and conditions that properly protect people and the environment should be set out and imposed for disposal of radioactive waste. Disposal of radioactive waste should comply with imposed requirements and conditions.

Report authors	Dr Paul Abraitis, David Brazier, Dr Greg Black

We have carried out a generic design assessment (GDA) of Hitachi-GE's proposed management and disposal arrangements for solid radioactive waste and spent fuel for the UK Advanced Boiling Water Reactor (UK ABWR) design. This report presents our findings based on information Hitachi-GE submitted in its radioactive waste management arrangements (RWMA), supporting documents and information it submitted to Radioactive Waste Management Ltd (RWM)[3].

We conclude overall that:

- in its submissions, Hitachi-GE describes how solid radioactive waste (low level waste (LLW), intermediate level waste (ILW) and spent fuel) will be generated, managed and disposed of throughout the facility's life cycle at a level of detail in line with our expectations for GDA
- the quantities of solid radioactive waste produced by the UK ABWR are broadly comparable to other light water reactor power stations across the world and that the UK ABWR design uses best available techniques (BAT) to minimise the mass and volume of solid radioactive waste that will need to be disposed of (Environment Agency, 2017a)
- solid radioactive waste can be treated and conditioned using proven and recognised techniques and that potential disposal routes have been identified for all solid LLW
- Hitachi-GE has provided information on the fuel composition and characteristics, the expected fuel burn up and the quantities of spent fuel that will arise, and described

[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

[3] RWM is company wholly owned by the NDA whose mission is to deliver a geological disposal facility and provide radioactive waste management solutions.

how spent fuel will be managed and disposed of throughout the life cycle of a UK ABWR at a level of detail in line with our expectations for GDA

- the proposed arrangements for interim management of higher activity solid wastes and spent fuel are unlikely to prevent their ultimate disposal, this conclusion is based on the conceptual options that have been described to date
- Hitachi-GE has obtained a view from RWM, as the UK authoritative source in providing such advice, on the disposability of ILW and spent fuel, responded to the RWM advice and provided an opinion to the regulators

Hitachi-GE has provided evidence of how it will minimise the generation and disposal of LLW and ILW and demonstrate that no LLW or ILW will be produced for which there is no foreseeable disposal route. We conclude that, subject to a satisfactory demonstration that spent fuel can be stored safely for the necessary period of time without significant degradation, there is no reason at this stage to believe that any of the ILW or spent fuel from the UK ABWR will not be disposable in a suitably designed and located geological disposal facility (GDF).

However, our conclusion is subject to a number of assessment findings (AFs):

Assessment Finding 9: A future operator shall, before procurement, provide detailed designs for solid radioactive waste management, storage and conditioning facilities that were covered at a conceptual level during generic design assessment, and demonstrate how these represent best available techniques.

Assessment Finding 10: A future operator shall demonstrate optimised management and disposal of solid radioactive wastes from the UK ABWR, addressing in particular:

- conditioning of higher activity waste arisings to ensure disposability
- selection of disposal routes for wastes at the low activity waste/high activity waste boundary
- management of spent nuclear fuel and any associated secondary wastes to ensure disposability
- selection of disposal routes for low activity waste

Contents

1. Introduction

We expect new nuclear power plants to be designed so that radioactive waste generated from their operation and decommissioning are minimised and optimised by applying best available techniques (BAT) and that, if it cannot be reused or recycled, it can safely be disposed of via existing or planned disposal routes.

We published guidance on our generic design assessment (GDA) process in 2013 (process and information document (P&ID) (Environment Agency, 2013). Table 1, Section 4 of the P&ID requires the requesting parties (RPs) to provide a description on how radioactive waste will arise, be managed and disposed of throughout the facility's lifetime. Section 2.1 of Table 1 of the P&ID requires the RPs to obtain a view from RWM, as the UK authoritative source in providing such advice, on suitability of disposal of higher activity waste (HAW), which includes intermediate level waste (ILW), high level waste (HLW) and spent fuel.

The P&ID requirements cover all radioactive waste, including that from normal operations and decommissioning, and includes waste generated from all activities, both routine and reasonably foreseeable non-routine activities, for example breakdown maintenance.

The preferred 'concentrate and contain' concept tends to direct waste to solid forms, rather than discharge via aqueous or gaseous routes. Minimising the quantity (mass and volume) of solid radioactive waste and spent fuel means better use can be made of the limited disposal facilities that are available. It also minimises the environmental impacts of transporting the waste to those facilities. There are also benefits in terms of utilisation of uranium resources and sustainability.

Currently, there are no final disposal facilities for HAW, but it is expected that any such waste managed in England and Wales will be disposed of to a geological disposal facility (GDF) (or facilities) that the government intends will be constructed (GB Parliament, 2014). The waste and spent fuel need to be suitably managed until the GDF is available.

The focus of GDA is on those facilities within the nuclear island that are specific to the reactor design. For the GDA stage, we focus on the fuel design and how spent fuel will be managed for eventual disposal. Aspects that are outside of the reactor facility, such as interim fuel storage arrangements away from the reactor facility, are developed and assessed more conceptually (Environment Agency and ONR, 2012). However, it is the RP's responsibility to demonstrate that spent fuel can be safely handled, stored and disposed of in so far as this is possible at this time. We expect the RP to provide sufficient confidence in managing spent fuel over the lifecycle of the facility, but accept that not all aspects of the design will be fully developed at this stage. This is also true for the disposal endpoint, given that only conceptual repository designs for HAW are available at this time.

We include non-aqueous liquid waste, such as oils and solvents, in our assessment of solid waste, as it needs to be managed and disposed of in similar ways. In order to assess the potential impact of a particular reactor design on the environment, we need to understand the quantities and characteristics of any such waste. We also assess the proposed management and disposal arrangements to make sure that any associated environmental impacts are likely to be minimised appropriately. The assessment of BAT and non-radioactive waste are the subject of separate assessment reports (Environment Agency, 2010a, Environment Agency, 2010b).

2. Assessment

2.1. Assessment method

Our assessment method was to:

- review appropriate sections of the documentation Hitachi-GE supplied, including the radioactive waste management arrangements (RWMA), the integrated waste strategy (IWS), the demonstration of BAT report, radioactive waste management case (RWMC), information Hitachi-GE supplied to RWM for its disposability assessment and the outcomes of the disposability assessment
- hold technical meetings with Hitachi-GE to improve our understanding of the information presented and to explain any concerns we had with that information
- assess the techniques Hitachi-GE proposed to prevent and minimise production of solid radioactive waste against our internal guidance and regulatory experience
- raise Regulatory Observations (ROs), Regulatory Queries (RQs) and Regulatory Issues (RIs), where appropriate
- identify any GDA Issues or Assessment Findings

2.2. Assessment objectives

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

- identified sources of solid radioactive waste
- demonstrated BAT in relation to arisings of radioactive waste
- information on treatment and conditioning of solid radioactive waste
- all disposal routes for solid radioactive waste
- quantified LLW and ILW arisings
- an adequate integrated waste and spent fuel strategy
- adequate and reliable information on fuel composition and characteristics, and proposed fuel burn up
- adequate and reliable information on spent fuel quantities and operating strategies in regard to spent fuel generation
- adequate information on the short and long-term management proposals for spent fuel and how this aligns with a disposal endpoint
- sufficient arguments that spent fuel from an UK ABWR would ultimately be disposable
- sufficient information supplied to RWM to carry out its disposability assessment
- acceptance of RWM findings
- identified at least one packaging and conditioning route that could be relied upon with reasonable confidence to provide disposable waste packages in a future GDF

2.3. Hitachi-GE documentation

We reviewed the following documents Hitachi-GE submitted or supplied during our detailed assessment (Table 1):

Table 1. Hitachi-GE documentation reviewed for this assessment

Document No	Title
NXA/23788023	Radioactive Waste Management, 'Generic Design Assessment: Summary of Disposability Assessment for Wastes and Spent Fuel arising from Operation of the UK ABWR'
NXA/23788023	Radioactive Waste Management, 'Generic Design Assessment: Disposability Assessment for Wastes and Spent Fuel arising from Operation of the UK ABWR. Part 1: Main Report'
NXA/23718693	Radioactive Waste Management, 'Generic Design Assessment: Disposability Assessment for Wastes and Spent Fuel arising from Operation of the UK ABWR. Part 2: Supporting Data'
GA91-9901-0022-00001_Rev H	Radioactive Waste Management Arrangements
GA91-9201-0003-0425 _Rev 3	Integrated Waste Strategy
GA91-9901-0023-00001_Rev G	Demonstration of BAT
GA91-9201-0003-00424 _Rev 2	Radioactive Waste Management Case
GA91-9201-0001-0175 - Rev 3	Topic Report of Decommissioning: Decommissioning Strategy
GA91-9201-0001-0176 - Rev 3	Topic Report of Decommissioning: Decommissioning Plan
GA91-9201-0001-0173 - Rev 6	Topic Report of Decommissioning: Decommissioning Waste Management
GA91-9201-0003-00458_Rev 0	High Level Optioneering on Spent Fuel Interim Storage
GA91-9101-0101-18000_Rev C	Generic PCSR[4] Chapter 18: Solid Radioactive Waste Management
GA91-9101-0101-19000_Rev C	Generic PCSR Chapter 19: Fuel Storage and Handling

[4] PCSR = Pre-construction safety report

Document No	Title
GA91-9101-0101-32000_Rev C	Generic PCSR Chapter 32: Spent Fuel Interim Storage
GA91-9101-0101-31000_Rev C	Generic PCSR Chapter 31: Decommissioning.
GA91-9201-0003-01150_Rev D	Response to RWM assessment report on UK ABWR waste and spent fuel disposability

2.4. Compilation of RQ, RO and RIs raised to date

Table 2 Summary of RQs, ROs and RIs related to solid waste

RQ/RO/RI	Date Issued	Title and summary
Regulatory Queries		
RQ-ABWR-0027	27-Jan-2014	Maintenance and re-kit query on waste streams Hitachi-GE was asked to clarify if all operational, maintenance and waste from redundant equipment was included in Table 8.1 of the submission: GA91-9901-0022-00001, 'UK ABWR GDA (Generic Design Assessment) Radioactive Waste Management Arrangements'
RQ-ABWR-0028	27-Jan-2014	Identification of high level waste (HLW) Hitachi-GE was asked to confirm that spent fuel is the only HLW generated and that no activated components above ILW threshold would be produced.
RQ-ABWR-0029	27-Jan-2014	Identification of HLW Hitachi-GE was asked to confirm which waste stream contains the spent fuel pond furniture.
RQ-ABWR-0030	27-Jan-2014	IX resin and incineration Hitachi-GE was asked to explain why ion exchange (IX) resin incineration is not being developed for the UK ABWR.

