Cyfoeth Naturiol Cymru
Natural Resources Wales

Environment Agency

Assessing new nuclear power station designs

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

Assessment report - AR04 Gaseous waste

December 2017

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Executive summary

Protective status	This document contains no sensitive nuclear information.

Process and Information Document	The following section of Table 1 in our process and information document (P&ID) (Environment Agency, 2016a) is relevant to this assessment: Item 5: Quantification of radioactive waste disposals. Provide quantitative estimates for normal operation of discharges of gaseous and aqueous radioactive wastes and provide proposed limits for gaseous and aqueous discharges.

Radioactive Substances Regulation Environmental Principles	The following principle (Environment Agency, 2010) is relevant to this assessment: RSMDP12 – limits and levels on discharges. Limits and levels should be established on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment.

Report author	Dr Claire Cailes

This report presents the findings of the assessment of information relating to gaseous radioactive discharges and proposed gaseous discharge limits that Hitachi-GE provided for the UK ABWR design, submitted to the Environment Agency under the generic design assessment (GDA) process. This report considers submissions received up to and including 31 August 2017.

During our assessment we raised one Regulatory Issue (RI), 2 Regulatory Observations (ROs) and 8 Regulatory Queries (RQs) related to gaseous radioactive discharges and proposed limits.

We conclude that Hitachi-GE has provided us with information on estimated gaseous discharges and proposed limits, and that it is clear how it has derived these discharge estimates and that the estimates are supported by suitable evidence.

We conclude that the proposed annual gaseous discharge limits for the UK ABWR are derived in a way that is consistent with our guidance and are of an appropriate order of magnitude.

We conclude that the gaseous discharges from the UK ABWR should not exceed those of comparable power stations across the world, and will be capable of meeting the limits set out below (Table 1):

Table 1. Proposed annual limits for gaseous discharges from the UK ABWR

Radionuclide or radionuclide group	Proposed annual limit for UK ABWR (Bq)
Argon-41 (Ar-41)	5.2E+12
Carbon-14 (C-14)	1.7E+12
Tritium (H-3)	1.0E+13
Noble gases (excluding argon-41)	2.2E+11

One assessment finding (AF) has been identified which is related to gaseous discharges of radioactive waste:

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

Contents

1. Introduction

This assessment considers the information that Hitachi-GE provided for its UK ABWR design. This report considers submissions received up to and including 31 August 2017. This assessment considers the gaseous radioactive discharges and proposed gaseous discharge limits that Hitachi-GE provided for the UK ABWR design. The assessment aims to establish whether the design could be operated in England and Wales in line with UK statute, policy and guidance on radioactive waste, or if changes to the design are required. The assessment also aims to identify any areas where not enough information has been provided in GDA, and any issues that should be taken forward to be considered at the site-specific permitting stage.

We expect new nuclear power plants to use best available techniques (BAT) to prevent and, where that is not practicable, minimise the creation of radioactive wastes, and to minimise the impact of discharges of radioactive waste on the environment. We have considered the application of BAT for the UK ABWR design, including BAT for gaseous radioactive discharges, in another assessment report (Environment Agency, 2017a).

Our consideration as to the acceptability of proposed discharges will be carried forward into our radiological impact assessment on members of the public and non-human species, for which we have written separate assessment reports (Environment Agency, 2017b, 2017c).

We have assessed the aqueous radioactive discharges and proposed limits for the UK ABWR; details of this assessment can be found in a separate assessment report (Environment Agency, 2017d).

1.1. Scope of this assessment

This assessment considers gaseous radioactive waste arisings from all aspects of normal operation, for example, at power, start-up, shut-down, outage, and discharges resulting from any other events expected to occur during the lifetime of the reactors (‘expected events’).

This assessment report does not cover gaseous radioactive waste arising from decommissioning at the end of the reactor life cycle. Our assessment of the UK ABWR decommissioning strategy is the subject of a separate assessment report (Environment Agency, 2017e).

The information Hitachi-GE provided does not consider discharges to the atmosphere from the service building. The structure of the service building is defined in GDA, but the services are not fully defined at this stage. Therefore, the details of the discharges from the service building will not be known until site-permitting stage. Any future operator will need to quantify discharges to the atmosphere from the service building. Hitachi-GE states that initial assessment of the gaseous discharges from the service building shows that these would be negligible. In addition, discharges from the dry solid low level waste (LLW) processing facility, the intermediate level waste (ILW) store and interim spent fuel store are not provided. These facilities are at concept design stage only. Any future operator will need to quantify discharges to the atmosphere from these facilities. Hitachi-GE states that the discharges from these facilities are expected to be a small fraction of the overall site discharges.

1.2. Statute, policy, guidance and requirements

In our process and information document (P&ID) (Environment Agency, 2016a), we set out our requirements to a requesting party (RP); the RP in this case is Hitachi-GE.

Hitachi-GE was required to:

- provide quantitative estimates for normal operation of discharges of gaseous waste
- provide estimates for monthly discharges:
    - on an individual radionuclide basis for significant radionuclides
    - on a group basis for other radionuclides

- via each discharge point and discharge route
- clearly show the contribution to gaseous discharges that each constituent aspect of normal operations makes including:
  - routine operation
  - start-up and shutdown
  - maintenance and testing
  - infrequent but necessary aspects of operation, for example, plant wash-out; and the foreseeable, undesired deviations from planned operation consistent with the use of BAT, for example, occasional fuel pin failures ('expected events')

- support gaseous discharge estimates with performance data from similar facilities and explain, where relevant, how changes in design or operation from those facilities affect the expected discharges
- demonstrate that discharges and waste arisings will not exceed those of comparable power stations across the world
- provide proposed limits for gaseous discharges (on a rolling 12-month basis) and explain how these limits were derived

The P&ID (Environment Agency, 2016a) provides more detail on what constitutes 'normal operation' and 'significant radionuclides'.

Normal operation includes the operational fluctuations, trends and events that are expected to occur over the lifetime of the facility, such as start-up, shutdown, maintenance and so on. It does not include increased discharges arising from other events, inconsistent with the use of BAT, such as accidents, inadequate maintenance, and inadequate operation.

Significant radionuclides are those which:

- *are significant in terms of the radiological impact for people or non-human species*
- *are significant in terms of the quantity of radioactivity discharged*
- *have long half-lives, may persist and/or accumulate in the environment, and may contribute significantly to collective dose*
- *are significant indicators of facility performance and process control*

We published our Radioactive Substances Regulation Environmental Principles (REPs) in 2010 (Environment Agency, 2010). The REP that is most relevant to assessing gaseous discharges is:

RSMDP12 – limits and levels on discharges. Limits and levels should be established on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment.

2. Design summary: gaseous discharges from UK ABWR

The UK ABWR discharges gaseous radioactive waste into the environment via the main stack located on the reactor building. Gaseous waste reaches the stack via one of 3 routes, via the off-gas system (OG), via the heating, ventilation and air conditioning system (HVAC) or via the turbine gland steam system (TGS).

Radionuclides discharged to the environment as gaseous waste are produced by 3 mechanisms within the reactor core:

- fission products produced from fission of tramp uranium or from leakage from fuel pin failure
- corrosion products produced from materials dissolved into the reactor water or particulates arising from wear and tear of the reactor
- activation products produced by neutron activation of water

Hitachi-GE has considered gaseous discharges arising from all modes of normal operation: start-up, at power, shutdown, outage and discharges resulting from any other events expected to occur during the lifetime of the reactor (‘expected events’). Hitachi-GE identified one expected event for the UK ABWR, which was fuel pin failure.

Information and assessment of aspects related to application of BAT for gaseous discharges can be found in another assessment concerned with the assessment of BAT for the UK ABWR design (Environment Agency, 2017a).

2.1. Off-gas system

The steam that leaves the reactor and travels to the turbines contains radionuclides. As the steam is condensed in the condenser, most radionuclides are also condensed and contained within the reactor water/steam circuit. However, some do not condense and instead enter the OG before being released to the atmosphere as gaseous radioactive discharges. Abatement techniques used in the OG reduce the amount of radionuclides that are discharged into the environment. Radioactive gases are delayed within the OG to enable those with short half-lives to decay before being discharged. Also, radioactive gases are filtered to remove particulate matter before being discharged. At present, there are no practicable techniques for abatement of carbon-14, and this is discharged to the environment from the stack via the OG.

