Assessing new nuclear power station designs

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

Assessment report - Independent dose assessment

12 December 2016

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Executive summary

The Office for Nuclear Regulation (ONR) and the Environment Agency (the nuclear regulators) are working together to ensure that any new nuclear power stations built in the UK meet the highest standard of safety, security, environmental protection and waste management. Together we have established a generic design assessment (GDA) process to consider the acceptability of the new nuclear power plants. One of the stages in the processes is consideration of the environmental acceptability of the design. This stage has been divided into two main phases, the first addressing generic design matters and the second dealing with applications for specific sites.

In the GDA process, we are carrying out detailed assessments of the environmental effects of each design, which will lead to a statement about the acceptability of the design. The statement on acceptability will be non-binding, but will give a strong indication of whether a design is likely to be acceptable in principle in the UK with respect to matters that the Environment Agency regulates.

Hitachi-GE has submitted its UK ABWR nuclear power plant design for evaluation under the GDA arrangements. In its submission, Hitachi-GE carried out assessments of potential doses to members of the public from discharges of radioactive waste to the atmosphere and to the marine environment.

As part of the GDA process, an independent assessment of the potential impact of liquid and gaseous discharges of radioactive wastes from the UK ABWR design has been carried out on behalf of the Environment Agency in accordance with the GDA approach outlined in our 'Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs' (P&ID) (Environment Agency, 2013). This assessment takes account of the discharge information, design and the generic site description, provided by Hitachi-GE.

As part of our review of the submission made by Hitachi-GE we have made an independent dose assessment. The aim of the independent assessment was to:

- independently verify the dose assessment made by Hitachi-GE, by seeking to reproduce the results using the same computer models and data chosen by Hitachi-GE
- validate the methods, parameters and assumptions used by Hitachi-GE for its dose assessment, taking account of guidance and experience
- independently estimate doses and other measures of radiological impact from the estimated discharges from the site

In its submission, Hitachi-GE assumed that the UK ABWR would be located on the coast. Hitachi-GE proposed limits on discharges of radioactive wastes to atmosphere and as liquids. The proposed limits were based on the annual maximum radioactive liquid and atmospheric discharges were used as the basis for assessing doses to the local population and collective doses. A tiered assessment approach was applied by Hitachi-GE to estimate doses to the local population. This involved using the Environment Agency's initial radiological assessment tool (IRAT) to make an initial assessment, followed by a more detailed assessment using the PC-CREAM 08 system and Atmospheric Dispersion Modelling System (ADMS) code for assessing short duration releases. As well as calculating doses to potential 'representative people', expected to be most exposed to the radioactive discharges, the software was used to estimate radiation doses to UK, European and world populations over the next 500 years. Hitachi-GE also estimated the potential radiation dose to plants and wildlife, and calculated doses to people from expected but sporadic short-term releases, in each case using specific but widely used software tools.

We were able to reproduce most of the calculations made by Hitachi-GE, but noted some areas in which more information was needed. Similarly, when validating the approach, models and data there were some areas in which additional information would be of benefit. This is particularly in respect of the potential short-term atmospheric discharges.

The Hitachi-GE assessment was validated and assessed against those principles for the prospective assessment of radiological discharges (Environment Agency et al., 2012) relevant to the GDA.

The overall conclusion is that the Hitachi-GE dose assessment was valid and provided a guide to the potential doses and other radiological effects of the UK ABWR that was suitable for the purposes of the GDA.

As an additional step in the assessment we made an independent dose assessment to provide an alternative perspective on the significance of the discharges from the UK ABWR. In our assessment, we found that the dominant contributor to the most exposed person's dose was routine discharges of radioactivity to air. Like Hitachi-GE we found that doses to people from the radioactive discharges are low, especially those resulting from the liquid discharges. The dominant radionuclide is carbon-14 discharged to atmosphere, and the dominant exposure pathway would be the ingestion of locally produced milk.

Our estimated doses to a representative member of the public were similar to those calculated by Hitachi-GE (Hitachi-GE, 2016a). The total dose was 24 μSv/y, well below the dose constraint of 300 μSv/y. The cautious nature of our assessment means that no other members of the public would be expected to receive higher exposures. Our estimates of the radiation dose to populations (the UK, Europe and the world) and doses to wildlife and plants did not indicate any effects that were potentially of concern.

The dose calculations in this study are only applicable to the GDA generic site and apply to a single UK ABWR unit. The results indicate that more than one unit could be accommodated at a site and still meet the Environment Agency's dose criteria, even allowing for radiation exposures from any other existing nuclear facilities. Sensitivity analysis undertaken in the study shows that if the UK ABWR were located at a different site the environmental concentrations would be expected to be similar to or lower than to those calculated in this assessment. If a site is selected and a permit requested then the assessments will need to be repeated and refined to take account of site-specific factors and the number of UK ABWR units that will be operated.

Contents

1. Introduction

The Environment Agency and the Office for Nuclear Regulation (ONR) are using the generic design assessment (GDA) process to evaluate the new nuclear power station designs proposed for the UK. This report is concerned with the UK Advanced Boiling Water Reactor (UK ABWR) that has been submitted for assessment by Hitachi-GE (the requesting party).

ONR, the Environment Agency and Natural Resources Wales assess aspects of candidate nuclear power station designs, relevant to nuclear safety and environmental impact respectively. These reflect the regulatory remits. This report is concerned with the radiological impact of the anticipated radioactive discharges from the UK ABWR - to air and water - over its projected operational lifetime (Environment Agency, 2013). Hitachi-GE has provided estimates of radiation doses to people and the environment from these discharges (Hitachi-GE, 2016a), which we have assessed in this report.

The GDA process does not consider a specific site where a reactor might be operated. This is because one purpose of GDA is to establish if the design would be generally acceptable for operation in the UK. A hypothetical generic site has therefore been proposed by Hitachi-GE for its assessment of the radiological impact of the expected radioactive discharges from the UK ABWR. The generic site is coastal as the design is assumed to use seawater for cooling. Other environmental characteristics of the site have been based on those found at existing nuclear sites in the UK. Hitachi-GE has made additional assumptions about the people who might be most exposed to its discharges and used these in its assessment.