RQ/RO/RI	Date Issued	Title and summary
RQ-ABWR-0031	27-Jan-2014	Rate of control rod waste arising Hitachi-GE was asked to provide the underpinning evidence for stated 5 units per year of control rod waste arisings.
RQ-ABWR-0032	27-Jan-2014	Disposability of control rods Hitachi-GE was asked to clarify what the appropriate disposal options for boron carbide or hafnium control rods are and which option is being assumed for GDA.
RQ-ABWR-0033	27-Jan-2014	Higher activity metals – other items Quantity of arisings of other items had not been given. Hitachi-GE was asked to clarify when this information would be available.
RQ-ABWR-0034	27-Jan-2014	Borderline wastes Hitachi-GE was asked to provide further information on: • arisings of borderline waste - what these would be and where they would be generated • confirm if 300 years decay storage has been proposed in GDA
RQ-ABWR-0035	27-Jan-2014	Fuel characteristics – cooling period Hitachi-GE was asked to explain the basis for assuming a cooling period of 100 years before geological disposal of spent fuel had been assumed.
RQ-ABWR-0036	27-Jan-2014	Packaging options – defective fuel Hitachi-GE was asked to: • clarify if statement on page 26 of GA91-9901-0022-00001, UK ABWR GDA (generic design assessment) radioactive waste management arrangements on defective/failed fuel referred to management of fuel after cooling in the spent fuel pool

RQ/RO/RI	Date Issued	Title and summary
		• provide details on when, in terms of GDA step, and in what document the management, disposability and interim storage of defective/failed fuel would be considered
RQ-ABWR-0037	27-Jan-2014	Interim storage - inspection Hitachi-GE was asked to clarify long-term storage plans for spent fuel. The implication from current submissions is that there will be a period of time, perhaps decades, where there would be no facility available other than spent fuel and ILW stores. If this is the case then how will maintenance, inspection and mitigation be provided if any issues were to arise?
RQ-ABWR-0091	26-Mar-2014	Implications of failed fuel for the disposal inventory Hitachi-GE was asked to provide a view on implications for the inventory of solid waste and number of disposal packages when considering the quantity of failed fuel that has been assumed in GDA.
RQ-ABWR-0100	04-Apr-2014	Contaminated oil generated by ABWR Hitachi-GE has been asked to explain why no active oils will be produced during operation. This review should cover all oil-using equipment and refer to operational experience in the UK and worldwide and, where appropriate, explain why the UK ABWR is different.
RQ-ABWR-0101	04-Apr-2014	Radiological fingerprint Hitachi-GE was asked to provide an explanation of the radiological fingerprint referred to in GA91-9201-0003-00045 Revision 0, Confirmation about high level waste (Response to RQ-ABWR-0028)
RQ-ABWR-0132	25-Apr-2014	Availability of incineration for LLW resins Hitachi-GE was asked to provide further information on: • why the 3 resin streams cannot remain segregated, considering incineration of at least one of the streams

RQ/RO/RI	Date Issued	Title and summary
		• what could be done to make sure that the low conductivity resin stream could meet the Low Level Waste Repository (LLWR) waste acceptance criteria for incineration • suitability of shielding calculation for drum/package type that would be used • whether improved dose modelling may be appropriate • whether decay storage would be possible • whether limiting the life expectancy of the resin is feasible
RQ-ABWR-0133	25-Apr-2014	Large, solid radioactive waste items Hitachi-GE was asked to: • demonstrate that waste that cannot be recycled or reused, such as large one-off items, that is the reactor pressure vessel heads and steam generators, can be managed on the UK ABWR site and will be disposable • confirm the UK waste category of this waste
RQ-ABWR-0229	03-Oct-14	Waste BAT studies (Argument 4e) Hitachi-GE was asked to: • provide 'Hitachi-GE's waste treatment assessment' and/or indicate specifically which document this refers to (or indicate when this will be provided) • clarify which specific metallic waste streams will be recycled • explain where the strategy Hitachi-GE has developed for the management of combustible waste and other relevant strategies have been documented or are being documented
RQ-ABWR-0230	03-Oct-14	Waste routes (LAW) (Argument 4c) Hitachi-GE was asked to: • explain the basis for the waste enquiry forms and how the waste arisings and inventories are consistent with the current assumptions from a reactor chemistry basis

RQ/RO/RI	Date Issued	Title and summary
		• indicate whether the proposed waste is close to any waste acceptance criteria (WAC) limits or is well bounded • indicate any sensitivity to pending reactor chemistry decisions and future operator decisions
RQ-ABWR-0231	03-Oct-14	BAT aspects of application of volume reduction processes for solid waste (Argument 3c) Hitachi-GE was asked to: • clarify when decisions on treatment of control rods will be made and when assessment of available options will be provided • provide documented and referenced evidence of any claims of compliance with LLWR, or other, WAC • clarify why resins and activated carbons are described as waste • provide a summary of current waste conditioning practices in relevant ABWRs, focusing on waste that is similar to that produced by the UK ABWR • provide the latest version of 'The Hitachi-GE Waste Treatment Study - BAT Optioneering report' and clarify how the concept design and corresponding safety case link to demonstration of BAT
RQ-ABWR-0234	03-Oct-14	BAT aspects of selection of methods to minimise solid waste generation (Argument 3b) Hitachi-GE was asked to: substantiate the statement that, "The design of the UK ABWR shall enable a future operator sufficient flexibility to segregate, collect, store and process waste in a manner that allows BAT to be applied to the management and disposal of waste". clarify the level to which detail will be specified for GDA purposes and what is for site-specific development
RQ-ABWR-0235	03-Oct-14	BAT aspects of solidified HCW

RQ/RO/RI	Date Issued	Title and summary
		Hitachi-GE was asked to clarify: • the source of the activated carbon arising as concentrated liquid waste and quantities anticipated • when, within GDA or beyond, any further assessment before the generation of resin waste to demonstration application of BAT will be carried out
RQ-ABWR-0236	03-Oct-14	BAT aspects of provision of waste management facilities Hitachi-GE was asked to: • provide a copy of the 'UK ABWR Radioactive Waste Facility and System Design Description' and indicate which UK codes and standards have informed the design • substantiate the statements "The current size and configuration of the radioactive waste management building is considered to offer any future operator the flexibility to make a range of choices" ... "The provision of such a flexible facility is considered to represent BAT at this stage", given that optioneering is ongoing • clarify, at a level in line with GDA, how the timing of batch waste condition campaigns will be determined, and the likely scheduling of disposals and any implications for storage capacity and timescales • clarify provisions for appropriate waste package storage conditions, inspection and monitoring to ensure continued disposability
RQ-ABWR-0237	03-Oct-14	Clarifications on aspects of storage timescales for solid and liquid waste Hitachi-GE was asked to: • explain the basis for the 2-year buffer storage capacity for LLW • identify if any waste is suitable for decay storage between waste categories, for example ILW to LLW and waste where decay storage is purely seen as good practice in relation to worker dose • provide further details of the radionuclide components of the stated inventories
RQ-ABWR-0241	03-Oct-14	Environmental impacts of gadolinia (Argument 1b)

RQ/RO/RI	Date Issued	Title and summary
		Hitachi-GE was asked to: • provide a summary of the likely inventory of gadolinia in spent fuel arisings and evaluate potential impacts following disposal, or provide assurances that disposability advice from RWM considers this aspect • to explain why advantages from use of gadolinia as a burnable poison outweigh any disadvantages
RQ-ABWR-0247	03-Oct-14	Temperature within the fuel pool Hitachi-GE was asked to: • confirm the envisaged pool temperature • provide information on the relationship between the pool temperature and the amount of gaseous radioactive waste, and any relevant OPEX to support this • confirm whether the proposed 52ºC has been identified as a limit and what factors have been considered in defining this
RQ-ABWR-0263	13-Oct-14	Completeness of inventory data presented in RWMA (E4) document and potential implications for disposal routes. Hitachi-GE was asked to: • provide a number of references as identified in GA91-9901-0022-00001 Revision D • indicate the extent that it is possible to provide assurances that specific identified waste types will no present significant challenges for compliance with the LLWR WAC • confirm if inventory information currently given as 'TBA' will be provided in GDA and the implications of this knowledge gap in terms of the arguments relating to compliance and the waste services contract (WAC)
RQ-ABWR-0303	28-Nov-2014	Decay heat dependencies on fuel assumptions, calculations and nuclide library selection.

RQ/RO/RI	Date Issued	Title and summary
		Hitachi-GE was asked to clarify assumptions, calculations and libraries that will be used in the UK ABWR fuel disposability assessment submission and why these are deemed appropriate for GDA.
RQ-ABWR-0304	28-Nov-2014	'No significant difference' between 9X9 and 10x10 fuels Hitachi-GE was asked to: • clarify what changes would be envisaged if 10x10 fuel was used as an assessment basis rather than 9x9, specifically what the likely magnitudes of any numerical differences in terms of heat output and specific activity would be • explain why using BS340J33 is seen as conservative in the context of disposability assessment
RQ-ABWR-0355	07-Jan-2015	Discharges and waste arisings: comparison with other power stations Hitachi-GE was asked to provide a demonstration that discharges and waste arising from the UK ABWR will not exceed those of comparable power stations across the world as is required by the P&ID.
RQ-ABWR-0365	28-Jan-2015	BAT waste management hierarchy Hitachi-GE was asked to: • provide further details of the UK ABWR waste streams and decontamination, separation and segregation techniques that will demonstrate application of the waste hierarchy • indicate the expected benefits of applying these techniques in minimising the production of ILW, LLW and very low level waste (VLLW) and maximising the clearance and exemption of relevant waste
RQ-ABWR-0366	28-Jan-2015	Replacement frequency of plant items and associated waste generation Hitachi-GE was asked to: • identify items that will generate appreciable waste volumes and/or inventories with a lifetime less than that assumed for the proposed design life of 60 years

RQ/RO/RI	Date Issued	Title and summary
		• indicate the assumed replacement frequency, and justification, for all of the items identified
RQ-ABWR-0367	28-Jan-2015	Spectral shift operational regime: uranium saving Hitachi-GE was asked to: • outline, and quantify if possible, the amount of spent fuel avoided by applying the proposed 'spectral shift operational system' compared with an operational system where this is not deliberately applied • identify any significant differences in the radionuclide inventory associated with the spent fuel as a result of applying this • provide a view as to the overall implications of the 'spectral shift' operations in terms of the amount of waste arising and other relevant factors to demonstrate that this represents an optimised operational system overall
RQ-ABWR-0368	28-Jan-2015	Disposability assessment and spectral shift Hitachi-GE was asked to clarify whether spent fuel data submitted to RWM as part of the disposability assessment process is consistent with an operational system based on 'spectral shift'.
RQ-ABWR-0545	02-Jun-2015	Source terms waste inventory data. Hitachi-GE was asked to describe how waste volumes have been estimated for all solid waste streams, including all arisings for storage and disposal.
RQ-ABWR-0564	15-Jul-2015	BAT 'route map' for solid waste Hitachi-GE was asked to: • explain why a BAT 'route map' summarising the BAT arguments relating to solid waste has not been included in the 'Demonstration of BAT' document • indicate the proposed scope and format and timescales for inclusion of a BAT 'route map' if it is to be produced
RQ-ABWR-1049	30-Aug-2016	Fuel pool environmental and evaporation factors.

RQ/RO/RI	Date Issued	Title and summary
		Hitachi-GE was asked to: • present the design parameters of the spent fuel pool and building • present evidence of optimisation of the design in terms of ALARP, thermal environmental factors and demonstration that discharges are BAT
RQ-ABWR-1135	25-Oct- 2016	Inconsistencies between submissions for decommissioning and reactor chemistry Hitachi-GE was asked to: • clarify if selection of surface treatment methods is out-of-scope of GDA and explain claims and arguments of how these minimise the arisings of radioactive wastes • confirm if decontamination of SSCs necessary to ensure ALARP conditions for workers • confirm if noble metal chemical addition (NMCA) will be deployed in the UK ABWR and explain both NMCA and on-line noble metal chemical addition (OLNC) are referred to in submissions
RQ-ABWR-1149	07-Nov-2016	Demonstration that damaged fuel management options are not foreclosed Hitachi-GE was asked to: • provide reasoned argument that spent fuel interim Store (SFIS) concept is capable of reducing risks as ALARP if options for managing damaged fuel are deployed • demonstrate that proposed options will not be foreclosed by demonstrating compatibility with the concept SFIS
RQ-ABWR-1151	07-Nov-2016	Borderline wastes and decontamination techniques in decommissioning. Hitachi-GE was asked to: • confirm statement that no borderline wastes would arise during decommissioning, and provide the basis for this assumption • demonstrate that proposed decontamination options are BAT and ALARP

RQ/RO/RI	Date Issued	Title and summary
		• clarify secondary wastes arisings from decontamination of metal and concrete wastes from decommissioning • give examples of decontamination, arisings of secondary wastes, re-categorisation of materials and justification of ALARP and BAT • provide examples of any re-use and re-cycling of material arising at decommissioning • provide a definition of what is meant by 'short half-life' radionuclides with respect to decommissioning waste management
RQ-ABWR-1473	01-Jun-2017	Reactor building solid ILW inventory. Hitachi-GE was asked to: • describe where solid ILW generated during 60 years operation would be stored/segregated and processed • provide references of where the above information is detailed in GDA submissions
Regulatory observation		
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 practicable (SFAIRP).
Regulatory issue		
RI-ABWR-0001	02-Jun-15	Definition and justification for the radioactive source terms in the UK ABWR during normal operations 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.