The OG contains 4 charcoal beds which the radioactive gases are passed through. The charcoal beds adsorb radioactive noble gases, allowing those radionuclides with short half-lives to decay within the OG rather than being discharged to the environment. Hitachi-GE states that the charcoal beds hold up isotopes of xenon for 30 days and isotopes of krypton for 40 hours, which reduces discharges of radioactive krypton and xenon to the environment by 99.997%. Radioactive argon is also held up by the delay beds for 7 hours, which reduces discharges of radioactive argon by 93%.

Iodine radionuclides are largely condensed and remain in the reactor circuit. Any iodine radionuclides that reach the OG are held up by the delay beds, reducing the amount that are discharged into the environment via this route to very low levels.

Tritium is largely removed from the OG gaseous waste stream by the OG recombiner and condenser. The recombiner joins hydrogen and oxygen to create water, which is condensed and returns to the condensate storage tank (CST) to be reused within the plant.

Gaseous radioactive discharges are released from the stack via the OG during start-up, at power, and shutdown. However, during outage, the turbine and condenser are isolated from the reactor by closure of the main steam isolation valves. Therefore, there are no discharges via the OG during outage.

2.2. Heating, ventilation and air-conditioning system

The HVAC maintains negative pressure in areas containing radioactivity by constantly drawing in air from around the plant, and discharging it to the atmosphere. This reduces uncontrolled releases of radioactivity through doors, windows and gaps. The HVAC is operational during all stages of normal operation, including outage. The UK ABWR employs high efficiency particulate air (HEPA) filters to reduce the amount of particulates in gaseous waste being discharged into the environment. Tritium and iodine radionuclides are discharged from the stack via the HVAC route.

2.3. Turbine gland steam system

The TGS supplies sealing steam to the high pressure and low pressure turbine glands – the gaps between the rotating shaft of the turbine, and the turbine casing. The sealing steam is supplied to the high pressure turbine gland to prevent the release of reactor water and steam from the turbine to the turbine building, as the high pressure turbine internal pressure is positive compared with the turbine gland. The sealing steam is supplied to the low pressure turbine to prevent air leaking into the main condenser, as the low pressure turbine internal pressure is negative compared with the turbine gland.

The steam used in the TGS is generated from liquid in the CST which contains radionuclides. After the steam has passed through the turbine glands, it is condensed. Any radionuclides that do not condense, and instead remain in the gaseous phase, are discharged into the environment via the main stack. Tritium and iodine radionuclides are discharged to the environment from the TGS. Particulates are also discharged, although HEPA filters are used to reduce these.

For the purposes of estimating discharges, Hitachi-GE assumes that 100% of carbon-14 is partitioned into the gaseous phase and released from the stack via the OG. Therefore, Hitachi-GE assumes that there is no carbon-14 in the CST and so there are assumed to be no discharges of carbon-14 via the TGS. We discuss the assumption that no carbon-14 remains in the liquid phase further in our assessment reports concerned with aqueous radioactive discharges (Environment Agency, 2017d) and BAT (Environment Agency, 2017a).

Discharges from the TGS occur during start-up, at power and shutdown. There are no discharges from the TGS during outage as the turbine does not operate during outage.

2.4. Estimated gaseous discharges and proposed limits

Hitachi-GE has provided us with information on the estimated annual gaseous discharges in generic environmental permit (GEP) Revision G ‘Quantification of discharges and limits’, Table 7.1-8 (Hitachi-GE, 2017). In addition, the estimated discharges from a fuel-pin failure is provided in GEP Revision G ‘Quantification of discharges and limits’, Table 7.1-10 (Hitachi-GE, 2017).

Hitachi-GE has identified some radionuclides as ‘significant’ for gaseous discharges to the environment and, therefore, important in any future site-specific permitting. Significant radionuclides are those that are discharged in large quantities, those with the biggest impact on members of the public and the environment, those that are indicators of plant performance or those that are listed in the European Commission recommendations (EU, 2004). The main gaseous discharges, in terms of amount discharged into the environment, are noble gases (argon-41 and isotopes of xenon and krypton), carbon-14 and tritium (H-3). Iodine radionuclides and some radioactive particulates are discharged from the stack in smaller amounts.

Hitachi-GE has provided us with proposed annual rolling limits for discharges of gaseous radioactive waste from the UK ABWR (Table 2). Annual limits are proposed for significant radionuclides, and are based on annual discharge estimates for normal operation plus discharges resulting from fuel pin failure. Hitachi-GE has conservatively based its annual discharge limits on the assumption of one fuel pin failure in any 12 months; Hitachi-GE states that the actual rate of fuel pin failure is expected to be much lower. Hitachi-GE assumes that elevated gaseous discharges continue for 14 days until power suppression isolates the failed fuel pin.

Table 2: Annual rolling limits for gaseous radioactive waste discharged from the UK ABWR, as proposed by Hitachi-GE

Radionuclide or radionuclide group	Proposed annual limit for the UK ABWR (Bq)
Argon-41(Ar-41)	5.2E+12
Carbon-14 (C-14)	1.7E+12
Tritium (H-3)	1.0E+13

Noble gases (excluding argon-41)	2.2E+11

The proposed annual limits include a headroom factor that is applied to the discharges from normal operation. The headroom factor for each radionuclide or radionuclide group has been derived based on the variability of data used to estimate the gaseous discharges; the headroom factors for significant radionuclides range from 1.9 to 3.8.

Hitachi-GE has taken into account our guidance on limit setting (Environment Agency, 2012) when deriving the gaseous discharge limits for the UK ABWR.

Estimated annual discharges of radionuclides and proposed annual limits provided by Hitachi-GE are shown in Table 3. The proposed annual limit for noble gases, excluding argon-41, is the sum of the proposed limits for the individual krypton and xenon isotopes.

Table 3: Annual discharges of radionuclides and associated limits for the UK ABWR, as proposed by Hitachi-GE

Radionuclide	Annual discharge (Bq)	Headroom factor	Discharge from fuel pin failure (Bq)	Proposed annual limit (Bq)
H-3	2.7E+12	3.8	0	1.0E+13
C-14	9.1E+11	1.9	0	1.7E+12
Ar-41	1.8E+12	2.9	0	5.2E+12
Kr-85	1.0E+08	2.1	1.1E+09	1.3E+09
Kr-85m	2.3E+09		5.5E+09	1.0E+10
Kr-87	2.3E+03		5.0E+03	9.8E+03
Kr-88	1.8E+08		5.5E+08	9.3E+08
Xe-131m	1.4E+08		2.6E+09	2.9E+09
Xe-133	1.0E+10		1.8E+11	2.0E+11
Xe-133m	1.7E+06		1.4E+07	1.8E+07
Xe-135	1.7E-11		3.1E-11	0*
Total for noble gases (excluding Ar-41)				2.2E+11

*Hitachi-GE omitted discharges of Xe-135 from the calculations for the annual limit for noble gases as the discharges of this radionuclide are small.

We also note that the operator will have a range of discharge reporting obligations, above those of the significant nuclides, for example the pollution inventory. This can be achieved through monitoring or by estimation or calculation accompanied by an appropriate level of supporting evidence.

3. Assessment

Hitachi-GE provided its GDA submission to regulators for assessment. This consisted of the generic environmental permit (GEP), pre-construction safety report (PCSR) and supporting documents.

3.1. Assessment methodology

The basis of our assessment was to:

- assess appropriate sections of the GEP and its supporting documents
- assess appropriate sections of the PCSR and its supporting documents
- hold technical meetings with Hitachi-GE to discuss the information presented and explain any concerns that we had with that information
- raise RQs to clarify our understanding of the information presented
- raise ROs and RIs where we believed that information provided was insufficient or unacceptable
- consider the gaseous waste disposal limits proposed for the UK ABWR
- compare gaseous discharges from the UK ABWR to that of other plants around the world
- identify any AFs and GDA Issues

Our assessment consisted of 2 stages; initial assessment stage and detailed assessment stage.