This report describes a detailed review of Hitachi-GE's radiological impact (dose) assessment to determine whether it meets the requirements described in the Process and Information Document (P&ID) (Environment Agency, 2013). The review was carried out on behalf of the Environment Agency by specialists from a technical specialist consultancy - Quintessa. This review builds on our initial assessment in 2014 (Environment Agency, 2014). It includes detailed checking of the dose calculations made by Hitachi-GE and a review of the assumptions used in the dose calculations. The report includes details of our independent dose assessment of the impact of the expected discharges to air and water from the UK ABWR.

The review of Hitachi-GE's assessment and our assessment are summarised in the main body of this report. It is organised as follows.

- Section **Error! Reference source not found.** summarises the scope of this review, and the approach taken.
- Section **Error! Reference source not found.** describes how the calculations made by Hitachi-GE were checked and the review of its modelling assumptions.
- Section **Error! Reference source not found.** presents our own independent assessment of the radiation doses, undertaken to provide a separate and independent point of comparison with Hitachi-GE's assessment.
- Section **Error! Reference source not found.** discusses the main findings and presents the conclusions.

The appendices contain more detail on the following topics.

- Appendix A presents the process of verification - checking the calculations made by Hitachi-GE
- Appendix B describes the process of validation reviewing the assumptions, models, data and other methods used by Hitachi-GE
- Appendix C presents the overall approach to the independent dose assessment
- Appendix D shows how the initial radiological assessment methodology was applied (Environment Agency, 2006a, b) to make an initial estimate of the doses to people from the discharges to air and water

- Appendix E describes the detailed dose assessment calculations for the anticipated atmospheric discharges
- Appendix F presents the dose assessment calculations for the anticipated liquid discharges
- Appendix G gives the calculated total dose to reference groups and the 'representative person' who is expected to be most exposed to the expected discharges from the UK ABWR and includes doses from direct radiation, and compares them with the regulatory criteria
- Appendix H contains an assessment of the potential doses from a short-term release of radioactivity to air
- Appendix I describes our assessment of the dose for UK, European and world populations (the "collective dose")
- Appendix J presents our assessment of doses to wildlife (non-human species)
- Appendix K presents an assessment of direct radiation

The review of the dose assessment (described in Section 2 and 3, and Appendices A and B of this report) examined the dose assessment submitted by Hitachi-GE in February 2016 (Revision E) (Hitachi-GE, 2016b). After the review was completed Hitachi-GE issued a revision that included slightly different discharge rates (Revision F, July 2016 (Hitachi-GE, 2016a)) but which was otherwise the same. Our independent dose assessment (Section 4 and Appendix C - K) was able to use the same discharge rates as Revision F of Hitachi-GE's assessment as it followed on from the review.

2. Scope and approach

The scope of the work is to confirm that Hitachi-GE's assessment of the potential radiological effects of discharges from the UK ABWR is suitable and sufficient (Environment Agency, 2013). To achieve this, the following work was undertaken:

- Independent verification of the dose assessment, by seeking to reproduce the results using the same computer models and data chosen by Hitachi-GE (Hitachi-GE, 2016a).
- Validation of the methods, parameters and assumptions used by Hitachi-GE for its dose assessments, taking account of guidance (for example that of the National Dose Assessment Working Group (NDAWG, 2009, 2011)) and our experience.
- The assessment has followed the relevant parts of the 'Principles for the Assessment of Prospective Public Doses' (Environment Agency et al., 2012).
- An independent assessment of radiation doses to public and to non-human species from the proposed discharges from the UK ABWR, using Hitachi-GE's estimated discharge rates. The assessments covered the different types of radioactive discharges (to water and air, short-term and long-term). We also require doses to be assessed to the most exposed individuals (including a 'representative person'), to the wider population ('collective dose'), and to non-human species.

The P&ID (Environment Agency, 2013) sets out the key information requirements for this stage of the GDA and thus the scope of this report. This states that the following require calculation:

- the annual dose to most exposed members of the public for liquid discharges
- the annual dose to most exposed members of the public for gaseous discharges
- the annual dose to the most exposed members of the public for all discharges from the facility
- the annual dose to the representative person for the facility

- the potential short-term doses, including via the food chain, based on the maximum anticipated short-term discharges from the facility in normal operation
- a comparison of the calculated doses with the relevant dose constraints
- an assessment of whether the build-up of radionuclides in the local environment of the facility, based on the anticipated lifetime discharges
- the total radiation dose to the UK, European and world populations, up to 500 years in the future
- the dose-rate to non-human species

The calculations of doses to people potentially living near the UK ABWR also need to include a contribution from direct radiation which emanates from the reactor and its associated facilities. Because this is not a discharge of radioactive material into the environment (rather, it is the radiation from radioactive material on the site) reviewing its assessment is outside the scope of this report. Off-site direct radiation is regulated by ONR. The contribution of direct radiation off-site is added to the doses to the public from discharges. In this assessment, we have used the assessment of direct radiation provided by Hitachi-GE (Hitachi-GE, 2016a) (see discussion in Appendix K).

For the other assessments, we require Hitachi-GE to provide a description of models that were used to calculate these doses and why they are appropriate. We also require that all the data and assumptions (with reasoning) that were used as input to the models have been clearly set out. These are the aspects that are explored with the verification and validation elements of our review. The independent dose assessment then provides a separate point of comparison for the outcomes.

3. Review of the Hitachi-GE dose assessment

3.1. Verification

The aim of verifying the radiological dose assessments is to check whether the assessment has been made correctly. This is an essential part of the GDA process (Environment Agency, 2013) as it builds confidence in information presented by the requesting party.

We have checked the results presented in the dose assessment report by Hitachi-GE (Hitachi-GE, 2016a) using information given in that report and using the same software. For routine liquid and atmospheric releases, 3 stages of assessment were undertaken by Hitachi-GE, which follows the approach described by the Environment Agency (Environment Agency, 2006a) for the initial radiological assessment methodology. Differences in results of about 1% may be due to rounding errors and have not been pursued. Larger discrepancies were explored in more detail to seek to identify the reasons for the difference.

The verification process and its outcomes are discussed in detail in Appendix A. Overall, most of the calculated values matched those presented by Hitachi-GE very closely (i.e. to within 1 %).