2.5. Arisings of solid waste

Hitachi-GE has outlined the sources and quantities of solid radioactive waste that are likely to arise in the Radioactive Waste Management Arrangements (RWMAs) document (Hitachi-GE, 2017a). This document also outlines the proposed management arrangements covering the UK ABWR life cycle, including decommissioning.

Coverage includes the arising, management and disposal of solid waste. The solid radioactive waste inventory is presented in Appendix A of the RWMA document (Hitachi-GE, 2017a). More detailed inventory data relating to solid waste is provided in detailed reports produced by Hitachi-GE (Hitachi-GE, 2017b & Hitachi-GE, 2016).

Hitachi-GE has identified a wide range of solid radioactive waste arisings and has categorised these according to UK practice and based on physical form and the nature and quantity of radioactivity that they contain, as well as their heat-generating capacity (Appendix 1).

Hitachi-GE describes how solid waste will arise within the nuclear island and how it will be managed, stored and conditioned for eventual disposal in dedicated waste management facilities. The radioactive waste building will house equipment associated with collecting, segregating and treating of the liquid and wet solid radioactive waste generated in the plant.

Certain waste management facilities are defined only at a conceptual level in GDA (Environment Agency and ONR, 2012) to illustrate what will be needed to enable waste management operations and disposal. Hitachi-GE has identified the following facilities that will require detailed design by future operators: the wet solid low level waste (WLLW); solid low level waste (SWF); wet solid intermediate level waste (WILW) facility; solid ILW (SILW) facilities; ILW store (ILWS) and a spent fuel interim store (SFIS). These are described further in the RWMAs document (Hitachi, 2017a). We have, therefore, included an assessment finding to ensure that a future operator will provide detailed designs for solid waste management facilities.

Assessment Finding 9: A future operator shall, before procurement, provide detailed designs for solid radioactive waste management, storage and conditioning facilities that were covered at a conceptual level during generic design assessment, and demonstrate how these represent best available techniques.

We asked Hitachi-GE to provide evidence that all solid waste had been appropriately identified including operational, maintenance and redundant equipment (RQ-ABWR-0027; RQ-ABWR-0366). As part of our interactions in relation to source terms, we asked specifically how solid waste volumes have been estimated (RQ-ABWR-0545).

At the time of writing the consultation document (5 August 2016), RI-ABWR-0001 and RO-ABWR-0006 remained open. Until these were formally closed, the estimated gaseous and aqueous radioactive discharges, estimated solid radioactive waste arisings, decommissioning source term and radiological impact assessments for GDA could change.

Therefore we had previously identified the following potential GDA Issue:

Potential GDA Issue 2 – Source terms for the UK ABWR. We require Hitachi-GE to provide a suitable and sufficient definition and justification for the radioactive source terms in the UK ABWR during normal operations.

RI-ABWR-001 and RO-ABWR-0006 are both now formally closed and both regulators are satisfied that the source term has been defined and underpinned to their satisfaction. Therefore we have now removed this potential GDA Issue from our final assessment.

2.5.1. Very low level waste (VLLW)

This will comprise mixed waste that will arise during reactor operations and decommissioning. This waste will include contaminated personal protective equipment (PPE), monitoring swabs, plastic, equipment, structures and other contaminated materials. Different forms of VLLW will require specific removal, handling, sorting and size reduction techniques depending on their physical form and characteristics before treatment and disposal.

Projected volumetric arisings are 14m^3/year (combustible) and 3m^3/year (non-combustible) (Hitachi-GE, 2017a). The radionuclide content of this waste depends on the operational source but will mainly comprise steel activation products.

It is proposed that this waste will be recycled, where practicable, (for metals), compacted, incinerated at an off-site facility, where practicable, or sent for direct disposal to permitted disposal sites. Future operators will need to select appropriate disposal routes.

2.5.2. Low level waste (LLW)

LLW is defined as waste with a radioactive content not exceeding 4 GBq per tonne of alpha, or 12 GBq per tonne of beta/gamma activity.

Operational LLW is mainly lightly contaminated miscellaneous waste, arising from plant maintenance and monitoring. Routine LLW arisings from plant consumables will include heating ventilation and conditioning (HVAC) filters, organic bead demineraliser resin and concentrate liquors from the high chemical impurities waste (HCW) evaporators.

Non-combustible waste is generated through routine operations, maintenance and decommissioning in radioactive areas. These will comprise materials such as metals, concrete, lagging, glass and LCW spent hollow fibre filter membrane. This waste may include some items that could be dealt with in ways other than direct disposal. Hitachi-GE envisages that future operators will apply the requirements of the waste management hierarchy so waste can be routed appropriately.

Miscellaneous combustible waste is generated through routine operations, maintenance and decommissioning in radioactive areas. The waste consists mainly of contaminated personal protective equipment, polyethylene (sheet, bag), paper, wood, cloth, rubber gloves, turbine oil waste and spent active carbon filter media. Subject to appropriate waste routing by future operators, it is envisaged that this waste will be subject to incineration at an off-site facility, followed by disposal of the resulting ash to the low level waste repository (LLWR).

Waste that will arise as wet material that can be conditioned to a solid form for disposal is termed ‘wet-solid’ LLW. This will comprise sludge, ion exchange resin, evaporator concentrates and activated carbon. Subject to appropriate waste routing by future operators, it is envisaged that this waste will be solidified by cement encapsulation on site for disposal to the LLWR.

LLW from decommissioning typically includes building materials such as concrete, metal plant and equipment. This will comprise large volumes of metal and concrete items. Many will be very large and require size reduction. Hitachi-GE recognises that waste will need to be segregated based on composition, radioactivity and contamination, and future operators will need to apply appropriate treatment and disposal strategies.

Hitachi-GE has broadly categorised LLW into ‘dry-solid LLW’ and ‘wet-solid LLW’, and estimates of annual arisings are provided, together with information as to the significant radionuclide inventory components (Appendix 1).

Total LLW arisings are envisaged to be around 84m^3/year, comprising 71m^3/year dry-solid LLW and 13m^3/year wet-solid LLW. The most significant volumes are associated with HVAC filters (around 24m^3/year), miscellaneous combustible LLW (37m^3/year) and wet solid LLW (13m^3/year) (Hitachi-GE, 2017a).

Hitachi-GE proposes that LLW will be subject, where practicable, to metals treatment, incineration, super compaction and disposal. This will depend on any future operators appropriately applying the waste management hierarchy and identifying the most appropriate (optimised) disposal routes.

Hitachi-GE observes that specific waste streams are likely to need considering in the future as 'borderline' waste, which is waste close to the LLW and ILW categorisation boundary. We sought further information on borderline waste via RQ-ABWR-0034. Organic bead demineraliser resins used in liquid clean-up plant are noted as this type of waste. Future operators will need to assess borderline waste using a method agreed with the disposal suppliers, as appropriate. This will be subject to normal regulatory oversight at that time and we identify this an assessment finding (Assessment Finding 9).

2.5.3. Intermediate level waste (ILW)

ILW has radioactivity levels that are higher than LLW but which do not generate enough heat to need special storage or disposal facilities. Hitachi-GE has identified a range of ILW that will arise from the UK ABWR. These will broadly comprise 'dry-solid' ILW and 'wet-solid' ILW (Appendix 1).

Dry-solid ILW comprises activated metals that have been subjected to irradiation and which have become significantly active (above LLW levels) within the reactor. This waste will include control rods and reactor components, such as neutron sources and metallic fuel channels. Metallic components of fuel assemblies are envisaged to be retained and disposed with the associated spent fuel (timescales of up-to 140 years are envisaged for spent fuel storage). Although some specific components are potentially (HLW) when produced (RQ-ABWR-0028; RQ-ABWR-0033; RQ-ABWR-0101), Hitachi-GE expects this dry-solid waste to be ILW at the time of disposal due to radioactive decay and cooling during storage (timescales of up to 100 years are envisaged).The predominant radionuclides giving rise to significant decay heat include cobalt-60, nickel-63, hafnium-178n and californium-252 (the latter in neutron sources).

Wet-solid ILW includes 90m^3 (per 60 year operational life) of sludge arising from filtration of water streams and 4.4m^3/year of powder ion exchange resins (arising from water treatment filter/demineralisers associated with the fuel pool and reactor clean-up circuit) (Hitachi-GE, 2017a).

We asked Hitachi-GE to confirm that that spent fuel is the only HLW being generated and that there are no activated components that are sufficiently heat generating to be considered HLW, especially activated core components (RQ-ABWR-0028 & RQ-ABWR-0029). Hitachi-GE has identified that some irradiated metals, including control rods and various reactor core components, will arise as HLW, that is, waste having significant heat output. It is argued that storing this type of waste will mean that it can be treated as ILW at the time of disposal, that is, decay storage is proposed. RWM has considered these aspects in the disposability assessment for HAW.

Hitachi-GE has selected cement encapsulation for solid items and solidification for wet-solid ILW into unshielded stainless steel as the conditioning options to be adopted for a disposability assessment by RWM. Interim storage for up to 100 years is assumed, awaiting disposal to the GDF (Environment Agency, 2017b).

2.5.4. Spent fuel

Spent fuel (SF) is considered as waste in GDA on the basis of an assumed once-through nuclear fuel cycle. This is consistent with the policy basis, as per the government white paper 'Meeting the Energy Challenge', (BERR, 2008) that new nuclear power stations should proceed on the basis that spent fuel will not be reprocessed. Hitachi-GE's proposed spent fuel management strategy for the UK ABWR comprises initial pool cooling, followed by dry storage and eventual geological disposal (Environment Agency, 2017b).

Significant radioactivity arises in spent fuel within the reactor core by nuclear fission, activation and in-growth of radionuclides. Much of this activity remains within the fuel, which will contain fission products, activation products and actinides. Approximately 9,600 assemblies are assumed to arise over 60 years' of operation. Interim storage periods of up to 140 years are assumed by Hitachi-GE, awaiting disposal to the GDF.

Spent fuel generates considerable radiogenic heat and, therefore, spent fuel management must take account of this. The heat output of fuel is also a consideration in terms of eventual disposal, as there are likely to be temperature limits imposed in the waste acceptance criteria of a future GDF.

2.5.5. Fuel design and manufacture

Hitachi-GE proposes using GE14 fuel in the UK ABWR. This is a modern fuel design that has benefitted from progressive development and optimisation of BWR fuel design (Hitachi-GE, 2017c). GE14 fuel consists of a fuel bundle composed of 92 fuel rods, 2 water rods, spacers, and upper and lower tie plates, and a channel that surrounds the fuel bundle. The fuel is in the form of uranium dioxide (UO_2) pellets that are stacked in a zirconium alloy cladding tube to form fuel rods. GE14 fuel cladding is manufactured from Zircaloy 2. Hitachi-GE describes this as a zirconium alloy widely used in the nuclear industry. It is produced using advanced manufacturing techniques to minimise variability.