Hitachi-GE provided its GDA submission to us in December 2013. We carried out our initial assessment and concluded that we needed additional information and improved clarity on some aspects of the submission. Together with the Office for Nuclear Regulation (ONR), we raised one RO on Hitachi-GE concerning source terms for the UK ABWR design. We also raised 2 RQs that are relevant to this report. Hitachi-GE submitted its updated submission in August 2014 and we carried out our detailed assessment. Together with ONR, we raised one RI on Hitachi-GE concerning source terms for the UK ABWR. We also raised one RO concerned with the TGS. Six RQs were also raised that are relevant to this report. A number of other RQs raised during the detailed assessment were concerned with the gaseous radioactive waste system and application of BAT. We discuss these further in our assessment report on BAT for the UK ABWR design (Environment Agency, 2017a).

In total, we raised one RI, 2 ROs and 8 RQs over the course of our assessment that are relevant to this report (see Section 3.4 for more detail). Hitachi-GE responded to the RI, ROs and RQs and we accepted the responses. Hitachi-GE updated the GEP submission in February 2016 (Revision E), July 2016 (Revision F) and August 2017 (Revision G) (Hitachi-GE, 2017). Relevant supporting documents were also updated to include information provided in response to the RQs.

3.2. Assessment objectives

This assessment considered if our requirements on gaseous discharges, as listed in the P&ID (Environment Agency, 2016a) had been adequately addressed, and aimed to answer the following questions:

- Have all sources of gaseous radioactive waste for the UK ABWR been identified?
- Have gaseous radioactive discharges from the UK ABWR been presented, and is the derivation of these discharges clear and supported with suitable evidence?
- Have the annual gaseous disposal limits for the UK ABWR been proposed, and is the derivation of these limits clear and appropriate?
- Do gaseous radioactive discharges from the UK ABWR exceed that of other comparable reactors across the world?

3.3. Hitachi-GE documentation

The relevant chapters of the GEP and PCSR, plus relevant supporting documents that have been referred to during this assessment are listed in Table 4. In addition, documents which Hitachi-GE submitted in response to RQs were also assessed.

Table 4: Hitachi-GE submissions referred to for assessment of gaseous radioactive waste disposals

Document reference	Revision	Title
GA91-9901-0019-00001	A-H	Summary of the generic environmental permit applications
GA91-9901-0025-00001	A-G	Quantification of discharges and limits
GA91-9901-0023-00001	A-G	Demonstration of BAT
GA91-9201-0003-00353	0-2	Methodology for expected event selection
GA91-9201-0001-00160	0-2	Topic report on discharge assessment during normal operation
GA91-9201-0003-00942	0-2	Source term manual general report
GA91-9201-0003-00863	0-2	Primary source term methodology report
GA91-9201-0003-00946	0-3	Process source term methodology report
GA91-9201-0003-00944	0-4	Calculation of process source term value
GA91-9201-0003-00976	0-1	End user source term methodology report
GA91-9201-0003-00941	0-2	Nuclide selection by end-user requirement
GA91-9201-0002-00054	3-4	Off-gas system basis of safety case
GA91-9201-0001-00125	2-3	Topic report on ALARP assessment for off-gas system
GA91-9101-0101-18003	B-C	Generic PCSR sub-chapter 18.3: off-gas radioactive waste management system

3.4. Our assessment

During our initial assessment, we raised one RO and 2 RQs that were related to gaseous discharges from the UK ABWR. During our detailed assessment, we raised one RI, one RO and 6 RQs that were relevant to gaseous discharges from the UK ABWR.

3.4.1. RO, RI and two RQs on source terms for the UK-ABWR

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

Together with ONR, we escalated the RO to an RI. A workshop was held on 19, 20 and 22 May 2015 at which we and ONR presented our requirements to Hitachi-GE and gave some examples of source terms that we have assessed for other nuclear power plant designers and operators. RI-

ABWR-0001 was raised on 3 June 2015. We held regular meetings with ONR and Hitachi-GE from June 2015 to July 2016. Hitachi-GE changed its approach to deriving and justifying source terms for the UK ABWR, using more OPEX data and providing more explanation of the methods used. Between November 2015 and February 2016 we received a number of reports documenting the derivation and justification of the UK ABWR source term. These provided information on the primary source term (radionuclides in the reactor water and steam), process source terms (radionuclides in different downstream systems within the plant) and end-user source terms (which included the source terms for gaseous and aqueous discharges).

On 15 January 2016, we raised 2 RQs concerning the source term documentation.

RQ-ABWR-0721 was raised on 15 January 2016 and requested more information on how the levels of gaseous discharges that are released during a fuel pin failure were derived. Hitachi-GE responded on 26 February 2016 providing more information on the OPEX used to derive the source terms for fuel pin failure and showing that any gaseous discharges during outage following fuel pin failure would be negligible. We accepted this response.

RQ-ABWR-0722 was raised on 15 January 2016 and posed a series of questions about the selection of radionuclides in the source term, including how radionuclides were selected for the source term for gaseous and aqueous discharges. Hitachi-GE responded to this RQ on 26 February 2016. Its response included details of how it had selected the radionuclides for the gaseous and aqueous discharges that is, based on OPEX, dose modelling and European Commission recommendations. We accepted this response.

In November 2015, we received a report from Hitachi-GE on source terms for discharges during normal operation, which was updated in February and June 2016. The GEP submission was updated to take account of the updated source term.

Following assessment and acceptance of the submissions concerning source terms for UK ABWR, RI-ABWR-0001 was closed in October 2016, and RO-ABWR-0006 was closed in April 2017.

At the time of writing our consultation document, both RI-ABWR-0001 and RO-ABWR-0006 remained open and we identified a potential GDA Issue requiring Hitachi-GE to provide a suitable and sufficient definition and justification for radioactive source terms in the UK ABWR during normal operations. As RI-ABWR-0001 and RO-ABWR-0006 are closed, this potential GDA Issue has been removed.

3.4.2. Other RQs raised during our assessment

RQ-ABWR-0193 was raised on 22 July 2014, asking about the effectiveness of the charcoal adsorbers over the 60-year operational lifetime of the UK ABWR. Hitachi-GE responded on 18 December 2014 stating that the risk of the charcoal deteriorating during the 60-year operational period was sufficiently low and that regular monitoring would take place to ensure that the charcoal beds remained functional. This statement was based on OPEX from 20 plants, only one of which had required replacement of charcoal due to reduced efficiency. We accepted this response.

RQ-ABWR-0194 was raised on 22 July 2014, requesting evidence that fuel pin failure was the only expected event for a UK ABWR, taking into account the 60-year operational life of the reactor. Hitachi-GE responded on 29 January 2015 and submitted a supporting document describing its methodology for selecting expected events. This document listed all of the systems within the UK ABWR that contain radioactivity and identified over 160 events that could occur within these systems. The document described how only one of these events, fuel pin failure, is expected to occur during the operational life of the reactor, and would result in the release of radioactivity to the environment. We accepted this response.

RQ-ABWR-0355 was raised on 7 January 2015, requesting Hitachi-GE demonstrate that the UK ABWR discharges would not exceed that of comparable power stations from across the world. This is one of our requirements laid out in the P&ID (Environment Agency, 2016a). The GEP Revision D submission did not provide any information on this or any commitment to provide it in future GEP revisions. Hitachi-GE responded to this RQ on 11 June 2015, providing some detail on discharges from comparable reactors. However, the response lacked discussion on comparison of the UK

ABWR discharges with that of the other reactors, particularly reasons for differences. We provided feedback to Hitachi-GE at a GEP progress meeting held on 28 to 29 July 2015. Hitachi-GE provided more information and improved discussion in the GEP Revision E submission. We accepted this response. We also undertook our own comparison of the UK ABWR discharges with that of other BWRs (see Section 3.5).

RQ-ABWR-0803 was raised on 17 March 2016 to ask for clarification on the identification of expected events for the UK ABWR. The response to a previous RQ (RQ-ABWR-0721) had mentioned unplanned shutdown as an expected event. However, the GEP supporting document on expected event selection identified fuel pin failure as the only expected event. Hitachi-GE responded to this RQ on 15 April 2016, stating that unplanned shutdown does not meet the definition of an expected event, as it does not lead to increased discharges to the environment, and that the terminology in the previous RQ response would be clarified. We accepted this response.