For marine discharges, we found the differences to be at or below 1% for all radionuclides and foodstuffs in most cases, indicating the results are the same with the exception of rounding errors. Results for the inhalation of sea spray by adults were almost exactly half those presented by Hitachi-GE. This compares to a discrepancy of only about 2% for infants. The difference is likely to be related to the assumed inhalation rates or occupancy of the beach. It was also found that the calculated doses for tellurium-123m was about 3-4% higher than presented by Hitachi-GE for all pathways and all age groups. The reason for this was not identified but is most likely to be related to a difference in the discharge rate or sorption coefficient for marine sediments.

For atmospheric discharges, the calculated exposures of adults are within 1% of Hitachi-GE's figures, for all combinations of pathways and radionuclides, with the exception of inhalation by infants. These differed by 1-2%, which is likely to be due to a rounding errors. The air concentrations by Hitachi-GE for short-term discharges could also be replicated using the Atmospheric Dispersion Modelling System (ADMS) code (CERC, 2012).

We also found some differences in the radionuclide concentrations in marine sediments for specific radionuclides (americium, cobalt, caesium, lanthanum, niobium and ruthenium). Hitachi-GE confirmed that this was because the sorption coefficients used were values specific to the Irish Sea, rather than the generic values used in the initial radiological assessment methodology and PC-CREAM 08 code.

There were also slight differences in the concentrations in soil calculated with the PC-CREAM 08 code for some of the radionuclide discharged in small amounts and the progeny (daughter) radionuclides. However, we established that Hitachi-GE's values appeared to be correct when compared with separate check calculations. It was therefore concluded that the differences relate to the way in which the contributions from ingrown progenies have been assessed. A side-check calculation indicates that the values presented by Hitachi-GE are consistent with the expected amount of ingrowth and are therefore likely to be correct.

Overall, the main outcomes of the Hitachi-GE dose assessment could be adequately verified. The doses calculated by Hitachi-GE were well below the dose criteria. The differences identified were minor and were traced to a small number of input data inconsistencies and some differences in data libraries in the version of codes used, and the method of applying the codes.

3.2. Validation

We also undertook a detailed review of the approach, methods and parameters used in the dose assessments to validate the approach used by Hitachi-GE. This validation exercise involved scrutinising the overall approach, including a review against the published principles for assessing doses from discharges (Environment Agency et al., 2012). Each part of the Hitachi-GE's dose assessment was reviewed. This involved reviewing the approach, models and data used to calculate:

- the annual dose from routine liquid discharges
- the annual dose from routine gaseous discharges
- doses from short-term discharges
- the "collective dose" (the total dose to a whole population) from discharges
- the dose to non-human species

The calculation of total doses from all pathways to exposed groups and the 'representative person' were assessed. In evaluating the significance of the discharges, these results are compared against regulatory dose criteria, in particular the source-related dose constraint of 300 μSv/y (Environment Agency et al., 2012).

Throughout the review the rationale and justification that had been presented was considered, taking account of the regulatory guidance and guidance from the main UK advisory group on dose assessments, the NDAWG. Where possible the data presented was checked against the information sources that were cited.

The observations are presented in detail in Appendix B. Overall, we found that Hitachi-GE had addressed most of our principles satisfactorily. Principles 1, 2, 6 and 13 (Environment Agency et al., 2012) were not fully satisfied in Hitachi-GE's dose assessment report. The reasons are as follows.

- Principle 1: 'Prospective dose assessment methods, data and results should be transparent and made publicly available' - there were some aspects of the dose assessment that were not fully transparent in terms of model data and assumptions.
- Principle 2: 'Workers, who are exposed to discharges of radioactive waste, but who do not work directly with ionising radiation and are therefore not normally exposed to ionising radiation, should be treated as if they are members of the public for the purpose of determining discharge permits or authorisations' - the Hitachi-GE dose assessment does not consider whether there are any such workers who may be exposed. However this is a site-specific matter and needs to be considered in the site-specific dose assessment.
- Principle 6: 'Significant additional doses to the representative person from historical discharges from the source being considered and doses from historical and future discharges and direct radiation from other relevant sources subject to control should be assessed and the total dose compared with the dose limit of 1 mSv/y' - the Hitachi-GE dose assessment does not refer to the contribution from other historical discharges or future discharges from other sources in this manner. However this is a site-specific matter and needs to be considered in the site-specific dose assessment

In GDA not all the principles may be directly relevant. Nevertheless, for completeness it would be appropriate to consider all the principles, noting those that may not be relevant to GDA.

4. Independent dose assessment

4.1. Scope and approach

The independent assessment reported in this work has a similar scope to that undertaken by Hitachi-GE (Hitachi-GE, 2016a). It involves making estimates of the potential doses to members of the public and non-human species from discharges to atmosphere and liquid discharges to the marine environment. It addresses the principles for the assessment of prospective public doses (Environment Agency et al., 2012). This assessment was designed to provide an independent view of the outcome of the discharges reported by Hitachi-GE (Hitachi-GE, 2016a) and is for a single UK ABWR unit.

We used the tiered approach described in Environment Agency guidance (Environment Agency, 2006a). The first two stages of dose assessment were undertaken using the initial radiological assessment tool (IRAT) (Environment Agency, 2006a, b). This provides a simple and conservative indication of the potential doses, and can be used to decide if a detailed assessment is necessary. A detailed assessment is likely to be required if the estimated dose exceeds 20 μSv/y. This usually involves more specific modelling of discharges and, where available, the use of information about the habits of people including the amounts of locally produced food that is eaten.

There are various calculation methods by which doses can be assessed. There is a number of existing software applications that are routinely used for the assessment of radioactive discharges which can be used for the detailed independent dose assessment:

- the PC-CREAM 08 dose assessment software for individual and collective doses to people from routine discharges to air and water (Smith and Simmonds, 2009)
- the ADMS code for short-term discharges of radioactivity to air (CERC, 2012)
- the ERICA code (Beresford et al., 2007), supported by other methodologies (Copplestone et al., 2001) for radiation doses to non-human species

The dose from direct radiation also needs to be taken into account when calculating total exposures for comparison with the dose constraints. However, the assessment of direct radiation exposures is not within the Environment Agency's and Natural Resources Wales' remit. Our assessment uses estimates of direct radiation values calculated by Hitachi-GE (Hitachi-GE, 2016a) which had been assessed by ONR. The people who are most exposed to direct radiation are likely to be similar to, or the same, people most exposed to atmospheric discharges. The consistency of the assessment approach for direct radiation with that for atmospheric discharges was considered in Appendix K.