It is proposed that the channels that surround each of the fuel element bundles will remain with the spent fuel to be disposed of together. Therefore, all components of the assembly will become spent fuel waste.

Fuel performance has important implications in terms of generating solid, liquid and gaseous waste that needs disposing of. 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 GDF. However, the potential transfer of fission products (FPs) from the fuel to the steam circuit and the spent fuel pool generates waste. We expect appropriate design, manufacture and management of nuclear fuel to minimise the quantity of waste that is generated, including spent fuel.

Hitachi-GE argues that design, manufacture and management of fuel will ensure optimisation in terms of reduced spent fuel and waste arisings. This is described predominantly in Hitachi-GE's 'Demonstration of BAT report' (Hitachi-GE, 2017c).

Hitachi-GE argues that GE14 is a modern fuel design that has benefitted from progressive development and optimisation of BWR fuel design, as evidenced by significantly reduced fuel failure rates in BWR reactor plant. GE14 fuel has been used for over 15 years and has been approved for use in Germany, Switzerland, Sweden, Finland, Spain, Mexico, Taiwan and the United States. Hitachi-GE, therefore, argues that there is extensive operational experience in GE14 fuel use in the BWR reactor fleet worldwide (Hitachi-GE, 2017d).

We note, however, that fuel technology is subject to progressive improvement. For example, an advanced fuel design known as GNF2 is currently being developed and progressively used in the BWR fleet and may offer advantages over GE14, assuming that eventually there is enough operational experience to fully support a case for using this fuel design. Given these aspects, a future operator will need to consider detailed fuel design further at the site-specific permitting stage, as improved fuels may be available at that time. In particular, any design improvements to minimise fuel failure during operation will need to be considered as this could bring benefits in terms of waste minimisation, and we have identified a related assessment finding, AF 3 (Environment Agency, 2017a).

Natural uranium will be enriched to manufacture the fuel and, therefore, recycled uranium from reprocessing is not assumed in GDA. Each UK ABWR fuel rod has an axial enrichment distribution with lower enrichment at both top and bottom. Fuel assembly burn-ups of between 50 GWd/tU and 60 GWd/tU are assumed. In GDA it is proposed that 60 GWd/tU would represent the maximum of a range of burn-up values for individual fuel assemblies, although individual fuel pin burn-ups may be up to 65 GWd/tU.

In addition to fuel assemblies, the UK ABWR reactor core will include 2 types of control rods used in shutdown and power control. We discuss matters relating to control rods, and the solid waste arisings, further in our review of the BAT case (Environment Agency, 2017a).

A small number of fuel assemblies also include a neutron poison, gadolinium oxide, which is mixed with the fuel and depletes slowly with burn up. This is used to control excess fuel reactivity, particularly during the early stages of a fuel cycle. We raised RQ-ABWR-0241 to further understand the environmental implications of using gadolinium oxide. Overall, it is argued that gadolinium has benefits in terms of reducing the need for control rod usage and replacement and simplified core management. No particular disadvantages, other than cost, have been identified. Much of the gadolinium is burnt during the fuel cycle. The reaction products are mostly short-lived (less than one year) and, therefore, offer little additional radionuclide inventory for disposal.

Unintended uranium on the external surfaces of the fuel is referred to as 'tramp uranium'. This has the potential to undergo nuclear fission and, therefore, to generate fission products, which generates waste via the steam circuit. Hitachi-GE observes that manufacture of GE14 fuel seeks to minimise the potential for the external surfaces of its fuel to become contaminated with uranium.

Hitachi-GE argues that only a small number of fuel assemblies may experience failure during normal operations. This failure is described as an ‘expected event’ in terms of estimating waste arisings. Hitachi-GE argues that a conservative assumption has been assumed for GDA purposes in terms of the anticipated number of fuel failures, that is tending to overestimate release rates and, therefore, radioactive waste arisings. Failure is envisaged as minor breaches in the cladding (pin holes and/or hairline cracks), rather than extensive cladding failure, which could compromise the physical integrity of the fuel.

Failure may be caused by debris fretting or pellet-clad interaction (PCI). Hitachi-GE describes design features and arrangements to limit these events (Hitachi-GE, 2017c). These comprise debris filters, barrier cladding in the fuel design, improved manufacturing and quality assurance procedures during pellet manufacture, together with operating strategies to minimise the risk of (PCI).

Debris filtration is included in the GE14 fuel and Hitachi-GE argues that fuel failure rates of 0.5 per 1000 fuel bundles can be demonstrated using current technologies. This represents a significant design improvement relative to earlier fuel designs where failure rates of 2.9 per 1000 fuel bundles were observed (Hitachi-GE, 2017d).

Hitachi-GE argues that reductions in PCI related failure have been attributed to the introduction of zirconium-lined barrier fuel cladding and improved manufacturing and operational practices. Evidence is provided that the total failure rate in 10x10 barrier fuel (such as GE14) due to PCI mechanisms is less than 4 parts per million (ppm).

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. The future operator will consider the detailed operational arrangements for fuel and core, and how this will be optimised to minimise waste at the site-specific permitting stage.

Hitachi-GE also provides evidence that experience with fuel handling equipment, such as that to be used in the UK ABWR, has resulted in no fuel damage or collision of fuel during fuel handling operations.

Overall, we conclude that Hitachi-GE proposes appropriate fuel design and manufacture and management arrangements for GDA of the UK ABWR. We note, however, that further consideration at the site-specific permitting stage will be required as improved fuels may be available at that time (Environment Agency, 2017a).

2.5.6. Non-aqueous liquid waste

We asked Hitachi-GE to consider the likely sources of contaminated non-aqueous liquids that might arise from the UK ABWR (RQ-ABWR-0100). We also suggested it consider UK nuclear operational experience.

In response, Hitachi-GE concluded that some potentially radioactive contaminated non-aqueous liquid or non-aqueous liquid contaminated waste will be generated in the UK ABWR. This will be generated through plant operations, such as maintenance of pumps and hydraulic equipment. This waste may be in liquid form or associated with materials such as rags, spill kit clean up waste and contaminated plant items. This waste is likely to be VLLW or LLW, or could be so lightly contaminated as to be out of scope of the regulations in terms of the definitions of radioactive waste (Defra, 2011).

Hitachi-GE has not quantified the specific nature of such arisings or the associated volumes, as these are particularly difficult to predict with any certainty and precision. However, it is argued that the amounts will be low and that appropriate segregation, characterisation and treatment/disposal options are available for any such waste. We accept that this is a reasonable argument at the GDA stage.

2.5.7. Minimisation of solid waste

Hitachi-GE has provided claims, arguments and evidence relating to the minimisation of waste arisings. This includes solid radioactive waste. We provide our assessment of these aspects in another assessment report (Environment Agency, 2017a).

Production of spent fuel is inevitable, but we expect to see optimisation to make sure that spent fuel is minimised. Hitachi-GE argues that design features of the UK ABWR and suitable operational regimes allow fuel to be used efficiently. Hitachi-GE observes that for the UK ABWR the first shutdown for refuelling will take place typically up to 13 months after the start of initial power and after that the cycle length can be varied up to 18 months using GE14 fuel. It is envisaged that the UK ABWR will discharge approximately 9,600 fuel assemblies over 60 years of operation. Each assembly will have an average discharged fuel burn-up of approximately 50 to 60 GWd/tU.

Hitachi-GE observes that efficient fuel use in the UK ABWR design means refuelling is less frequent. This produces less spent fuel and associated HAW compared with early BWR designs. To illustrate this, Hitachi-GE observes that BWR fuel bundles typically achieved discharge exposures of approximately 20 GWd/t during the 1970s, while more recently BWRs loaded with 10x10 fuel bundles, such as GE14, fuel have achieved discharge exposures of 50 GWd/t (Hitachi-GE, 2017c).

Features of the UK ABWR design that allow fuel to be used efficiently and related arguments are described in the ‘Demonstration of BAT’ document (Hitachi-GE, 2017c). The main aspects relate to the configuration and geometry of the reactor core, which has evolved over many years of BWR operation. It is argued that a BWR has lower power density, larger fuel inventory, more fuel bundles and a smaller ratio of fuel assembly exchange than a PWR. Flexibility of the fuel loading pattern in the UK ABWR means fresh fuel can be placed at the core interior and old fuel placed at the core periphery. In addition, each fuel rod has axial enrichment distribution with lower enrichment at both the top and bottom end. These characteristics lead to a decrease in neutron leakage and, therefore, increased fuel efficiency.

Hitachi-GE also argues that 'spectral shift operation' offers benefits in terms of saving uranium. The boiling region of the core has a high void fraction due to steam bubble formation, which reduces neutron moderation, resulting in the fuel located in this region experiencing a high energy neutron spectrum. This produces plutonium from fertile nuclides (predominantly uranium-238). In spectral shift operation, the core is operated at the high void fraction in the early to middle fuel cycle and plutonium build-up is promoted. The core is then operated at the low void fraction towards the end of the cycle so that fissile plutonium burn-up is promoted. Overall, it is argued, the reactivity of plutonium produced during the cycle improves fuel efficiency.

We queried the implications of spectral shift operations in terms of spent fuel arisings (RQ-ABWR-0367). Overall, based on scoping calculations, Hitachi-GE demonstrated that spectral shift can reduce spent fuel arisings and the overall spent fuel radionuclide inventory. The dominant effect is a reduced fuel reloading frequency (down by 2.6%) based on the simple comparison presented in response. Hitachi-GE also confirmed that the effects of spectral shift are encompassed within the spent fuel data supplied to RWM for disposability assessment (response to RQ-ABWR-0368). The response suggested that the effects of spectral shift are bounded by the assumed burn-up.

Overall, we conclude that the UK ABWR design allows fuel to be used efficiently and saves uranium consistent with reducing spent fuel for disposal. However, as discussed above, we note that improved fuels may be available at that the time of deployment, and these may lead to further improvements in fuel efficiency and uranium saving. Any significant advances in fuel technology will need to be considered at the site-specific stage.

2.5.8. Comparison of solid waste arisings

Hitachi-GE has provided estimates for the annual arisings (of LLW and ILW (Hitachi-GE, 2017a).

The total normalised arisings[5] of LLW (61.2 m^3) and ILW (32.1m^3) exceed the European Utility Requirement objective of less than 50m^3 per 1000 MWe plant-year of operation (EUR, 2001). This objective has been used for comparing solid waste arisings between different light water reactor designs in GDA[6].

In response to RQ-ABWR-0355 'Discharges and waste arisings: comparison with other power stations', Hitachi-GE could not provide detailed comparative data for solid waste arisings (only one data source was provided for solid waste). An Environment Agency study (Environment Agency, 2016a) also had difficulty in benchmarking the solid waste arisings based on internationally available literature sources for BWR.

RWM has compared radionuclide inventories for the most active ILW stream and for spent fuel from PWR assessed to date as part of the UK ABWR disposability assessment (RWM, 2015)[7]. RWM concluded that the radioactivity arising in solid forms from the UK ABWR is dominated by

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[5] Treated annual LLW (disposed or stored) 82.6 m^3 (Table A2.3-1); ILW arisings 43.28 m^3 (Tables A2.4-1 - A2.4-4) Figures taken from Hitachi-GE, 2017a. Normalised from rating of single UK ABWR unit, 1,350 MWe (Hitachi-GE, 2017e).

[6] Note that in our earlier GDA assessments of the AP1000 design (a pressurised water reactor) the representative numbers were: 65.1 m^3 LLW per 1000 MWe plant-year of operation; 36.6m^3 ILW per 1000 MWe plant-year of operation. For the EPR reactor design (a pressurised water reactor) the numbers were: 14.1m^3 LLW and 26.6m^3 per 1000 MWe plant-year of operation.