RQ-ABWR-0850 was raised on 18 April 2016, requesting additional justification for the selection of the headroom factor used to derive the proposed limits for gaseous and aqueous discharges. Hitachi-GE derived the headroom factor for each radionuclide based on the variability of the OPEX data used to derive the source term, and assumed that this variability was linearly related to the expected variability in the discharges. We requested justification to support this assumption and also for some discussion on the quality of the data used to underpin the headroom factor. Hitachi-GE responded on 1 June 2016, explaining the basis for the assumption that variability in OPEX data was linearly related to variability in discharges, and presented graphs showing the distribution of OPEX data. We accepted this response.

RQ-ABWR-1117 was raised on 7 October 2016, requesting an explanation for the apparently higher gaseous discharges of tritium and carbon-14 from the UK ABWR when compared with the mean discharges from comparable operating reactors. Hitachi-GE responded on 25 November 2016, explaining that the apparently higher discharges of tritium and carbon-14 could be accounted for due to conservative assumptions used in the estimation of UK ABWR discharges of these radionuclides. We accepted this response.

3.4.3. RO on turbine gland steam system

During our detailed assessment of the UK ABWR design, it became apparent that a source of gaseous radioactive discharges to the atmosphere had been omitted from the submission. This source was the TGS that uses steam, generated from liquid in the CST, to seal the turbine shaft. Together with ONR, we raised RO-ABWR-0071 on 6 June 2016, requesting more information on the TGS, including information on the application of BAT and discharges. Hitachi-GE submitted information in response to this RO and updated the GEP Revision F submission to include discharges from the TGS. We accepted Hitachi-GE's response to this RO and RO-ABWR-0071 was closed in November 2016.

3.5. Assessment results

This section summarises the results of our assessment of the information Hitachi-GE provided with respect to gaseous discharges and proposed limits for the UK ABWR design. We consider each of our assessment objectives in turn.

- **Have all sources of gaseous radioactive waste for the UK ABWR been identified?**

Hitachi-GE has considered gaseous radioactive waste from all aspects of normal operation, including from fuel pin failure. Radioactive wastes discharged from the stack via the OG, HVAC and TGS have been considered.

Hitachi-GE updated its GEP submission to include gaseous discharges from the TGS, and submitted this along with other information in response to RO-ABWR-0071. We are satisfied that discharges from this source have been adequately captured in the submission.

We have agreed that gaseous discharges from the dry solid LLW processing facility, ILW store, interim spent fuel store, and service building are out-of-scope for GDA and will need to be considered, as necessary, at the site-specific permitting stage.

We conclude that all sources of gaseous radioactive waste have been identified, noting those sources that are out of scope for GDA.

- **Have gaseous radioactive discharges from the UK ABWR been presented and is the derivation of these discharges clear and supported with suitable evidence?**

Hitachi-GE has presented estimated gaseous discharges for the UK ABWR in GEP Revision G submission 'Quantification of discharges and limits' chapter (Hitachi-GE, 2017). Deriving estimated discharges was part of wider work to define and justify the source terms for the UK ABWR and was the subject of RI-ABWR-0001 and RO-ABWR-0006. Hitachi-GE has provided a number of documents in response to this RI and RO which we have accepted resulting in the closure of RI-ABWR-0001 and RO-ABWR-0006.

We conclude that Hitachi-GE has presented estimates of gaseous discharges for the UK ABWR. It is clear how these discharge estimates have been derived and this is supported by suitable evidence.

- **Have the annual gaseous disposal limits for the UK ABWR been proposed, and is the derivation of these limits clear and appropriate?**

Hitachi-GE has provided proposed annual gaseous discharge limits for the UK ABWR in the GEP Revision G submission 'Quantification of discharge and limits' chapter (Hitachi-GE, 2017). The limits have been derived by adding a headroom factor onto the estimated discharges. The headroom factor is based on the variability of the data on which the source term is based.

Annual limits have been proposed for those radionuclides that Hitachi-GE has identified as significant in gaseous discharges: carbon-14, tritium and noble gases (argon-41 and isotopes of krypton and xenon). We are satisfied that the selection of significant radionuclides is appropriate, and consistent with European Commission recommendations (EU, 2004) and our guidance (Environment Agency, 2012).

When permitting a new facility, we recognise that there may be considerable uncertainty regarding the level of discharges to the environment. Therefore, new facilities may have greater headroom than facilities that are already operating. Hitachi-GE has been conservative when estimating gaseous discharges for the UK ABWR. Therefore, we expect gaseous discharges to be lower than those detailed in the GEP.

We conclude that gaseous discharge limits for the UK ABWR have been proposed, and that the derivation of these limits is consistent with our guidance and of an appropriate order of magnitude.

- **Do gaseous radioactive discharges from the UK ABWR exceed that of other comparable reactors across the world?**

Since the beginning of nuclear power generation, regulators have required operators of nuclear power stations to take samples, carry out measurements and determine radioactivity in discharges. These measurements are particularly valuable in confirming what the impact is on the environment and whether there is any impact on the food chain.

The main radionuclides or radionuclide groups discharged from nuclear power stations as gaseous waste include:

- tritium (H-3) – a low energy beta emitting radionuclide with a half-life of 12.3 years
- carbon-14 (C-14) – a low energy beta emitter with a very long half-life. It can be taken up by crops
- noble gases (isotopes of krypton and xenon, and argon-41) – beta and gamma emitters. Half-lives of noble gases vary from a few minutes to years

- iodine radionuclides – several radionuclides of iodine are formed during nuclear fission. The most important of these is iodine-131, a beta and gamma emitter with a relatively short half-life of 8 days. It can be deposited in crops and then ingested, or can be deposited on grass which is grazed by cows and subsequently appears in milk
- particulates – this group includes fission products such as caesium-137 with a half-life of 30 years, and activated corrosion products such as cobalt-60 with a half-life of 5.3 years

We commissioned Public Health England to gather data and information on radioactive discharges from comparable boiling water reactors (BWRs) worldwide. The results of this work are published in a report (Environment Agency, 2016b). The authors obtained discharge data by contacting the relevant operators and regulators, or from publicly available sources. In order to compare discharges between different reactors, the report presents discharges having normalised them to gigabecquerels per gigawatt-hour (GBq/GWeh). Data were normalised based on actual power output for the operating reactors. Data were collected for BWRs in Finland, Germany, Japan, Spain, Sweden, Switzerland and USA. In total, data from 24 BWR stations were collected, although data were not available for all radionuclides for every power station.

In order to compare discharges from the UK ABWR with those of other BWRs, the UK ABWR discharges have been normalised to gigabecquerels per gigawatt-hour (GBq/GWeh). Data were normalised based on estimated discharges at full power.

Care must be taken not to draw comparisons too closely as there are many uncertainties in the data, including variation in sampling and monitoring techniques between different power stations.

3.5.1. Tritium (H-3)

Annual gaseous tritium discharges from BWRs range from 3.4E-06 to 1.5 GBq/GWeh. The UK ABWR annual gaseous tritium discharge is 2.3E-01 GBq/GWeh. Data are presented in Table 5 and Figure 1.