4.2. Radioactive discharges

The independent dose assessment uses the discharge limits for releases of radioactivity to air (Table 1) and water (Table 2) proposed in Hitachi-GE's study (Hitachi-GE, 2016a). The discharges were assumed to continue for 60 years, (the operational lifetime of the UK ABWR).

The atmospheric discharges were assumed to be from a single 57 m high stack, as this is the smallest stack currently in operation at an existing ABWR (Hitachi-GE, 2016a). Cautiously, the stack height has been adjusted to 1/3 of this value (19 m) to provide an effective release height for radioactive emissions which takes account for the turbulent effects of any nearby buildings (Jones, 1983). Cautiously, no account was taken of the upwards velocity of the discharged air.

Liquid discharges have been assumed to occur continuously over the course of the year at the annual discharge limits proposed by Hitachi-GE (Hitachi-GE, 2016a) (Table 2).

The dose assessment process is required to consider the potential impacts of the maximum short-term release that could be expected to occur under normal operating conditions. For short duration releases, which would be to the atmosphere, the discharge rate specified by Hitachi-GE (Hitachi-GE, 2016a) has been used (Table 3; see further discussion in Section **Error! Reference source not found.**).

Table 1: Proposed annual discharge limits for releases to atmosphere by a single UK ABWR, estimated by Hitachi-GE (Hitachi-GE, 2016a)

Radionuclide	Discharge (Bq/y)	Radionuclide	Discharge (Bq/y)
Ag-110m	3.9E+01	Kr-85	1.3E+09
Am-241	6.6E-04	Kr-85m	1.0E+10
Ar-41	5.2E+12	Kr-87	9.8E+03
Ba-140	3.5E+04	Kr-88	9.3E+08
C-14	1.7E+12	La-140	4.1E+04
Ce-141	4.9E+04	Mn-54	9.0E+04
Ce-144	4.5E+04	Nb-95	1.1E+05
Cm-242	4.9E-01	Pu-238	9.4E-03
Cm-243	4.9E-05	Pu-239	1.2E-03
Cm-244	6.2E-03	Pu-240	1.9E-03
Co-58	1.5E+05	Sb-122	4.9E+02
Co-60	1.5E+05	Sb-124	4.9E+04
Cr-51	1.3E+05	Sb-125	9.8E+03
Cs-134	9.4E+03	Sr-89	4.1E+04
Cs-137	5.7E+03	Sr-90	2.6E+03
Fe-59	2.4E+04	Xe-131m	2.9E+09

H-3	1.0E+13	Xe-133	2.0E+11
I-131	3.2E+08	Xe-133m	1.8E+07
I-132	1.1E+08	Zn-65	4.1E+04
I-133	7.3E+07	Zr-95	5.3E+04
I-135	4.3E+07	-	-

Table 2: Annual discharge limits for releases to the marine environment from a single UK ABWR, proposed by Hitachi-GE (Hitachi-GE, 2016a)

Radionuclide	Discharge (Bq/y)	Radionuclide	Discharge (Bq/y)
Ag-110m	5.70E+00	La-140	7.00E+03
Am-241	1.10E-01	Mn-54	4.00E+05
Ba-140	6.20E+03	Nb-95	1.80E+05
Ce-141	4.50E+04	Ni-63	8.60E+05
Ce-144	2.40E+05	Pu-238	3.60E+00
Cm-242	2.10E+00	Pu-239	5.70E-01
Cm-243	4.90E-03	Pu-240	9.00E-01
Cm-244	4.50E-01	Ru-103	2.70E+04
Co-58	8.20E+04	Ru-106	1.90E+04
Co-60	8.20E+05	Sb-122	1.20E+02
Cr-51	3.70E+04	Sb-124	5.30E+04
Cs-134	5.70E+03	Sb-125	8.20E+04
Cs-137	6.60E+03	Sr-89	9.00E+03
Fe-55	9.40E+06	Sr-90	4.50E+03
Fe-59	2.10E+04	Te-123m	6.20E+01
H-3	7.60E+11	Zn-65	1.10E+05
I-131	6.00E+04	Zr-95	8.20E+04

Table 3: Maximum short-term discharges to the atmosphere from a UK ABWR, estimated by Hitachi-GE (Hitachi-GE, 2016a)

Radionuclide	Discharge (Bq/y)	Radionuclide	Discharge (Bq/y)
Kr-85	1.10E+09	Xe-131m	2.60E+09
Kr-85m	5.50E+09	Xe-133	1.80E+11
Kr-87	5.00E+03	Xe-133m	1.40E+07
Kr-88	5.50E+08		

4.3. Generic site

The GDA process involves assessing the reactor design at a generic site. The generic site should generally be defined in a cautious but not unrealistic way. Cautious assumptions may include selecting a site that is appropriately representative but with characteristics that lead to lower environmental dispersion. The habits of people that are included in the assessment may lead to higher exposure. The use of habits data is discussed in the following sub-section. There is merit in making some cautious assumptions if they can cover a range or envelope of potential sites in the UK at which the reactor could operate. Such an approach has been used by GDA studies for other reactor designs. It ensures that the dose assessment within the GDA will indicate the potential effects of the UK ABWR at a range of sites.

The UK ABWR may be operated at several sites in England and Wales. For the independent assessment, the generic site used was derived following an examination of site characteristics for all of the existing nuclear sites in England and Wales. Those with the lowest dispersion of radioactive discharges were identified. This approach determines where the highest environmental concentrations could arise for the discharges presented in Table 1 and Table 2. The analysis of sites is presented in Appendix C. The review outcomes suggest that the existing nuclear site at Oldbury in Gloucestershire provides a reasonable basis for the independent dose assessment. This has amongst the lowest levels of dispersion of radioactive releases to air and water of the existing nuclear sites in England and Wales. The characteristics of this location have therefore been adopted. In its assessment, Hitachi-GE used Wylfa as the basis for its generic site (Hitachi-GE, 2014). Default data for the environment around Oldbury and other nuclear sites in the UK and Europe are available in the description of models and data for the PC-CREAM 08 code (Smith and Simmonds, 2009).