[7] RWM (2015) observe that for the UK ABWR and PWRs the overall radionuclide inventories for waste and spent fuel will be broadly similar. This is borne out by comparing radionuclide inventories for the most active ILW stream and for spent fuel from the reactor types that RWM has carried out as part of the UK ABWR disposability assessment. These types of waste contain the bulk of the radioactivity that arises in solid form. The comparable inventories reflect similarities in design in terms of fuel types that is similar enrichment and materials of fabrication.

radionuclides within the decommissioning waste streams. Comparison with reported activities for similar waste concluded that radionuclide activity in the UK ABWR waste streams is comparable with that for Sizewell B (the UK's only operational PWR).

We note that it has been difficult to obtain extensive, relevant data on solid waste arisings for comparative purposes. However, overall and in broad terms, it seems reasonable to conclude that the UK ABWR design is not unusual in terms of solid waste arisings when compared to other modern light water reactor designs.

2.5.9. Managing and disposing of lower activity waste (LAW)

Hitachi-GE has sought to demonstrate that LAW arising from the UK ABWR design could be disposed of to appropriate routes based on currently established practice and national plans (Appendix 1). LAW comprises solid radioactive wastes with a radioactive content not exceeding 4 GBq per tonne of alpha, or 12 GBq per tonne of beta/gamma activity. For the UK ABWR, this includes, VLLW, dry-solid LLW and wet-solid LLW (Appendix 1).

We note, in particular, that Hitachi-GE argues that operators of a future UK ABWR would be able to select the 'optimal disposal routes for wastes transferred to other premises' (Claim 4) and the associated arguments (4a – 4e) and evidence (Hitachi-GE, 2017c). We raised a number of RQs relevant to the management and disposal of LAW: RQ-ABWR-0229; RQ-ABWR-0230; RQ-ABWR-0231; RQ-ABWR-0234; RQ-ABWR-0235; RQ-ABWR-0236; RQ-ABWR-0237, RQ-ABWR-0365 and RQ-ABWR-0564. Each of these queries was satisfactorily addressed for our assessment purposes.

Hitachi-GE's arguments (4a – 4e) relate to providing waste management facilities, selecting optimal (most appropriate) disposal routes, agreement in principle for LAW disposal routes, disposability assessment for higher activity waste and compatibility with existing UK waste BAT studies. We consider these arguments further in our assessment report on BAT (Environment Agency, 2017a). Overall, Hitachi-GE argues that appropriate disposal routes for LAW would be enabled via the UK ABWR design. We have no reason to dispute this argument and would expect future operators to select optimised disposal routes as available at that time.

We queried the completeness of inventory data presented in the RWMA document and any potential implications for disposal routes (RQ-ABWR-0263). Hitachi-GE responded to this query and has updated the inventory data accordingly. We also sought assurances from Hitachi-GE regarding the implications of recently revised waste acceptance criteria in the waste services contract.

We conclude that Hitachi-GE has appropriately demonstrated that all LAW arisings from the UK ABWR design would be disposable. In this context, we mean all appropriate forms of disposal, including incineration. This demonstration is in line with our expectations for GDA. We also consider that the proposed solid waste conditioning options are a suitable basis for assessment at the GDA stage (Appendix 1).

2.5.10. Managing and disposing of higher activity waste (HAW)

The ILW and spent fuel that would arise from the UK ABWR are forms of HAW. There are currently no final disposal facilities in the UK for HAW. It is expected that HAW will be disposed of to one or more GDFs (GB Parliament, 2014). In the meantime, HAW will need to be managed in a way that adequately protects people and the environment, without compromising eventual disposal in a future GDF.

Any future site operator will decide how to manage its waste and condition it to be disposed of with appropriate regulatory oversight at that time. Hitachi-GE argues that it has considered the viable options for HAW in the supporting optioneering for GDA. We are satisfied that appropriate options have been considered in GDA and recognise that any future operators may select alternative options subject to regulatory approvals and when supported by appropriate options studies at that time. We are also satisfied that the selected options are sufficient to demonstrate that the waste produced by the UK ABWR can be disposed of based on the GDA assessment context. We have, therefore, included an assessment finding to ensure a future operator demonstrates how solid waste management routes will be optimised.

Assessment Finding 10: A future operator shall demonstrate optimised management and disposal of solid radioactive wastes from the UK ABWR, addressing in particular:

- conditioning of higher activity waste arisings to ensure disposability
- selection of disposal routes for wastes at the low activity waste/high activity waste boundary
- management of spent nuclear fuel and any associated secondary wastes to ensure disposability
- selection of disposal routes for low activity waste

2.5.11. RWM disposability assessment process

We expect the RP to obtain a view from RWM on the disposability of HAW (Environment Agency, 2013). We also expect the RP to consider and respond to the advice from RWM. This requires the RP to identify at least one credible route by which the HAW from the UK ABWR could be conditioned and safely disposed of, and to provide grounds for reasonable confidence that the route(s) could be followed successfully if pursued by a future operator.

The overall objective of the disposability assessment process is to provide confidence that the future management and disposal of waste packages has been taken into account as an integral part of their development and manufacture (NDA, 2014). As part of this process, operators seek advice from RWM and seek to demonstrate that the waste packages produced by the proposed conditioning process will be compatible with plans for the GDF. RWM conducts a comprehensive disposability assessment of operator proposals against published safety assessments relating to transport, repository operations and repository post-closure. Disposability assessments are typically conducted in a staged approach, which includes conceptual, interim and final stage assessments. The regulators scrutinise the operation of the disposability assessment process in the context of the GDF programme as a whole.

For GDA purposes, a single stage disposability assessment is conducted on waste conditioning proposals provided by the RP. Assessment is to a level of detail that is commensurate with GDA expectations. The GDA disposability assessment process comprises three main components: a review to confirm the waste and spent fuel properties; an assessment of the compatibility of the proposed waste packages with concepts for geological disposal; identification of the main outstanding uncertainties, and associated research and development needs, relating to the future disposal of the waste. The process follows a similar overall approach to the detailed disposability assessments that would be conducted for any future operators in support of future waste conditioning proposals. Any future operators would be expected to pursue full disposability assessments from RWM and ideally to achieve RWM endorsement for waste conditioning proposals at that time. This may build on the findings of the GDA disposability assessment if the same waste conditioning options are pursued.

2.5.12. Joint guidance on managing higher activity waste

The regulators (ONR, Environment Agency, Natural Resources Wales and Scottish Environment Protection Agency (SEPA)) have issued joint guidance (ONR, Environment Agency, SEPA and Natural Resources Wales, 2015) on how nuclear site licensees should manage HAW to meet regulatory requirements. This guidance recommends that licensees develop and maintain radioactive waste management cases (RWMCs) for all higher activity waste, addressing the longer term safety and environmental issues associated with the waste.

Important components of a RWMC include:

- optioneering studies, to show how the conditioning option was selected and how it fits within an integrated waste strategy (IWS)
- a description of what conditioning will be carried out on the waste, or the justification for storing the waste without conditioning
- evaluating disposability, a reasoned judgement must be provided on whether the conditioned waste meets the anticipated requirements for acceptance from a potential disposal site operator, where a proposal is for storing waste in an unconditioned form, a suitable outline of a proposed conditioning strategy for the waste should be included (this forms the basis for a suitable 'exit strategy' for producing a disposable package)

Other aspects that should be covered in RWMCs are:

- possible deterioration of the waste during storage
- main constraints on how the waste will be managed in the future, such as storage conditions and monitoring requirements
- arrangements for preserving information that might be needed to ensure safety and environmental protection during the future management of the waste stream and to make sure the waste can be accepted in a future long-term storage or disposal facility
- management, including disposal, of secondary radioactive waste arisings, especially those from the waste conditioning and storage

We recognise that only limited and provisional details can be provided by a RP at the GDA stage on some aspects of a RWMC. For example, in GDA, any RWMC will consider limited disposability assessments for conceptual waste packaging options only and will necessarily reflect that arrangements for waste information management will be the responsibility of future operators. We conclude that the RWMC produced by Hitachi-GE has addressed our expectations for the GDA stage in terms of the scope, content and level of detail.

2.5.13. Assessment of Hitachi-GE's disposability case

The disposability assessment RWM carried out for Hitachi-GE has made assumptions to allow the production of a comprehensive and detailed data set describing the ILW and spent fuel to be generated from operation and decommissioning of the UK ABWR. At a later stage, more specific and detailed proposals will be required for endorsing waste packaging proposals through the existing disposability assessment process.

This disposability assessment of the UK ABWR is the first time that disposal of waste from a boiling water reactor (BWR) has been considered in the UK; the closest equivalent in the UK is the Pressurised Water Reactor (PWR) at Sizewell-B operated by EDF Energy. BWRs operate at lower pressures than PWRs, and the reactor pressure vessel is larger in volume. Fuel assemblies used in a UK ABWR are smaller than those used by PWRs.

Despite the differences between the UK ABWR and PWRs, both designs are light water reactors, with fuel pellets fabricated from uranium dioxide with similar enrichments of uranium-235, and with broadly similar energy outputs. Both designs use zirconium-based cladding, and stainless and carbon steel. Both also use zirconium-based and Inconel metals in the spent fuel assembly and reactor vessel. Therefore, it is to be expected that the radionuclides listed in the waste and spent fuel inventories and the activities of these radionuclides will be broadly similar.

Main assumptions made by Hitachi-GE

Main assumptions Hitachi-GE made in its disposability submission to RWM are as follows:

- The site comprises one reactor unit. Packaged SF and ILW arising will be stored at the site where it was generated pending the availability of a GDF.
- The design basis for the UK ABWR fuel is to use the GE14 type (as described in Hitachi-GE, 2017c)
- Government policy, standards, legislative and regulatory environments remain unchanged, or changes pending have no significant impact.
- Packaging options will reflect only currently available technologies.
- Definitions of waste categories for SF and ILW will remain unchanged.
- The information takes the SF and waste that will be generated from the reference reactor design and the processes, equipment and facilities comprising that design as a starting point.
- In line with the government white paper (BERR, 2008), it is assumed that spent fuel will not be reprocessed but will be treated as a waste stream and stored, packaged and disposed of accordingly.
- The presence of failed fuel will not be assessed. However, RWM and the regulators are interested in the proposed strategy for dealing with this.
- Because GDF designs are only at an illustrative, conceptual stage and waste acceptance criteria are not available, the focus will be to ensure that spent fuel can be safely stored on-site for an extended interim period of many decades and will remain suitable for disposal.
- Hitachi-GE outlined a range of spent fuel management options that would be available to any future site operator. However, for the purpose of GDA, it selected using the spent fuel disposal container that has been developed by RWM. Before packaging the fuel for disposal, Hitachi-GE has assumed a dry cask storage system for interim storage of SF.

2.5.14. RWM's assessment of the disposability of proposed ILW packages

During GDA we expect to see evidence that, for each of the higher activity waste streams, there is at least one identified conditioning route that could be relied upon with reasonable confidence to provide disposable waste packages. A future operator will be expected to assess conditioning options at the site-specific permitting stage, or to demonstrate why the waste conditioning options identified during GDA remain valid at that time.

Hitachi-GE proposed packaging operational ILW based on established current practice for similar waste in the UK, including 3 m^3 drums and 3 m^3 boxes for operational ILW such as resins and control rods. We questioned the rate of arisings of control rod waste (RQ-ABWR-0031) and how BAT was demonstrated in this regard (Environment Agency, 2017a).

The proposals for packaging decommissioning ILW, such as the reactor pressure vessel and internals, were originally based on using UK standard waste containers consistent with RWM standards and specifications. Reactor vessel ILW was assumed by Hitachi-GE to be conditioned in into 3 m3 or 4 m boxes.