Table 5: Normalised annual gaseous tritium discharges from BWRs and normalised estimated annual gaseous tritium discharges for the UK ABWR

n=number of plants for which data were obtained

	Year	Mean gaseous H-3 discharges (GBq/GWeh)			n
		Mean	Minimum	Maximum	
BWR	2005	1.6E-01	6.4E-03	5.0E-01	15
	2006	1.7E-01	2.0E-02	6.7E-01	15
	2007	1.5E-01	1.3E-02	5.6E-01	16
	2008	1.1E-01	1.3E-05	3.7E-01	16
	2009	1.3E-01	2.2E-02	4.0E-01	16
	2010	1.4E-01	1.9E-02	5.6E-01	17
	2011	1.0E-01	3.4E-06	3.8E-01	17
	2012	1.8E-01	1.3E-02	1.5E+00	16
	2013	2.1E-01	2.4E-03	1.5E+00	16
UK ABWR		2.3E-01			

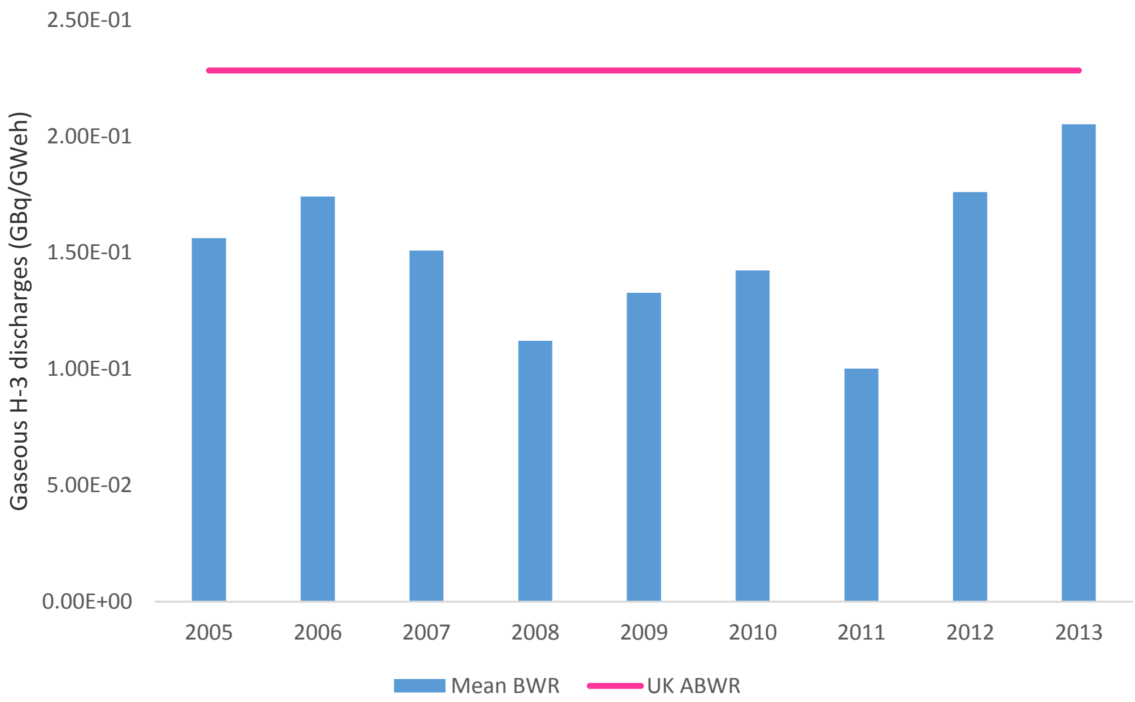

Figure 1: Mean normalised annual gaseous tritium discharges for BWRs 2005 to 2013

Solid pink line shows normalised UK ABWR estimated annual gaseous tritium discharges

Estimated annual discharges of gaseous tritium from the UK ABWR are higher than the mean annual discharges of gaseous tritium from other operating BWRs and sit within the upper end of the range of discharge data obtained from other operating BWRs.

In its submission, Hitachi-GE suggests that the apparent higher gaseous tritium discharges from the UK ABWR compared with other operating BWRs is due to conservative assumptions that have been made when estimating gaseous discharges.

The majority of the tritium discharges reach the stack via the TGS. Hitachi-GE states that, for the purposes of estimating discharges, the steam flow rate of the TGS is assumed to be at a maximum margin; in reality, the flow rate will be lower during plant operation. The assumption of maximum steam flow rate leads to higher estimated discharges via this route.

3.5.2. Noble gases

Annual noble gas discharges from BWRs range from 4.8E-06 to 1.6E+01 GBq/GWeh. The UK ABWR estimated annual noble gas discharge with and without fuel pin failure is 1.7E-01 and 1.5E-01 GBq/GWeh respectively. Data are presented in Table 6 and Figure 2.

Table 6: Normalised annual noble gas discharges from BWRs and normalised estimated annual noble gas discharges for the UK ABWR

n=number of plants for which data were obtained

	Year	Mean noble gas discharges (GBq/GWeh)			n
		Mean	Minimum	Maximum	
BWR	2005	1.5E+00	2.7E-02	1.6E+01	15
	2006	1.1E+00	1.0E-05	7.2E+00	17
	2007	1.2E+00	1.4E-02	5.1E+00	15

	2008	8.0E-01	4.8E-06	3.5E+00	15
	2009	1.1E+00	5.8E-03	7.9E+00	14
	2010	6.7E-01	4.8E-03	3.7E+00	19
	2011	7.5E-01	8.1E-04	4.6E+00	18
	2012	8.7E-01	3.3E-03	7.0E+00	15
	2013	7.8E-01	5.9E-04	6.6E+00	16
UK ABWR (no fuel failure)		1.5E-01			
UK ABWR (with fuel failure)		1.7E-01			

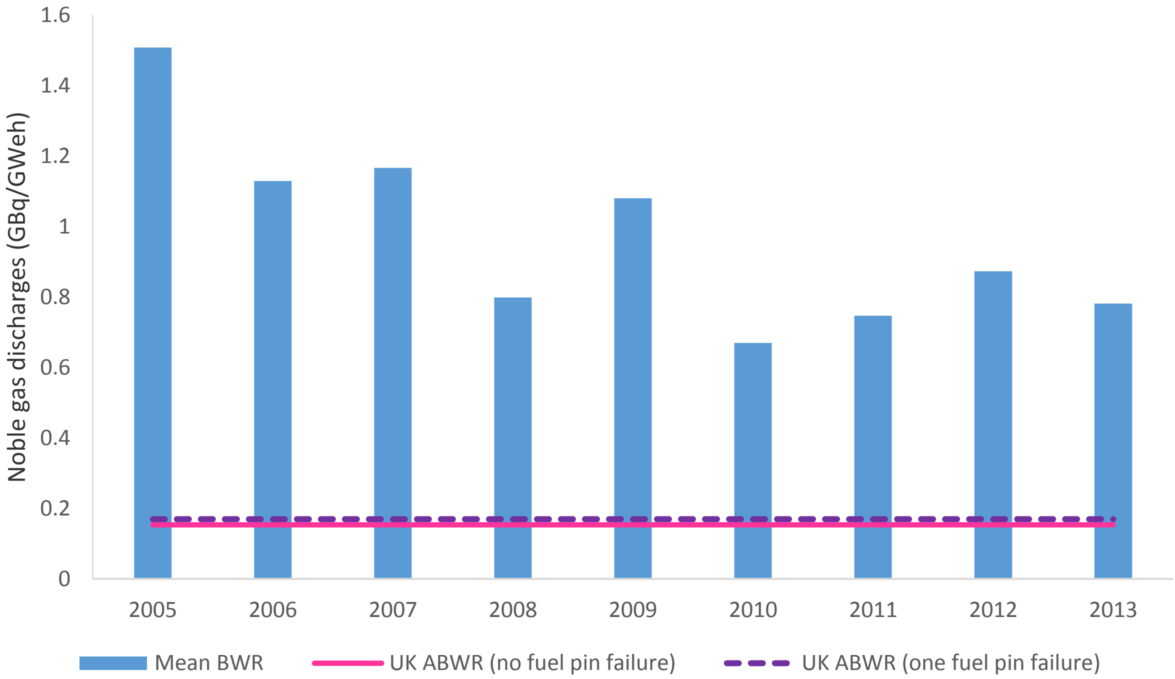

Figure 2: Mean normalised annual noble gas discharges from BWRs 2005 to 2013

Solid pink line shows normalised UK ABWR estimated annual noble gas discharges excluding discharges from fuel pin failure. Dashed purple line shows normalised UK ABWR estimated annual noble gas discharges including discharges from a failed fuel pin

Estimated annual discharges of noble gases from the UK ABWR are lower than the mean annual discharges of noble gases from other operating BWRs and sit at the lower end of the range of data obtained for operating BWRs.