4.4. Potentially exposed people

As with the site characteristics, it is appropriate to make suitably cautious assumptions for the habits and behaviour of potentially exposed people near the site. The assumptions made should not be unrealistic. Members of the public can be exposed to radionuclides discharged to atmosphere or to the marine environment by a range of exposure pathways. The exposure pathways considered in the independent assessment are typical of those evaluated in radiological assessments of discharges from other nuclear sites. Guidance provided by the NDAWG has also been taken into account.

For discharges to atmosphere, the independent assessment considered the following exposure pathways:

- inhalation of radionuclides discharged to atmosphere
- ingestion of radionuclides in locally produced foods following the deposition onto farmland of radionuclides discharged to atmosphere
- external irradiation from radionuclides in the atmosphere and deposited on the ground following discharge to atmosphere

For discharges of liquids to the marine environment, we considered the following exposure pathways:

- inhalation of contaminated seawater in the form of sea spray
- ingestion of radionuclides in locally caught fish and shellfish
- external irradiation from radionuclides into coastal sand / sediment (at the beach), including exposure to the skin from handling contaminated fishing gear

Food consumption rates and occupancy assumptions for use in the prospective independent dose assessment have been based on generic values and national survey data.

The initial radiological assessment methodology (Environment Agency et al., 2006b) defines possible candidates for the representative person that provide a basis for this study. There are two key groups - a local resident family (whose habits will lead to high exposure to atmospheric discharges) and a fishing family (whose habits lead to high exposure to liquid discharges to the sea). Details of their assumed behaviour, in respect of the exposure pathways described above, are presented in Appendix C (general information), E (exposure to atmospheric discharges) and F (exposure to liquid discharges).

4.5. Results

4.5.1. Initial radiological assessment of the UK ABWR

We used the initial radiological assessment methodology (Environment Agency, 2006a, b) to undertake an initial assessment of the estimated discharges from a single UK ABWR. The assessment is presented in detail in Appendix D.

The initial assessment makes very conservative assumptions about the dispersion of released radionuclides in the Stage 1 assessment. Dose per unit discharge values were multiplied by the estimated discharge rates (Table 1 and Table 2) to determine the calculated dose. The results are shown in Table 4. The total dose from atmospheric discharges is above 20 µSv/y, indicating that further assessment is required. The doses for liquid discharges are well below this level, but in order to provide a point of comparison with Hitachi-GE's assessment, the subsequent stages of detailed assessment have been undertaken.

Stage 2 of the initial radiological assessment (IRA) allows simple refinements to reflect site-specific characteristics that affect dose. Scaling factors provided in the IRA methodology have been used to take account of the fact that atmospheric discharges will be from a 57 m high stack rather than at ground-level. An effective release height of a third of this value (i.e. 19 m) has been assumed to take into account building wake effects (Jones, 1983). The liquid discharge doses were adjusted to take account of a slightly more dispersive marine environment of the generic site. The resulting Stage 2 doses are shown in Table 4.

The total dose from atmospheric discharges remains slightly above 20 µSv/y, indicating a detailed (Stage 3) assessment is appropriate. This is presented in Sections **Error! Reference source not found.** to **Error! Reference source not found.**. The dominant radionuclide for atmospheric discharges is carbon-14 in foods.

The doses from liquid discharges remained very low and well below 20 µSv/y. This is because the expected discharges of radionuclides as liquids are very low. The dominant radionuclides for liquid discharges are cobalt-60 (external radiation from beach sediments) and tritium (H-3) (ingestion of seafood).

The results from the independent dose assessment for atmospheric discharges are very similar to those presented by Hitachi-GE (Hitachi-GE, 2016a), which is unsurprising given the similar methods applied. There is a slight difference in the Stage 2 dose for which Hitachi-GE calculated a value of 24 µSv/y compared to 25 µSv/y. This is because slightly different scaling factors were adopted from the initial radiological assessment methodology (Environment Agency, 2006a).

For the liquid discharges, our Stage 1 value accords with that presented by Hitachi-GE (Hitachi-GE, 2016a). However, the Stage 2 value we calculated is about 10 times greater than that given by Hitachi-GE (Hitachi-GE, 2016a). This is because we selected a generic site with lower marine dispersion, hence the environmental concentrations are higher but the radiological impacts remain well below the dose criterion.

Table 4: Doses (in µSv/y) from the discharges of a single UK ABWR, estimated using the initial radiological assessment methodology

Stage	Discharges	Food ingestion	External irradiation	Inhalation	Total
Stage 1	Atmospheric discharges	60	17	67	143

	Liquid discharges	0.0011	0.0023		0.0035
Stage 2	Atmospheric discharges	21	1	4	26
	Liquid discharges	0.00086	0.0018		0.0027

4.5.2. Individual doses to people most exposed to radioactive substances

In the Stage 3 detailed independent dose assessment, we calculated individual doses to groups of people most exposed to each of the main radioactive discharges from the UK ABWR:

- the local residents, who are most exposed to atmospheric discharges
- a fishing family, who are most exposed to the liquid discharges

Each of these exposure groups was only assumed to be exposed to one form of discharge (air or liquid, respectively). The assumptions for their behaviour were cautious, and these exposure groups can be assumed to be more exposed than any other groups including non-nuclear workers in the vicinity of the site.

Their dose was calculated on the basis of the proposed annual discharge limits for air and water estimated by Hitachi-GE (see Table 1 and Table 2) for a period of 60 years. The site characteristics and human habits used in the calculations are described in detail in Appendix E (atmospheric releases) and F (liquid discharges). The total doses are presented in Table 5.

Table 5: Summary of the total doses (in μSv/y) to people most exposed to atmospheric and liquid discharges from a single UK ABWR, calculated by the independent dose assessment

Group	Age	Inhalation	External	Dose from all foods	Main food type	Dose from main food type	Total
Local resident (atmospheric discharges)	Adult	2.1	0.3	10.6	Milk	5.3	13
	Child	2.0	0.2	12.1	Milk	8.5	14
	Infant	1.6	0.12	22.4	Milk	20	24
Fisherman (liquid discharges)	Adult	5.7E-08	1.3E-04	3.7E-04	Fish	1.7E-04	4.9E-04
	Child	5.4E-09	1.9E-05	1.1E-04	Fish	4.5E-05	1.3E-04
	Infant	3.8E-10	1.9E-06	2.4E-05	Fish	2.3E-05	2.5E-05

For the local resident exposed to atmospheric discharges, the highest dose is to the infant (24 μSv/y dominated by exposure through the ingestion of milk and milk products. The key radionuclide in this case is carbon-14 (91% of the total dose to the infant) with much of remainder of the dose associated with iodine-131 (4.7%), tritium (3.9%) and argon-41 (0.5%).