RWM identifies several areas which require further evaluation at a later stage (RWM, 2015). Overall RWM has judged the proposals for packaging operational and decommissioning ILW to be potentially viable. While further development needs have been identified, including the need to demonstrate the expected performance of the proposed waste packages, these would be the subject of future assessment under the (full) disposability assessment process when a future operator has developed further details on the packaging proposals.

The potential impact of the disposal of UK ABWR operational and decommissioning ILW on the size of a GDF has been assessed. It has been concluded that the ‘footprint area’ needed to dispose of ILW from the UK ABWR corresponds to approximately 45 m of vault length for each UK ABWR for higher strength rock. For RWM, the illustrative fleet of 4 UK ABWR reactors represents no significant change in the overall footprint compared with current assumptions in the published 2013 disposal inventory.

RWM judges the additional risks posed by the ILW (from an illustrative fleet of UK ABWRs) to be small in the context of the total ILW inventory destined for the GDF. Furthermore, since RWM’s generic assessment, based on a generic geology, indicates risks well within regulatory criteria, particularly the post-closure risk guidance level of one in a million per year, with the additional ILW from the UK ABWRs. However, RWM’s generic assessment rests on assumptions, by no means all of which have been demonstrated to be bounding. Indeed, some assumptions are essentially specifications of what will need to be achieved for the GDF to meet regulatory criteria. These assumptions will need to be confirmed in due course.

2.5.15. RWM assessment findings to be addressed during future disposability assessment interactions

RWM’s overarching findings for ILW include:

- The optimum time for disposal of the ILW. In particular, Hitachi-GE has proposed disposing of the waste shortly after it is generated. For some of the waste streams, this raises concerns in meeting transport limits and operational limits at the GDF. These could be addressed by a period of decay storage for the relevant waste.
- Hitachi-GE proposed that the reactor pressure vessel (RPV) decommissioning waste was packaged in 3 m3 or 4m boxes. The evaluations found that a significant period of decay storage would be required before some of the waste from this waste stream could be transported and placed in the proposed GDF if 4 m boxes were used. It was, therefore, recommended that these wastes should be placed in 3m^3 boxes and transported in standard waste transport containers.
- The control rods in the UK ABWR design differ from those in the previously assessed PWR designs where the potential exists to dispose of them with the spent fuel. We queried the proposed disposal options for control rods (RQ-ABWR-0032). In the case of the UK ABWR, the control rods, both hafnium and boron carbide variants, are separate from the fuel assemblies and are proposed to be disposed of as ILW. The nature of this waste is inherently challenging and it will require a period of decay storage before Hitachi-GE’s proposal for grout encapsulation in 3m^3 boxes. While they raise no insurmountable issues to prevent disposal, they will need to be subject to further assessment as the disposal plans are further developed.

Hitachi-GE accepts RWM’s advice, which future operators will need to consider further during the site-specific disposability assessment process in support of a conceptual stage disposability assessment. Hitachi-GE notes its initial waste management plans were developed to minimise the time raw and packaged waste was stored on-site, while making sure there was enough waste for efficient processing and packaging.

Additional aspects that RWM identified for consideration in any future submission for the UK ABWR ILW waste streams are identified below.

Resins and cruds

RWM notes that the conditioning factor of 3 that has been applied for the resins may be optimistic based on experience from Sizewell-B and that a conditioning factor of 10 may be more appropriate.

RWM notes that zinc added for water chemistry control could be incorporated into crud waste streams, for example if it plates out on steel surfaces instead of, or as well as, being taken up by ion exchange resins. Zinc could potentially act as a cement set retardant in crud and resin waste forms if present in sufficient quantities.

Hitachi-GE notes in its response that the experience at Sizewell-B is not necessarily applicable as the resins and cruds contain boron, also a cement set retardant, because of the dosing requirements of the storage pools. The UK ABWR reactor water does not contain boron. Hitachi-GE notes that further work to optimise waste loadings and grout formulations is required to demonstrate that the waste form is sufficiently robust for disposal. This work would be needed to complete the waste product specification (WPrS) that typically accompanies an interim stage disposability assessment.

RWM also notes that information on the types of resins present in the waste, and discussion of the expected degradation products would be needed as part of future submissions.

The decontamination resins waste stream inventory used in the assessment has a relatively high fissile content per package, exceeding screening levels and not being declared fissile excepted packages. This would require further evaluation in any future disposability assessment.

In future interactions under the disposability assessment process, the operator should propose a method for calculating the maximum package inventories for cruds and resins.

Hitachi-GE acknowledges that further information and assessment on resins will be needed as part of site specific disposability assessment work. Specific attention will be paid to the fissile content of the decommissioning resins. This is particularly important as it informs the criticality compliance assurance documentation (CCAD) that needs to be submitted before the interim stage assessment.

Control rods

RWM advises that Hitachi-GE's assumption of a packing density of 40 control rods per $3m^3$ box may be too high to facilitate grout encapsulation and cooling. RWM estimates 15 control rods can be placed in each box. Also, that there is a relatively high cobalt-60 inventory that may challenge transport regulations.

Hitachi-GE recognises that further development of the inventory, processing and packaging of the control rods is needed, including developing an approach to packaging the waste in a way that avoids concentrating the more highly irradiated components. Hitachi-GE proposes to address these issues as part of a site-specific disposability assessment that will draw upon more realistic inventory data.

Activated metals

RWM notes the neutron sources do not include antimony, which is a common element in modern neutron sources. It also notes that the monitoring probes may include fission chambers containing uranium. RWM requires that any uranium within the probes should be reported in more detailed disposability assessments submitted by a future operator.

Hitachi-GE plans for the UK ABWR reactor to use californium based neutron sources, avoiding the need to use chemotoxic neutron sources such as those containing antimony and beryllium. The monitoring probes do contain uranium and the radionuclide inventory will be updated accordingly as part of a disposability assessment carried out by a future site operator.

RWM notes that antimony and beryllium may be present in activated metal waste that presents a chemotoxic hazard. RWM also notes that the packing density of mixed metal packages is considered unfeasible on volume grounds and that the heat output would exceed transport limits at the proposed time of disposal.

Hitachi-GE accepts that a more detailed analysis of the constituent parts of the various waste streams would be conducted for a site-specific assessment as the reactor design progresses in order to highlight the presence of any toxic or hazardous materials.

2.5.16. Managing and disposing of spent fuel

The level of detail expected in GDA for spent fuel and waste management was clarified in a letter to Hitachi-GE (Environment Agency and ONR, 2012). Detailed design of spent fuel disposal arrangements is a matter for a future operator. For GDA, the Environment Agency expects a case to be provided that demonstrates that there is a credible strategy and option to manage spent fuel until a compatible disposal endpoint is available. However, it is recognised that any final decisions and detailed approaches are matters for a future operator.

Hitachi-GE’s proposed spent fuel management strategy for the UK ABWR comprises initial pool cooling, followed by dry storage and eventual geological disposal. It is proposed that spent fuel is stored in an on-site fuel store, sufficient to accommodate the arisings from its 60-year operational lifespan and encompassing the period from generation to availability of a disposal route via the assumed GDF.

Hitachi-GE proposes to manage fuel by initial spent fuel pool storage in the reactor building (up to 10 years for last fuel load before decommissioning). This is routine practice at reactor sites. We have assessed the waste arisings from the pool storage phase and identified no issues. The reactor cooling pool will utilise filter demineralisers for clean-up and the waste arisings will be conditioned for eventual disposal as ILW (Environment Agency, 2017a). Evaporation from the pool provides a source term to the HVAC, and we note that this route gives rise to discharges of volatile radionuclides.

We did query the proposed operational temperature limit for the spent fuel pool (proposed 52 ºC limit) as this is considerably higher than pool temperatures in current UK spent fuel storage pools (RQ-ABWR-0247). There are related implications in terms of gaseous discharges due to evaporation of tritium and iodine. Higher rates of evaporation can result in higher gaseous discharges, although these are considered low in terms of impact (Environment Agency, 2017c). Hitachi-GE responded to indicate that the pool temperature limit is unlikely to be approached and anticipate long-term pool temperatures of around 40 ºC, even with the highest envisaged fuel loadings. Hitachi-GE argues that the discharge implications of higher pool storage temperatures are likely to affect only tritium and iodine nuclides. We accept this but will expect pool temperatures to be subject to suitable arrangements to minimise any associated gaseous source terms.

Hitachi-GE has proposed, as a planning basis for GDA, that fuel storage periods of up to 140 years may be needed. This encompasses periods of reactor pool storage and subsequent interim storage, the latter covering the period between reactor pool storage and eventual disposal at a GDF.

In providing advice to Hitachi-GE, RWM has advised that the required timescales for the UK ABWR spent fuel to allow sufficient cooling to meet repository thermal limits depends on the final GDF design and location. RWM has identified required storage periods of between 40 and 130 years to meet thermal acceptance criteria based on a range of repository concepts at this time

(RWM, 2015). A period of 140 years of storage would encompass the range of required storage times in all cases RWM considered in the disposability advice it provided to Hitachi-GE.

Hitachi-GE performed an optioneering study to identify an optimised concept for interim fuel storage (Hitachi-GE, 2017d). This considered the following options: wet storage in a purpose built separate spent fuel pool, dry storage in metal canister with concrete overpack, dry storage in metal casks and dry storage within vaults. The study also considered a wide range of attributes, including environmental impact, which encompassed waste arisings.

Hitachi-GE's optioneering study identified dry storage in metal canisters with concrete overpacks as the lead option based on a multi-attribute decision analysis. This option scored higher than the others, that is, it is preferred against all 'environmental impact' attributes other than land use, which is a measure of the spatial extent of the storage facility. Hitachi-GE considers that the optioneering demonstrated conclusively that a concrete overpack system is the best available approach for spent fuel interim storage for the UK and observe that this is a 'proven option' used in the U.S. The vault option scored nominally higher against land use, as it has a smaller footprint. Dry cask storage is standard practice internationally and has recently been implemented for storing spent PWR fuel at Sizewell-B.

The proposed storage casks are not suitable for disposal and repacking will be required. Robust disposal containers manufactured from either copper or steel are considered and each would contain 12 fuel assemblies from a UK ABWR based on the concept design for GDA. The container materials are assumed to be durable and corrosion-resistant, so that they provide long-term containment for the radionuclides contained within the spent fuel. Future operators will need to consider options for spent fuel conditioning that are based on the best scientific knowledge and considerations from national programmes and approaches at that time.

We note that dry storage offers advantages in terms of avoiding waste discharges and limited secondary waste arisings, such as ion exchange resins from pool clean-up in wet fuel storage options. In particular, we note arguments that there will be no discharges or further waste arisings during the period of interim dry storage. It is argued that the only public dose implications in normal operations will be via direct radiation 'shine', which is a matter that is regulated by the Office for Nuclear Regulation (ONR). Direct shine is a contributor to projected total site dose and we have considered this in our assessment of public dose (Environment Agency, 2017h).

Should significant repackaging of spent fuel waste be needed for final disposal, there is a possibility that additional radioactive waste might arise. For example, fuel degradation during interim storage could result in the contamination of storage casks. Should storage containers not prove compatible with any final disposal arrangements, these may arise as waste should any associated contamination not be able to be easily removed. We would expect a future site operator to make sure that waste storage facilities are compatible with envisaged disposal endpoints at the time of implementation. We also queried proposed arrangements for spent fuel inspection during long-term storage (RQ-ABWR-0037). Such aspects will be considered further at the detailed design stage and is identified as an assessment finding (Assessment Finding 10).

Clearly no long-term storage option is supported by operational experience over the proposed storage timescales (up to 140 years). At this time, there is also no international experience in recovering fuel following such long-term storage periods, nor in the geological disposal of spent fuel. We are satisfied, however, that there is no reason to assume that long-term dry storage and recovery for eventual disposal is not technically feasible at this time. This is consistent with the Environment Agency view on geological disposal (Environment Agency, 2016b).