3.5.3. Iodine radionuclides

Annual gaseous discharges of iodine radionuclides from BWRs range from 7.3E-11 to 2.1E-02 GBq/GWeh. The UK ABWR estimated annual gaseous discharge of iodine radionuclides is 2.7E-05 GBq/GWeh. Data are presented in Table 7 and Figure 3.

Table 7: Normalised annual gaseous discharges of iodine radionuclides from BWRs and normalised estimated annual gaseous discharges of iodine radionuclides for the UK ABWR

n=number of plants for which data were obtained

	Year	Mean gaseous discharges of iodine radionuclides (GBq/GWeh)			n
		Mean	Minimum	Maximum	
BWR	2005	8.5E-05	7.3E-11	8.0E-04	17
	2006	2.4E-04	1.6E-08	3.0E-03	17
	2007	2.0E-04	4.7E-09	2.3E-03	18
	2008	8.2E-05	1.8E-07	6.6E-04	14
	2009	1.2E-04	7.3E-09	1.2E-03	17
	2010	1.3E-03	1.1E-07	2.1E-02	19
	2011	2.4E-04	6.5E-08	3.0E-03	22
	2012	2.1E-05	1.8E-08	1.2E-04	15
	2013	2.9E-05	1.4E-07	1.3E-04	14
UK ABWR		2.7E-05			

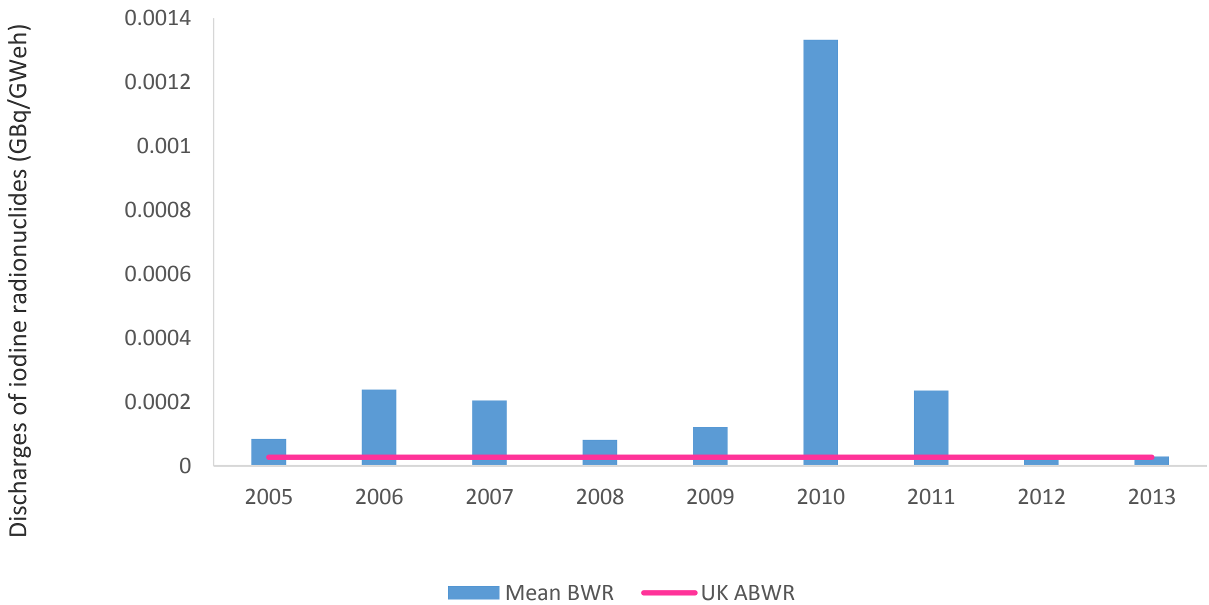

Figure 3: Mean normalised annual gaseous discharges of iodine radionuclides from BWRs 2005 to 2013

Pink line shows normalised UK ABWR estimated annual gaseous discharges of iodine radionuclides

Estimated annual discharges of gaseous iodine radionuclides from the UK ABWR are lower than the mean annual discharges of gaseous iodine radionuclides from other operating BWRs and sit at the lower end of the range of data obtained for operating BWRs.

3.5.4. Particulates

Annual airborne particulate discharges from BWRs range from 1.3E-13 to 1.6E-04 GBq/GWeh. The UK ABWR estimated annual airborne particulate discharge is 2.1E-08 GBq/GWeh. Data are presented in Table 8 and Figure 4.

Table 8: Normalised annual gaseous particulate discharges from BWRs and normalised estimated annual gaseous particulate discharges for the UK ABWR

n=number of plants for which data were obtained

	Year	Mean gaseous particulate discharges (GBq/GWeh)			n
		Mean	Minimum	Maximum	
BWR	2005	9.1E-06	1.7E-08	4.8E-05	16
	2006	1.6E-05	2.2E-07	1.6E-04	15
	2007	9.5E-06	2.0E-08	7.9E-05	17
	2008	5.7E-06	3.9E-09	2.7E-05	17
	2009	1.1E-05	2.2E-08	3.4E-05	16
	2010	9.2E-06	6.9E-09	3.6E-05	15
	2011	5.7E-06	5.0E-09	2.2E-05	16
	2012	4.5E-06	1.3E-13	2.3E-05	16
	2013	4.8E-06	2.2E-09	3.1E-05	16
UK ABWR		2.1E-08			

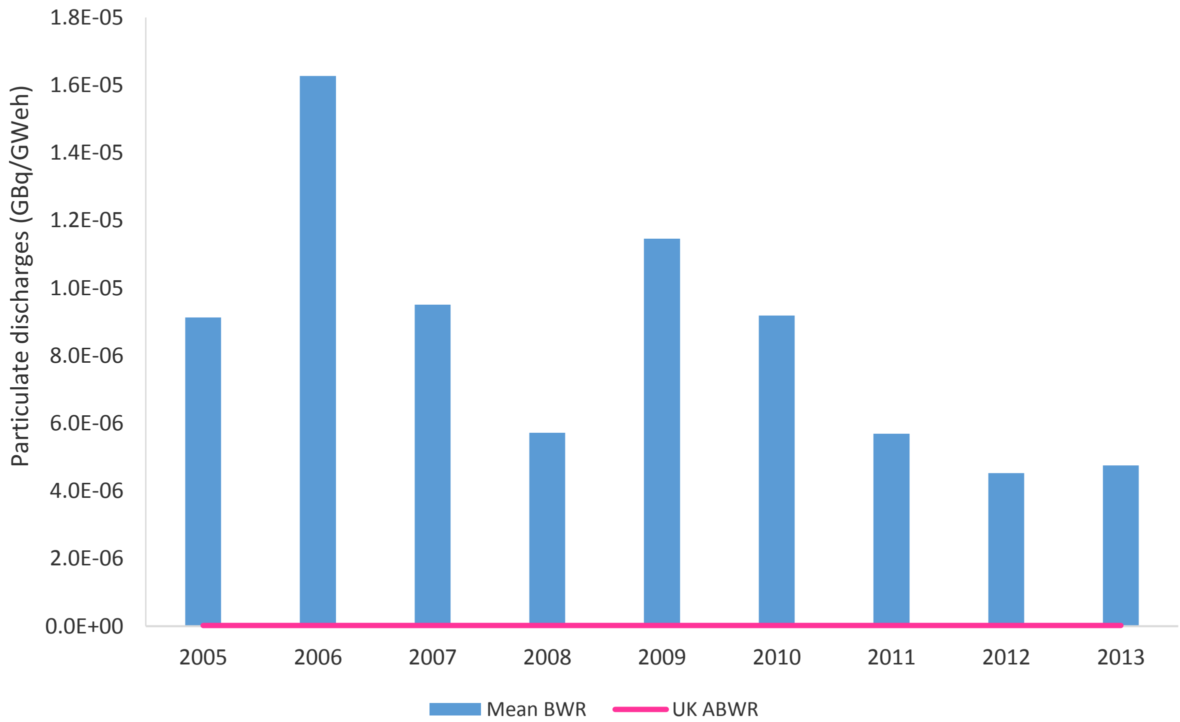

Figure 4: Mean normalised annual airborne particulate discharges from BWRs 2005 to 2013

Pink line shows normalised UK ABWR estimated annual airborne particulate discharges

Estimated annual discharges of airborne particulates from the UK ABWR are lower than the mean annual discharges of airborne particulates from other operating BWRs and sit at the lower end of the range of data obtained for operating BWRs.