Doses resulting from liquid discharges are very much lower (0.0005 μSv/y). In this case, adults receive the highest doses. Sea food (in this case crustaceans and fish) being the most important dose pathway. The key radionuclides are tritium (62% of the total dose to the adult), cobalt-60 (26%) and zinc-65 (10%). Further details of the results are given in Appendices E and F.

The independent dose assessment calculated doses to adults, children and infants that were the same as those calculated by Hitachi-GE (Hitachi-GE, 2016a) to 2 significant figures. Although different sites were used in the dose assessments, the main factor in determining exposure is stack height and distance. The independent dose assessment took a residential distance rounded to 300 m rather than the 270 m used in the Hitachi-GE study, but the distance at which food was produced was the same, and food pathways dominate the dose.

The independent dose assessment calculated higher doses for the liquid discharge pathways than those reported by Hitachi-GE (Hitachi-GE, 2016a) but the values remain well below the dose criterion (20 μSv/y). The highest dose calculated in the independent assessment (the adult fisherman) is three times higher than 1.6E-04 μSv/y reported by Hitachi-GE (Hitachi-GE, 2016a). This is because the independent assessment adopted more cautious assumptions to define marine dispersion.

4.5.3. Dose to the 'representative person'

For a Stage 3 assessment it is necessary to calculate total doses to people most exposed from all exposure pathways. The most exposed person is referred to as the 'representative person'. The key criterion is the source-related dose constraint of 300 μSv/y, but a level of 20 μSv/y is defined below which further refinement of dose assessments is not needed (Environment Agency et al., 2012).

The independent dose assessment evaluated 2 candidates for the representative person, based on the local resident and fisherman used to assess doses from atmospheric and liquid discharges. The habits of the candidates for the representative person allowed for exposure to gaseous and liquid radioactive discharges. The local resident was assumed to spend a lot of time on land near the reactor in a house and outdoors, eat a lot of food produced near the reactor, spend an average amount of time on the local beach and eat average amounts of local seafood. The fisherman was assumed to spend less time on land near the reactor, but to spend more time on the beaches and to consume lower amounts of terrestrial food than the local resident. The habits of the candidates for the 'representative person' are described in Appendix G.

Direct irradiation from radioactivity within the UK ABWR is not regulated by the Environment Agency or Natural Resources Wales, but needs to be included in the total dose. The independent study therefore used the doses calculated by Hitachi-GE (Hitachi-GE, 2016a) from direct irradiation (scaled to an exposure distance of 300 m). This is discussed in Appendix K, and the scaled doses from direct radiation range from 0.3 to 1 in μSv/y depending on exposure group and age.

The total doses for the independent assessment are shown in Table 6. Radioactivity released to air is the largest contributor to dose for all exposed individuals. For all potentially exposed people, the dose is dominated by carbon-14 and ingestion pathways, principally cow's milk and milk products. For the infant in the farming family (assumed to consume 320 litres of milk per year) 91% of the dose is associated with carbon-14, and 83% is associated with milk and milk products.

Table 6: Summary of the total doses (in μSv/y) to candidate 'representative person' from a single UK ABWR, calculated by the independent dose assessment

Dose assessment group	Age	Atmospheric discharges	Liquid discharges	Direct radiation*	Total	Dose constraint
Local resident farmer	Adult	13	6.3E-05	0.9	14	300
	Child	14	5.0E-05	0.5	15	300
	Infant	24	1.9E-06	0.3	24	300
Local fisherman	Adult	7.5	4.9E-04	0.9	8.4	300
	Child	8.8	1.3E-04	0.5	9.3	300
	Infant	12	2.5E-05	0.3	12	300

Note: *The direct radiation assessment is described in Appendix K.

The local resident farmer is the most exposed due to spending a high percentage of time at work outdoors close to the reactor. The local fisherman and family receive the same or slightly lower direct radiation doses. This group is assumed to live near the site and spend the same time (or in the case of adult slightly less time) outdoors near the site and (in the case of the adult) more time on the beach.

Doses from liquid discharges are very low reflecting the relatively limited amount of radioactivity discharged by this route. The UK ABWR is designed to recycle liquid effluents and retain and reuse them without discharge. Under certain conditions liquid discharges may occur but under most circumstances there will only be infrequent discharges of small amounts of liquid effluent. Although discharges are likely to be made as batches it is still appropriate to assess them as part of continuous releases. The principles for prospective dose assessment (Environment Agency et al., 2012) states that given the other uncertainties in the assessment process, the results based on continuous release are appropriate for these normal operational daily variations in discharges.

On the basis of the calculated doses for the assumed discharges, a single site could operate more than one UK ABWR and remain within the site-related constraint of 500 µSv/y. A first estimate of the total dose to an individual from discharges can be assumed to be proportional to the number of reactors. Furthermore, even when account is taken of the possible additional radiation doses from existing nuclear sites (including historic discharges), the public dose limit is unlikely to be exceeded for the most exposed person. The highest recently estimated dose from an existing nuclear site is around 300 µSv/y, which includes exposure to past discharges of liquids from Sellafield, the Low Level Waste Repository (LLWR) and the phosphate plant near Whitehaven (Environment Agency et al., 2014).

The total doses calculated by Hitachi-GE (Hitachi-GE, 2016a) for representative persons are shown in Table 7. For the assessment, Hitachi-GE (Hitachi-GE, 2016a) has assumed the local resident and fisherman live 270 m from the site. The actual total dose from a UK ABWR from gaseous discharges and direct radiation will depend on site-specific factors, including terrain and the actual location of the people and their houses relative to the reactor.

The differences in doses from discharges, between the independent and Hitachi-GE assessments has been considered earlier. For the atmospheric pathway, the doses calculated by Hitachi-GE are almost exactly the same for the farming family, as the dose is dominated by food ingestion which is assumed to be sourced from the same distance from the stack. For the fishing family, the independent assessment is slightly more conservative in the exposure duration assumed. For the liquid discharge pathway, the main reason for the higher doses calculated in the independent dose assessment is the more cautious assumptions used for the generic site, in terms of the marine dispersion characteristics.