We raised query RQ-ABWR-0091 to understand if fuel failure, of the type envisaged in the definition of an 'expected event', would have any significant implications for disposal. Hitachi-GE argues that the types of failure that are envisaged are minor pin hole cracks that will not lead to significant breach of the cladding that would need special handling or disposal arrangements. We queried options for dealing with failed fuel (RQ-ABWR-0036) and any associated implications (RQ-ABWR-0091).

We understand, from RWM advice, that the environmental safety case for the GDF is unlikely to rely on cladding integrity as a major contributor to radionuclide containment, such as in the KBS-3 disposal concept. Therefore, our understanding at this time is that any implications of cladding failure are deemed of low significance in relation to projected impacts in the long term following disposal. However, we will expect the potential implications of any fuel failures in relation to the disposal case to be considered further, and we will expect a future operator to seek advice on such matters from RWM.

Overall, we agree that adopting a dry storage concept for the interim storage of spent fuel is a suitable assumption to support the generic design for the UK ABWR. Ensuring the performance of spent fuel during storage so as not to compromise eventual disposal is a matter for future operators to consider further. ONR regulates the storage of waste on nuclear licensed sites. We will seek a view from ONR as it continues to assess the suitability of conceptual proposals for interim fuel storage. Advice from ONR will help inform our final view on this matter as GDA proceeds.

2.5.17. On-site interim storage of spent fuel

ONR will indicate its requirements for a demonstration that safety can be assured during storage, possibly for significant timescales. Since the disposability assessment assumes that this storage takes place, our view on disposability must be subject to such a demonstration being provided to ONR's satisfaction.

2.5.18. Transport of spent fuel to a GDF

ONR will indicate its requirements for a demonstration that safety can be assured when transporting spent fuel to a GDF. RWM planning for transporting packaged spent fuel to a GDF is at an early stage of development. Consequently, although the UK ABWR spent fuel may influence the arrangements, for example, through the need for additional shielding, RWM has judged that sufficient flexibility exists in the outline designs for transport of spent fuel disposal packages to a GDF to allow suitable arrangements to be developed.

2.5.19. RWM's assessment of the disposability of spent fuel packages

Hitachi-GE identifies several options for packaging of spent fuel for on-site interim storage and eventual disposal. However, the RWM disposability assessment for the spent fuel from the UK ABWR is based on it being over-packed for disposal, using robust disposal containers manufactured from a suitable material such as copper or steel to ensure long-term containment. The choice of container material depends on the properties of the host rock setting for a GDF. RWM recognises that the performance of the disposal container will be an important element of a disposal safety case. Consequently, it is anticipated that RWM will continue to develop container designs, including the designs of containers for UK ABWR spent fuel, to substantiate the continued robustness of current assumptions and tailoring the designs to whatever site is ultimately identified.

The radiological risks calculated for the disposal of spent fuel reflect the assumed performance of the proposed packaging options. Sensitivity analysis carried out by RWM has demonstrated that while the calculated risk would be influenced by the performance of the container material, together with the performance of other engineered barriers and the geological barrier, the overall magnitude of the risk was calculated to be below the regulatory guidance level.

The potential impact of the disposal of UK ABWR spent fuel on the size of a GDF has been assessed. The scenario of 16 GW of nuclear new build has been estimated previously to produce spent fuel containers that will fill approximately 202 disposal tunnels in a GDF in high strength rock. The assumed operating scenario for a single UK ABWR gives rise to an estimated 800 spent fuel disposal containers, requiring approximately 18 disposal tunnels for disposal in higher strength rock. For the RWM illustrative fleet of 4 UK ABWR reactors, representing 5.40GW, this would be equivalent to 72 disposal tunnels. This indicates that the required number of disposal tunnels is within the range assumed for a 16 GW fleet of new nuclear build.

We queried the spent fuel inventory data Hitachi-GE provided to RWM for the disposability assessment, in terms of the decay heat assumptions, nuclide library selection (RQ-ABWR-0303) and assumption of fuel configuration (RQ-ABWR-0304). RWM checked Hitachi-GE's spent fuel assembly inventories by using independent calculations, which were confirmed to be conservative. RWM assumed each disposal container would contain 12 fuel assemblies, delivered to the disposal facility packaged in the disposal containers, which in turn would be transported in a reusable transport container. RWM concluded that the inventory data Hitachi-GE supplied, together with supplementary data, has provided a reliable and conservative data set that can give confidence in the calculations of the GDA disposability assessment.

2.5.20. Fuel burn-up and cooling times

Hitachi-GE provided information to support 2 fuel assembly burn-up scenarios: 50 GWd/tU and 60 GWd/tU, for a reactor operating life of 60 years. These burn-up figures are relatively high compared with current light water reactor operations in the UK. Increased burn-up implies that the fuel is used more efficiently and that the volume of fuel to be disposed of will be smaller per unit of electricity produced. However, increased irradiation leads to individual fuel assemblies with an increased concentration of fission products and higher actinides, leading, in turn, to spent fuel assemblies with higher thermal output and dose-rate. This is recognised as an important consideration in the assessment of spent fuel from the UK ABWR when compared to the assessment of lower burn-up fuel, for example from reactors that have operated historically and are operating at the present.

In order to derive an appropriate cooling time before disposal, RWM considered the performance of the disposal system as a whole in different geological host rocks. The materials used as part of the engineered barrier system, and the characteristics of the host rock, will affect the thermal criteria used to determine the acceptability of the heat output from waste packages consigned for disposal. In the current generic phase of the GDF programme, generic thermal criteria were used to determine approximate cooling times required before disposal of spent fuel. Different thermal criteria were applied in the illustrative disposal concepts for different host rocks. In higher strength rock, the temperature criterion requires that the temperature of the inner surface of the bentonite buffer should not exceed 100 °C. In lower strength sedimentary rock, the temperature criterion is that the buffer temperature should not exceed 125 °C at its mid-point. In evaporites, the temperature criterion is that the temperature of the host rock should not exceed 200 °C. These limits are consistent with criteria used in disposal programmes in other countries.

Based on a spent fuel waste package containing 12 UK ABWR fuel assemblies and adopting the spacing used in the illustrative designs for higher strength rock, it would require between 50 and 100 years for the activity, and therefore heat output, of the UK ABWR fuel to decay sufficiently to meet the existing temperature criterion. This period allows for both the range of predicted ABWR fuel burn-up (50 – 60 GWd/tU) and the range of rock characteristics that may be encountered for a GDF at a depth of 650 m.

The cooling time needed to meet the temperature criteria in the lower strength sedimentary rock illustrative design has a greater range owing to a greater range in the thermal conductivity of the lower strength sedimentary host rocks that could be used to host a GDF. The cooling time required in lower strength sedimentary rocks is currently estimated to be between 50 and 130 years. This range is for the same burn-ups as the higher strength rock case.

For the illustrative designs in evaporite host rocks, the cooling time required is estimated to be less than 40 years.

These cooling times depend on a number of uncertainties, in particular the conservative assumptions made in developing the inventory for spent fuel, the uncertainty in the physical properties of the various components of the GDF, in particular the thermal conductivity of the host rock, and the details of the underground design, for example package spacing and facility depth. These uncertainties could be reduced by further work, for example, by refining the assessment inventory, by taking into account the cooling of the spent fuel being stored before the end of the operational period. Ultimately, cooling times can be managed by considering alternative container and GDF designs. RWM will continue to look at the options.

2.5.21. RWM identifies 4 assessment findings in relation to spent fuel management

- The storage of spent fuel in water pools means that drying techniques will need to be put in place to avoid the potential for internal pressurisation of storage/disposal containers and to make sure that they would comply with transport regulations.
- Storage conditions will need to be managed to maintain integrity of the fuel assembly and cladding and any storage/disposal container during storage operations. If a wet storage strategy were to be implemented, a main requirement would be to maintain conditions to preserve the integrity of any stainless steel components, for example tie bars. If a dry storage system were implemented, temperature and relative humidity would need to be controlled to minimise the potential for degradation, for example by hydride embrittlement of fuel assembly components and any disposal container.
- RWM recommends that a future operator considers extending safeguards provisions through to disposal, particularly for spent fuel, and considers, working with RWM, whether and how the safeguards status of spent fuel will be terminated.
- Further confirmation would be sought during future interactions under the disposability assessment process that all chemotoxic species have been identified.

Hitachi-GE recognises that these issues would need to be addressed as part of the site-specific disposability assessment for spent fuel, once spent fuel management strategies and facilities are agreed.

3. Compliance with Environment Agency requirements

Table 3. Compliance with Environment Agency requirements

P&ID Table 1 Section or REP	Comments
P&I Table 1 items 4 and 5 (solid waste aspects only)	We are satisfied that the correct parts of the P&ID have been addressed through Hitachi-GE's documentation in relation to this topic.
P&I Table 1 (generic site)	We are satisfied that the correct parts of the P&ID have been addressed through Hitachi-GE's documentation.
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, with the results shown in the 'Demonstration of BAT' document. BAT arguments are presented to demonstrate that the design enables efficient fuel use and includes measures to reduce fuel failure (and, therefore, waste arisings).
RSMDP8 – Segregation of waste	The design of the UK ABWR takes into account the needs of appropriate waste management techniques, such as keeping waste streams separated where appropriate. The RWMA document demonstrates the philosophy underpinning waste management arrangements, including appropriate emphasis on the waste hierarchy. The 'Approach to optimisation' document demonstrates how the most suitable equipment and management techniques are assessed and applied. Systems descriptions are provided in PCSR Chapter 18: Radioactive Waste Management.
Principle RSMDP9 – Characterisation	Each radioactive waste stream will be characterised and managed in accordance with BAT to ensure most appropriate handling and disposal. This approach is outlined in the RWMA document for solid waste streams, and the 'Approach to sampling and monitoring' document for radiation measurements in liquid and gaseous streams.
Principle RSMDP10 – Storage	Information on the proposed storage practices is outlined in the RWMA document and relevant PCSR chapters. Hitachi-GE argues that liquid and solid waste will be stored independently inside multi-layered containment to prevent any radioactivity leaks from the facilities. The storage methods for liquid and solid waste, including spent fuel, aim to take account of all requirements in terms of being passively safe and enabling future treatment options, where applicable, and disposal.
Principle RSMPD15 – Requirements and conditions for disposal of waste	Disposability assessments and radioactive waste management cases for significant waste streams are referenced by the RWMA document. Compliance with actual disposal requirements as detailed in the environmental permit will be the responsibility of future operators.

4. Public comments

Hitachi-GE received 5 public comments up to 15 August 2017 concerned with solid waste management.

On 8 January 2014, Hitachi-GE received a comment asking where on-site spent fuel was stored and what precautions would be in place when spent fuel is removed from the reactor building. Hitachi-GE responded that spent fuel would be stored safely on-site for an interim period before ultimate disposal, noting that the developer would decide on the exact layout of such storage facilities.

On 13 January 2014, Hitachi-GE received a comment from Warwickshire Council stating that the GDA should consider the whole lifetime of the design, including decommissioning, and enquiring where LLW would be disposed of. Hitachi-GE responded that considering decommissioning is a requirement of GDA and that it would produce a decommissioning strategy. Hitachi-GE further stated that it would provide information on LLW disposal in future submissions.

On 28 August 2015, Hitachi-GE received a comment asking what volume of 'highly radioactive waste' would be expected to be produced per year and how this would be stored, recycled or reduced. Hitachi-GE responded that the exact volumes of waste produced would depend on the operating conditions, which are decisions for the operator.