3.5.5. Carbon-14

Annual gaseous carbon-14 discharges from BWRs range from 4.1E-03 to 1.1E-01 GBq/GWeh. The UK ABWR estimated annual gaseous carbon-14 discharge is 7.7E-02 GBq/GWeh. Data are presented in Table 9 and Figure 5.

Table 9: Normalised annual gaseous carbon-14 discharges from BWRs and normalised estimated annual gaseous carbon-14 discharges for the UK ABWR

n=number of plants for which data were obtained

	Year	Mean gaseous carbon-14 discharges (GBq/GWeh)			n
		Mean	Minimum	Maximum	
BWR	2005	5.8E-02	3.1E-02	1.1E-01	5
	2006	4.6E-02	4.1E-03	1.0E-01	5
	2007	7.1E-02	4.2E-02	1.1E-01	6
	2008	5.6E-02	3.4E-02	9.9E-02	6
	2009	5.9E-02	3.7E-02	9.0E-02	6
	2010	5.5E-02	3.6E-02	1.0E-01	17
	2011	6.0E-02	3.4E-02	8.9E-02	17
	2012	5.7E-02	5.2E-03	8.3E-02	16
	2013	6.1E-02	1.4E-02	8.2E-02	16
UK ABWR		7.7E-02			

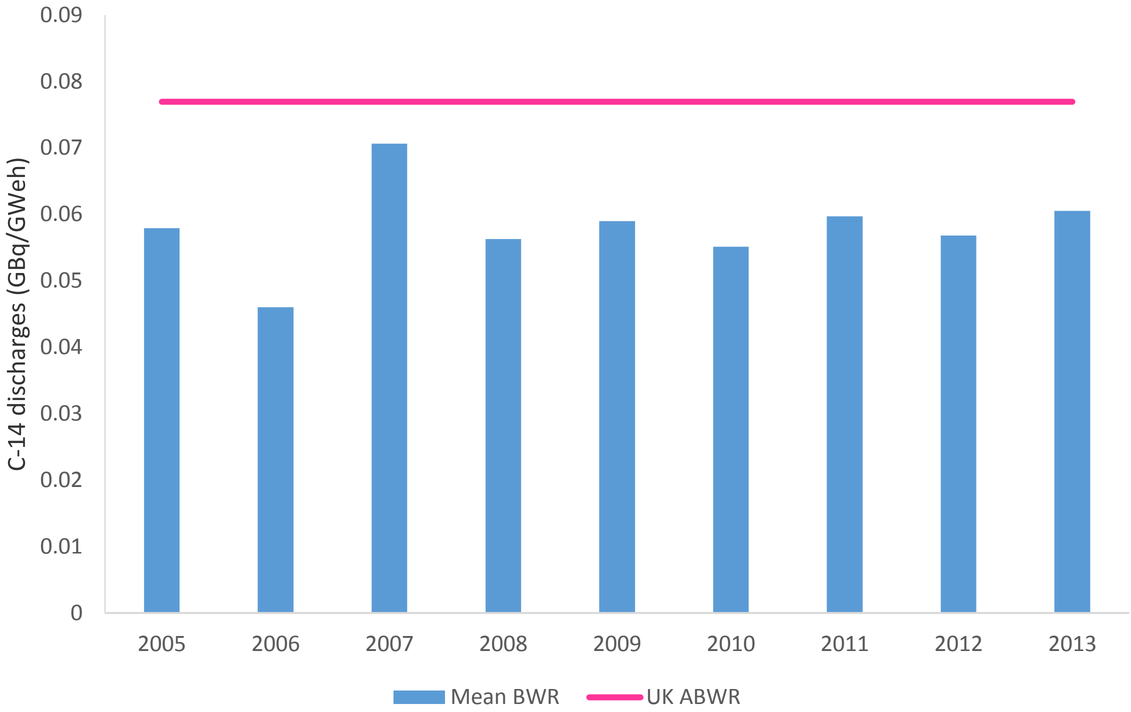

Figure 5: Mean normalised annual gaseous carbon-14 discharges from BWRs 2005 to 2013 Pink line shows normalised UK ABWR estimated annual gaseous carbon-14 discharges

Estimated annual discharges of gaseous carbon-14 from the UK ABWR are higher than the mean annual discharges of gaseous carbon-14 from other operating BWRs and sit in the upper end of the range of data obtained for operating BWRs.

Hitachi-GE has assumed that all carbon-14 is discharged via the gaseous route and that none enters the liquid waste streams. This is a conservative assumption when considering radiological impact of discharges, as carbon-14 is not abated in the gaseous phase and is released to the environment. However, this assumption means that the normalised estimated discharges of gaseous carbon-14 may appear higher than normalised gaseous carbon-14 discharges from operating plants. The assumption that no carbon-14 enters the liquid waste streams is discussed further in our assessments reports on BAT (Environment Agency, 2017a) and aqueous waste (Environment Agency, 2017d) and is the subject of an assessment finding:

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

In addition, Hitachi-GE does not make any claim for retention of carbon-14 on the charcoal adsorbers. In reality, some gaseous C-14 may be abated by the charcoal adsorbers.

3.5.6. Conclusion

Estimated annual gaseous discharges of noble gases, iodine radionuclides and airborne particulates from the UK ABWR are lower than mean gaseous discharges for other operating BWRs. Estimated annual gaseous discharges of carbon-14 and tritium from the UK ABWR are higher than the mean discharges from other operating BWRs, but still sit within the range of data values obtained for operating BWRs across the world.

We conclude that gaseous radioactive discharges from the UK ABWR do not exceed those of comparable power stations across the world.

4. Compliance with Environment Agency requirements

Table 10. Compliance with Environment Agency requirements

P&ID Table 1 Section or REP	Compliance comments
P&ID Table 1 section 5: Quantification of radioactive waste disposals. Provide quantitative estimates for normal operation of discharges of gaseous and aqueous radioactive wastes. Provide proposed limits for gaseous and aqueous discharges.	Hitachi-GE has provided estimates of gaseous radioactive waste disposals for normal operation; how it has derived these estimates is clear and supported by suitable evidence. Hitachi-GE has provided proposed limits for the disposal of gaseous radioactive waste; how it has derived these limits is clear and consistent with our guidance (Environment Agency, 2012). Our assessment of discharges of aqueous radioactive wastes is provided in a separate assessment report (Environment Agency, 2017d).
RSMDP12 – Limits and levels on discharges: Limits and levels should be established on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment.	Hitachi-GE has provided proposed limits for the disposal of gaseous radioactive waste; how it has derived these limits is clear and consistent with our guidance (Environment Agency, 2012). Our assessment of discharges of aqueous radioactive wastes is provided in a separate assessment report (Environment Agency, 2017d).

5. Public comments

Hitachi-GE received 3 public comments concerned with gaseous discharges to the environment.

On 7 January 2014, Hitachi-GE received a comment asking how the UK ABWR design prevented fission product release into the condenser cooling water and then to atmosphere via cooling towers. Hitachi-GE responded to this comment, stating that, in the UK ABWR design, there is no pathway for fission products to reach the condenser water circulation pipes for release to the environment via that route. In addition, Hitachi-GE stated that the OG is designed to minimise fission product release to the atmosphere by allowing radioactivity to decay prior to release.

During our public consultation, we received several comments concerning the assessment of gaseous radiological discharges from the UK ABWR (Environment Agency, 2017f). The responses to these comments are presented in our decision document (Environment Agency, 2017g).