Table 7: Total doses (in µSv/y) to candidate 'representative person' from a single UK ABWR, calculated by Hitachi-GE (Hitachi-GE, 2016a)

Group	Age	Atmospheric discharges	Liquid discharges	Direct radiation	Total
Local resident	Adult	13	8.8E-06	0.94	14
	Child	14	9.5E-06	0.47	15
	Infant	24	2.2E-06	0.32	24
Fisherman	Adult	6.0	2.3E-04	0.94	6.9
	Child	6.7	6.2E-05	0.47	7.1
	Infant	9.5	5.4E-06	0.32	9.8

4.5.4. Individual doses from potential short-term releases

Variation in radioactive discharges from an operating ABWR occurs due to sporadic events during the plant's normal operation. The principles for prospective dose assessment (Environment Agency et al., 2012) require an assessment of the potential radiological consequences of such releases, to ensure dose constraints and limits are met.

The main expected short duration releases are to atmosphere. The characteristics of the release have been taken from Hitachi-GE (Hitachi-GE, 2016a). Hitachi-GE has stated the cause of the release would be a fuel pin failure and the release would take place over a period up to two weeks. For convenience and to add an element of conservatism, Hitachi-GE has taken the release to occur over 24 hours. Hitachi-GE has also indicated that any such release would be of noble gases only (isotopes of xenon and krypton). Hitachi-GE expect that other radionuclides would be retained in the reactor coolant. There are various numerical models available for assessing air concentrations for such a release, most of which rely on Gaussian plume dispersion. Hitachi-GE has used ADMS (CERC, 2012), which is one such model and which satisfies the guidance provided in NDAWG (NDAWG, 2011). ADMS has also been used in the independent assessment of a short-term release also.

Estimating off-site air concentrations and doses from a short-term release is challenging because meteorological conditions are both site, time and weather condition dependent. Consequently, there are varying degrees of conservatism that can be introduced when ascribing representative parameters. The independent assessment has therefore been to evaluate air concentrations for a range of weather patterns including:

- low pressure weather systems - cloudy overcast and breezy conditions
- high pressure systems - less cloud, more sun and light winds

The time of day / year is also important (especially in the high pressure case) because it affects the level of ground heating by the sun (and consequently, thermal mixing of the atmosphere). Ground heating varies with season and cloud cover. In order to ascertain the dispersion of the plume under a range of conditions, calculations have been undertaken for the winter and summer solstices and for the autumn equinox, assuming a release height of 19 m, an emission velocity of 0 m/s, and a discharge temperature equal to the ambient temperature (i.e. that plume buoyancy is not important) . For each scenario, the daily mean air concentrations have been calculated by averaging the hourly output data from ADMS. The results (see Appendix H) show that overcast and relatively calm conditions tend to lead to higher predicted air concentrations than clear or windy conditions. Alternative calculations using the R91 model (Clarke, 1979) showed generally lower air concentrations than ADMS for a range of weather conditions (further details are presented in Appendix H). It should be noted that high air concentrations are predicted to persist for only a period of a few hours during the course of a day, in some cases.

On the above basis and using ADMS, dose calculations were made using both the maximum daily mean air concentration and the maximum hourly mean concentration (but assuming that it only persists for several hours only). The exposed person was assumed to be located at the same distance (300 m) from the stack and have the same habits as the critical groups in the assessment of continuous discharges (Appendix E). However, the dose pathway was restricted to external exposure only, since noble gases are non-depositing. The results of the dose calculations are presented in Appendix H and summarised in Table 8.

Table 8 shows that the most exposed person is an adult exposed for a short period when the plume concentration is highest. The dominant radionuclides are krypton-85m (11% of the dose), krypton-88 (16%) and xenon-133 (72%). The dose using the peak concentration is around twice that calculated if the mean concentration over a 24 h period is assumed. The doses for the daily average exposure are less than half those calculated by Hitachi-GE. It has not been possible to determine the reason for the difference as the discharge, occupancy and dose factors are the same and the atmospheric dispersion factor differs by only a small amount. However both assessments show that the doses are very low, and the results are far below the dose criterion.

Table 8: Estimated doses in μSv from a short-term release calculated in the independent dose assessment

Exposed group	Independent dose assessment	Hitachi-GE result
Adult (daily mean)	0.0041	0.019
Child (daily mean)	0.0028	0.017
Infant (daily mean)	0.0026	0.016
Adult (2 hour peak)	0.0020	not assessed

4.5.5. Collective doses to exposed populations

The collective dose provides a measure of the exposure of all people to radioactive discharges. It is the sum of all doses to a defined population, over a defined time. Guidance (Environment Agency et al., 2012) recommends that the populations considered should be the UK residents, Europeans, and the global population, and that the time period over which doses are summed be 500 years. Collective doses to these populations have been calculated in the independent study using the PC-CREAM 08, which has models and data for the calculation of collective dose.

The collective dose results, described in more detail in Appendix I, are summarised in

Table 9. There are no specific criteria against which the collective dose is compared, although collective doses are used to inform decisions on the permitting of discharges. However, we note that the average per caput dose may be informative (Environment Agency et al., 2012). The average per caput dose to a person in the UK is calculated to be 0.014 μSv/y, based on the UK population assumption in PC-CREAM 08 of 59.6 million (Smith and Simmonds, 2009). Public Health England has advised that per caput doses of less than 10 μSv/y are unlikely to be considered significant.