On 7 January 2016, Hitachi-GE received a comment asking how much spent fuel was estimated to be accumulated on site at the end of an assumed 40 years of operation, the burn-up range, interim storage arrangements and if there was a limit to the time spent fuel can be stored on-site. Hitachi-GE responded that the exact quantities of spent fuel will ultimately depend on the operating conditions selected by a future operator, but an assumed case had been included in GDA.

On 7 January 2016, Hitachi-GE received a comment asking if there were any limits to either the quantity or time that spent fuel could be stored on site. Hitachi-GE responded these issues were not within scope of GDA.

On 11 November 2016, Hitachi-GE received a comment asking for clarification if the steam entering the turbines would be radioactive and, if so, what special measures would be required in the turbine hall and if, as result, the UK ABWR would produce more radioactive wastes relative to other designs. Hitachi-GE responded to confirm that, unlike PWRs, which have a secondary circuit, the UK ABWR, as with all BWRs, is a direct cycle design. However, Hitachi-GE confirmed that contamination of the turbine components would be minimal and that the turbine hall would not require the same level of containment as the reactor pressure vessel. Hitachi-GE also stated that there was no correlation between a direct or secondary cycle design and generation of wastes.

On 13 February 2017, Hitachi-GE received a comment regarding the proposed management of HAW. Hitachi-GE responded to clarify that on-site storage for approximately 150 years followed by disposal in a GDF for HAW is based on UK government policy and is the preferred solution for these types of waste.

We held a public consultation on our preliminary GDA assessment findings (Environment Agency, 2016c), which ran for 12 weeks, from 12 December 2016 to 3 March 2017. We received a number of consultation responses, all of which have been published in full for everyone to view (Environment Agency, 2017e). Our replies to each point raised are presented within our decision document (Environment Agency 2017f). However, points raised that were in GDA scope and relevant to solid waste and spent fuel are summarised below:

We received a response (ABWR-05) from the Berkeley Site Stakeholder Group (ABWR-05) raising concerns 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 had 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 that represents BAT, including the choice and operation of fuel.

In response to question 7 (solid waste) we received a query that raised concern about the comparison of the waste arisings between a UK ABWR and other similar reactor types. We have noted that this type of information is difficult to obtain and concluded that the comparisons undertaken by Hitachi-GE and RWM indicate that the waste arisings from a UK ABWR are comparable to similar reactors, and those which have been submitted for GDA (Environment Agency, 2016a).

We received a response (ABWR-19) from an individual asking for quantification of the amount of spent fuel (in terms of millions of TBq) that would be accumulated at the Wylfa interim store after 60 years and how this compared to the total activity of waste at the Sellafield site. We reviewed publicly available information and were not able to provide the total activity in terms of TBq. However, Hitachi-GE had estimated that a UK ABWR would generate 9,600 fuel assemblies during a 60 year operational lifetime.

It is difficult to compare waste arisings from different types of facilities. However, in its generic design assessment (RWM, 2016), RWM has compared the activity in a proposed UK ABWR spent fuel package to that from Sizewell B (the UK’s only operating PWR), and concluded that the radionuclide inventories for UK ABWR and Sizewell-B fuel are similar.

Data on the waste arisings at Sellafield can be found in the UK Radioactive Waste Inventory (NDA, 2016).

5. Conclusion

We conclude overall that:

- in its submissions, Hitachi-GE describes how solid radioactive waste (low level waste (LLW), intermediate level waste (ILW) and spent fuel) will be generated, managed and disposed of throughout the facility’s life cycle at a level of detail in line with our expectations for GDA
- the quantities of solid radioactive waste produced by the UK ABWR are broadly comparable to other light water reactor power stations across the world and that the UK ABWR design uses best available techniques (BAT) to minimise the mass/volume of solid radioactive waste that will need to be disposed of (Environment Agency, 2017a)
- solid radioactive waste can be treated and conditioned using proven and recognised techniques and that potential disposal routes have been identified for all solid LLW
- Hitachi-GE has provided information on the fuel composition and characteristics, the expected fuel burn up and the quantities of spent fuel that will arise, and described how spent fuel will be managed and disposed of throughout the life cycle of a UK ABWR at a level of detail in line with our expectations for GDA
- the proposed arrangements for interim management of higher activity solid wastes and spent fuel are unlikely to prevent their ultimate disposal. This conclusion is based on the conceptual options that have been described to date

- Hitachi-GE has obtained a view from RWM, as the UK authoritative source in providing such advice, on the disposability of ILW and spent fuel, responded to the RWM advice and provided an opinion to the regulators

We conclude that all relevant aspects of the P&ID in relation to solid radioactive waste have been addressed. The case Hitachi-GE presented is in line with the Environment Agency's and Natural Resources Wales's expectations for GDA. We further conclude that Hitachi-GE has provided a satisfactory submission in relation to spent fuel for the UK-ABWR, and we have identified no issues in relation to spent fuel to prevent us issuing a statement of design acceptability (SoDA).

Furthermore, Hitachi-GE obtained disposability advice from RWM and produced a report responding to this advice and how it will be taken forward. We have reviewed the exchanges between Hitachi-GE and RWM and are satisfied that due process has been followed in respect of obtaining advice on disposability of ILW and spent fuel. Subject to satisfactorily demonstrating that spent fuel can be stored safely for the necessary period of time without significant degradation and safely transported to a GDF, we see no reason to believe that any of the ILW or spent fuel from a UK ABWR will not be disposable in a suitably designed and located GDF.

We have engaged with ONR throughout our assessment and conclude that the arrangements proposed by Hitachi-GE for the UK ABWR at the GDA stage are suitable.

RWM has also identified a range of assessment findings with regards to the proposed management of waste and spent fuels which a future site operator will need to address through RWM's disposability assessment work.

We have identified the following Assessment Findings:

Assessment Finding 9: A future operator shall, before procurement, provide detailed designs for solid radioactive waste management, storage and conditioning facilities that were covered at a conceptual level during generic design assessment, and demonstrate how these represent best available techniques.

Assessment Finding 10: A future operator shall demonstrate optimised management and disposal of solid radioactive wastes from the UK ABWR, addressing in particular:

- conditioning of higher activity waste arisings to ensure disposability
- selection of disposal routes for wastes at the low activity waste/high activity waste boundary
- management of spent nuclear fuel and any associated secondary wastes to ensure disposability
- selection of disposal routes for low activity waste

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List of abbreviations

Abbreviation	Details
ABWR	Advanced boiling water reactor
ALARA	As low as reasonably achievable
BAT	Best available techniques
BERR	Department for Business Enterprise and Regulatory Reform
BWR	Boiling water reactor
CCAD	Criticality compliance assurance document
CF	Condensate filter
CUW	Reactor Water Clean-up water
DECC	Department of Energy and Climate Change
FP	Fission product
FPC	Fuel pool cooling and clean-up system
GDA	Generic design assessment
GDF	Geological disposal facility
GEP	Generic environmental permit
HAW	Higher activity waste
HCW	High chemical impurity waste
HLW	High level waste
HVAC	Heating, ventilation and air conditioning
ILW	Intermediate level waste
IILWS	Interim intermediate level waste store

Abbreviation	Details
IWS	Integrated waste strategy
IX	Ion exchange
LAW	Lower activity waste
LCW	Low chemical impurity waste
LLW	Low level waste
LLWR	Low Level Waste Repository (Limited)
LoC	Letter of compliance
NDA	Nuclear Decommissioning Authority
NRW	Natural Resources Wales
ONR	Office for Nuclear Regulation
P&ID	Process and information document
PCI	Pellet-clad interaction
PCSR	Pre-construction safety report
PWR	Pressurised water reactor
P&ID	Process and information document
REP	Regulation Environmental Principle
RI	Regulatory issue
RO	Regulatory observation
RP	Requesting party
RPV	Reactor pressure vessel
RQ	Regulatory query

Abbreviation	Details
RSR	Radioactive substances regulation
RWM	Radioactive Waste Management (Limited)
RWMA	Radioactive waste management arrangements
RWMC	Radioactive waste management case
SEPA	Scottish Environment Protection Agency
SFAIRP	So far as is reasonably practicable
SFIS	Spent fuel interim store
SLLW	Solid low level waste
SILW	Solid intermediate level waste
SoDA	Statement of design acceptability
UK	United Kingdom
VLLW	Very low level waste
WAC	Waste acceptance criteria
WILW	Wet intermediate level waste
WPrS	Waste product specification
WSLLW	Wet solid low level waste

Appendix 1: Summary of solid waste arisings

Summary table of solid radioactive waste arisings and proposed management and disposal routes (Tables A2.3-1 to A2.9-1 in (Hitachi-GE, 2017a)). The assessment of BAT is the subject of a separate assessment report (Environment Agency, 2017a).

Table A1: Summary table of solid waste arisings

Waste type	Key radionuclides and specific activity	Description	Source	Annual or periodic arisings and disposals volume	Waste management route
VLLW	Dependent upon operational source; mainly steel activation products.	Miscellaneous combustible: paper, polythene, cloth.	Maintenance operations	14 m^3/year arising combustible (3 m^3/year after compaction) 3.4 m^3/year non-combustible	Compact and incineration Metal recycling service and disposal at an appropriately permitted site (For example, LLWR)
Dry-solid LLW	iron-55, cobalt-60, zinc-65, manganese-54, cesium-137, strontium-90, antimony-125	HVAC filters.	HVAC system	24 m^3/year HVAC + miscellaneous. combustible (9 m^3/year after compaction)	Compact and incineration
	iron-55, cobalt-60, manganese-54, nickel-63	Miscellaneous combustible: paper, polythene, cloth, Low Chemical impurity Waste, spent activated carbon.	As for VLLW combustible plus LD.	37.2 m^3/year (12 m^3/year after compaction)	Compact (not for spent activated carbon) and incineration

Waste type	Key radionuclides and specific activity	Description	Source	Annual or periodic arisings and disposals volume	Waste management route
	iron-55, cobalt-60, magnesium-54	Recyclable metals.		2.3 m^3/year	Off-site recycling
	iron-55, cobalt-60, magnesium-54	Non-combustible and non-compactable waste (including (LCW) filter membrane metals unsuitable for recycling and condensate filters (CFs)).	As for VLLW non-combustible plus LCW and CF system.	7.7 m^3/year	Disposal at an appropriately permitted site (For example, LLWR)
Wet-solid LLW	iron-55, cobalt-60, magnesium-54, nickel-63	Organic bead demineraliser resin (condensate, LCW, HCW), HCW evaporator sludge, granular activated carbon from LD system.	Condensate, LCW, HCW, LD.	13.3 m^3/year (before cementation)	Disposal at an appropriately permitted site (For example, LLWR)
Dry-solid ILW	cobalt-60, nickel-63 (californium-252 in neutron source)	Activated metals: control rods, reactor components (for example, neutron source unit).		Control rods: 676 units/60 years HAW metals: 33 t/60 years Fuel channels to be disposed of with SF.	Disposal at GDF
Wet-solid ILW	iron-55, cobalt-60, magnesium-54, zinc-65	Organic powder demineraliser resin (reactor water clean-Up system (CUW) and fuel pool cooling and clean-up (FPC)	CUW, FPC, CF & LCW.	4.4 m^3/year, 270 m^3/60 years powder resin. 1.5 m^3/year, 90 m^3/60 years sludge (before cementation).	Disposal at GDF

Waste type	Key radionuclides and specific activity	Description	Source	Annual or periodic arisings and disposals volume	Waste management route
		systems), sludge (crud) from CF and LCW filters.			
Fuel	FPs, activation products and actinides	Fuel assemblies of GE14 design: uranium dioxide pellets within zircaloy cladding; fuel rods held in bundles.	Fuel	Approximately 150 assemblies/year (including 6.8 t/year fuel channels)	Disposal at GDF

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