Comment ABWR-03 expressed concern that UK ABWR discharge estimates are based on modelling rather than on empirical data. A request was also made for us to provide all available data for plutonium, americium and curium isotopes and tritium for BWRs/ABWRs and the UK ABWR. Our response explained that the discharge estimates are based on a mixture of empirical and modelled data. At existing reactors, in accordance with local regulations, some radionuclide discharges are not monitored and reported, so there are no recorded discharge data; for these radionuclides modelling was employed to conservatively estimate discharges. Discharges from tritium from precursor or existing BWRs/ABWRs is available in our report (Environment Agency, 2016b). Discharges of plutonium, americium and curium from precursor BWRs and ABWRs are not reported separately as this data is not available. Details of discharges from proposed UK ABWRs of plutonium, americium, curium and tritium can be found in the submission from Hitachi-GE (Hitachi-GE, 2017).

Comment ABWR-05 expressed disappointment that the source term issue for the UK ABWR had not been resolved prior to the consultation. Our response explained that RI-ABWR-0001 and RO-ABWR-0006 concerned with source terms are now closed.

Comment ABWR-09 asked if any organisation was known to be actively researching or funding development of abatement for tritium and carbon-14. Our response included some examples of such research. Ongoing research and development into tritium prevention/abatement appears to be limited. Some examples are: research into development of a tritium recovery system from Candu tritium removal facility (China Academy of Engineering Physics, China; SC I.S. TECH SRL, Romania); removal and recycling of tritium from fusion exhaust gases (JET – Culham Centre for Fusion Energy); research into prevention of fuel cladding failure and release of tritium from failed fuel (Imperial College London funded by EPSCR and Ministry of Defence); and use of graphene filters to remove particulate and volatile radionuclides from waste streams (Nuclear Decommissioning Authority; Office for Nuclear Regulation). Ongoing research and development into carbon-14 abatement appears to be limited. There is some wider research being undertaken into carbon capture, storage and reuse. Also, there is some research into the use of graphene filters for carbon-14 (Nuclear Decommissioning Authority; Office for Nuclear Regulation).

Comment ABWR-09 asked about the likelihood of more than one fuel pin failing at any one time. Our response explained that OPEX related to the frequency of fuel pin failure and the discharges to environment resulting from fuel pin failure was examined during our detailed assessment. Two or more fuel pins failing at the same time is not an event that is expected to occur during the lifetime of the plant and, therefore, is outside the scope of normal operations. The Office for Nuclear Regulation (ONR) assesses events that occur outside of normal operation.

Comment ABWR-09 also asked if the higher gaseous discharges of tritium and carbon-14 are a feature of the UK ABWR design, and if there will be impact on radiocarbon dating technology that may be used for relics for archaeological sites. Our response explained that the apparently higher gaseous discharges of tritium and carbon-14 from the UK ABWR when compared with other operating plants are due to the conservative assumptions used in the estimation of these discharges for the UK ABWR. Any impacts of carbon-14 discharges on radiocarbon dating technology that may be used for relics from archaeological sites were not considered as part of GDA.

Comment ABWR-28 expressed concern that estimated discharges from UK ABWR do not include discharges resulting from failures or accidents. Our response explained that we consider the impact of discharges from normal operation, which includes any events that can be expected to occur during the lifetime of the plant (such as fuel pin failure). Our assessment does not consider the impact of uncontrolled releases to the environment resulting from failures or accidents that are not expected to occur during the lifetime of the plant. ONR's assessment of the UK ABWR included consideration of accidents.

Comment ABWR-33 asked why there is no gaseous discharge limits proposed for iodine-131. Our response explained that iodine-131 is not classed as a significant radionuclide in the UK ABWR discharges. Only radionuclides classed as significant have associated proposed limits.

Two comments (ABWR-05 and ABWR-35) pointed out errors in the first table of Chapter 9 of the consultation document where units for proposed gaseous discharge limits were given as GBq rather than Bq. Our response noted the error and corrected it in the decision document.

Three comments (ABWR-35) pointed out errors in the text associated with the tables detailing the comparison of the discharges from UK ABWR with that of other operating plants. Our response noted the errors and corrected them in the decision document.

None of the comments received or our responses to them have any significant impact on our findings or conclusions, which remain unchanged.

6. Conclusion

We are satisfied that Hitachi-GE has identified all sources of gaseous radioactive waste, noting that gaseous discharges from the dry solid LLW facility, ILW store, interim spent fuel store, and service building are out-of-scope for GDA and will need to be considered, as necessary, at site-specific permitting stage.

Hitachi-GE has provided us with estimates of gaseous radioactive discharges for the UK ABWR. We conclude that the derivation of these estimates is appropriate, clear and supported by suitable evidence. We conclude that gaseous discharge limits for the UK ABWR are consistent with our guidance and of an appropriate order of magnitude.

We conclude that the gaseous discharges from the UK ABWR should not exceed those of comparable power stations across the world, and will be capable of meeting the limits set out in Table 11 below:

Table 11. Proposed annual limits for gaseous discharges from the UK ABWR

Radionuclide or radionuclide group	Proposed annual limit for the UK ABWR (Bq)
Argon-41 (Ar-41)	5.2E+12
Carbon-14 (C-14)	1.7E+12
Tritium (H-3)	1.0E+13
Noble gases (excluding argon-41)	2.2E+11

One assessment finding has been identified which is related to gaseous discharges of radioactive waste:

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

References

Author	Reference
Environment Agency, 2010	Radioactive Substances Regulation – Environmental Principles, Regulatory Guidance Series No RSR1, Version 2. Environment Agency, 2010.
Environment Agency, 2012	Criteria for setting limits in the discharge of radioactive waste from nuclear sites. Version 1. Environment Agency, 2012.
Environment Agency, 2016a	Process and information document for generic assessment of candidate nuclear power plant designs. Version 3. Environment Agency, 2016.
Environment Agency, 2016b	Discharges from boiling water reactors; A review of available discharge data. Environment Agency, 2016.
Environment Agency, 2017a	Generic design assessment of new nuclear power plant: assessment of best available techniques for Hitachi-GE UK ABWR design. AR03.
Environment Agency, 2017b	Generic design assessment of new nuclear power plant: assessment of radiological impacts on members of the public for Hitachi-GE UK ABWR design. AR09.
Environment Agency, 2017c	Generic design assessment of new nuclear power plant: assessment of radiological impacts on non-human species for Hitachi-GE UK ABWR design. AR10.
Environment Agency, 2017d	Generic design assessment of new nuclear power plant: assessment of aqueous radioactive waste disposal and limits for Hitachi-GE UK ABWR design. AR05.
Environment Agency, 2017e	Generic design assessment of new nuclear power plant: assessment of solid radioactive waste and spent fuel for Hitachi-GE UK ABWR design. AR06.
Environment Agency, 2017f	Assessing new nuclear power station designs. Generic design assessment of Hitachi-GE Nuclear Energy Limited's UK Advanced Boiling Water Reactor. Responses to GDA consultation for the UK ABWR. July 2017.
Environment Agency, 2017g	Assessing new nuclear power station designs. Generic design assessment of Hitachi-GE Nuclear Energy Limited's UK Advanced Boiling Water Reactor. Decision document. December 2017.
EU, 2004	EU Commission Recommendation 2004/2/Euratom of 18 December 2003 on standardised information on radioactive airborne and liquid discharges

Author	Reference
	into the environment from nuclear power reactors and reprocessing plants in normal operation.
Hitachi-GE, 2017	Quantification of discharges and limits, GA91-9901-0025-00001, Revision G.

List of abbreviations

Abbreviation	Details
ABWR	Advance Boiling Water Reactor
AF	Assessment Finding
ALARP	As low as reasonably practicable
BAT	Best available techniques
BWR	Boiling Water Reactor
CST	Condensate storage tank
GDA	Generic design assessment
GEP	Generic environmental permit
HEPA	High efficiency particulate air
HVAC	Heating, ventilation and air conditioning system
ILW	Intermediate level waste
LLW	Low level waste
OG	Off-gas system
ONR	Office for Nuclear Regulation
OPEX	Operational experience
P&ID	Process and information document
PCSR	Pre-construction safety report
REP	Radioactive Substances Regulation Environmental Principle
RI	Regulatory Issue
RO	Regulatory Observation
RP	Requesting party

Abbreviation	Details
RQ	Regulatory Query
TGS	Turbine gland steam system
UK ABWR	UK Advanced Boiling Water Reactor

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