Table 9: Collective dose (manSv), truncated at 500 years, for each year of radioactive discharge from a single UK ABWR nuclear power plant for the independent dose assessment

<table>
<tr><th>Discharges</th><th>Dose type</th><th>UK population</th><th>EU population</th><th>World population</th></tr>
<tr><td rowspan="3">Atmospheric discharges</td><td>First pass</td><td>0.65</td><td>3.1</td><td></td></tr>
<tr><td>Global circulation</td><td>0.18</td><td>1.4</td><td>30</td></tr>
<tr><td>Total (atmospheric)</td><td>0.83</td><td>4.5</td><td>30</td></tr>
<tr><td rowspan="3">Liquid discharges</td><td>First pass</td><td>8.1E-08</td><td>1.7E-07</td><td>2.0E-07</td></tr>
<tr><td>Global circulation</td><td>1.5E-07</td><td>9.2E-07</td><td>2.6E-05</td></tr>
<tr><td>Total (marine)</td><td>2.3E-07</td><td>1.1E-06</td><td>2.6E-05</td></tr>
<tr><td colspan="2">Total</td><td>0.83</td><td>4.5</td><td>30</td></tr>
</table>

The independent dose assessment calculated collective doses per year of discharge from the global circulation of atmospheric releases that were the same as those given by Hitachi-GE

(Hitachi-GE, 2016a); see Table 10. However, the first pass doses are greater for the independent dose assessment. We calculated 0.65 manSv, compared with 0.43 manSv by Hitachi-GE (Hitachi-GE, 2016a) for the UK population. For Europe, we obtained 4.5 manSv compared with 2.9 manSv. The location of the discharge has some bearing on the UK collective dose (for example due to proximity to population centres), but the EU dose is unlikely to be very sensitive to this aspect. The differences arise from the meteorological conditions assumed to prevail at the site. The site we chose, Oldbury, does not exhibit as much atmospheric dispersion as that chosen by Hitachi-GE so the concentrations of radionuclides in air are greater, even at distance. For example, for our case we calculated concentrations 1.6 times higher than Hitachi-GE even at a 1000 km distance.

Table 10: Collective dose (manSv), truncated at 500 years, for each year of radioactive discharge from a single UK ABWR nuclear power plant calculated by Hitachi-GE

Discharges	Dose type	UK population	EU population	World population
Atmospheric discharges	First pass	0.25	1.5	-
	Global circulation	0.18	1.4	30
	Total (atmospheric)	0.43	2.9	30
Liquid discharges	First pass	2.3E-07	6.0E-07	8.9E-07
	Global circulation	1.5E-07	9.2E-07	2.6E-05
	Total (marine)	3.8E-07	1.5E-06	2.7E-05
Total		0.43	2.9	30

The collective dose for liquid discharges differs slightly from the results presented by Hitachi-GE (Hitachi-GE, 2016a). As the model used in both assessments is very similar, the differences can be attributed to differences in model input data. For the independent dose assessment, the Oldbury site was chosen as the site on which to base the assessment, whereas Hitachi-GE's assessment was similar to Wylfa. The independent dose assessment also used more recently recommended concentration factors for seafood (IAEA, 2004a) than those used as defaults in PC-CREAM 08.

4.5.6. Radiation exposure of non-human species

Wildlife (non-human species) are exposed to radionuclides discharged to the environment. Both the principles for the prospective assessment of public doses (Environment Agency et al., 2012) and the Environment Agency process for the GDA (Environment Agency, 2013) require that doses to the most exposed non-human species be assessed. We have undertaken this assessment using the same assumptions for the generic site and rates of discharge used in the assessment of doses to people. Species living on land were assumed to be located at the site boundary (taken to be 300 m), while marine biota were assumed to be in the local marine environment, where concentrations in seawater and sediment are highest.

Doses were assessed using the ERICA methodology, supplemented by an Environment Agency model for noble gases (Copplestone et al., 2001), for a wide range of non-human species. Carbon-14 was the dominant radionuclide for terrestrial biota. The highest dose rate was 0.2 µGy/h. The most exposed species varied (birds, reptiles and mammals) but smaller biota (for example insects and molluscs) were less exposed. In contrast, the most exposed biota in the marine environment were mammals. The rates of exposure lie well below the screening value of 10 µGy/h applied to non-human species. This finding is consistent with that reported in the assessment of non-human species by Hitachi-GE (Hitachi-GE, 2016a).

5. Conclusions

An independent assessment has been undertaken of the estimated radioactive discharges from the UK ABWR that is being proposed for development in England and Wales by Hitachi-GE. There were 3 aims of the work:

- independently verify the dose assessment made by Hitachi-GE, by seeking to reproduce the results using the same computer models and data chosen by Hitachi-GE
- validate the methods, parameters and assumptions used by Hitachi-GE for its dose assessment, taking account of published guidance and experience
- independently estimate doses and other measures of radiological impact from the estimated discharges from the site

All the doses predicted by Hitachi-GE were low and well below the dose constraint of 300 µSv/y, ranging up to 24 µSv/y for atmospheric discharges (mostly from carbon-14) and much less than 1 µSv/y for liquid discharges.

Hitachi-GE's study addressed those principles for the prospective assessment of radiological discharges (Environment Agency et al., 2012) that are relevant in the case of GDA. However in some cases the approach or data used were not fully transparent which affected our verification process.

We were able to verify most of the calculations made by Hitachi-GE, but noted some areas in which there was insufficient information (or explanation of the information) to enable resolution of the outcomes and allow complete verification. These proved relatively simple to resolve by way of discussion with Hitachi-GE and through Regulatory Queries (RQs). The outcomes did not significantly affect the estimated doses.

When validating the approach, models and data, there were some areas in which additional information would be of benefit. This is particularly in respect of addressing the approach to and uncertainties in the potential short-term atmospheric discharges.

The overall conclusion is that Hitachi-GE's dose assessment provides a suitable guide to the potential doses and other radiological effects of the UK ABWR.

An independent dose assessment was then undertaken to provide an alternative perspective on the significance of the discharges from the UK ABWR. This differed from the Hitachi-GE study in several respects, in particular the site used as the basis for the generic site characteristics. Oldbury was chosen on which to base the site for the independent assessment. Basing the assessment on this location is bounding and more limiting compared with the site chosen used by Hitachi-GE. For the rest of the independent assessment most aspects of the modelling codes and data were the same as those used by Hitachi-GE, although some more recent input data was incorporated than the default ones in PC-CREAM 08 (as discussed in Appendix C). The independent assessment assumed similar habits and locations of potentially exposed people to those in the Hitachi-GE study.

The independent assessment outcomes were very similar to those by Hitachi-GE. The highest doses were from atmospheric discharges of which carbon-14 is the main radionuclide. The dominant exposure pathway is the ingestion of locally produced milk.

The radiological impacts of routine liquid discharges are very low, much less than much lower than the doses atmospheric releases, reflecting the design of the UK ABWR in which liquid effluents are retained and recycled with minimal discharges.

Our estimated doses to the 'representative person' were the same as those calculated by Hitachi-GE (Hitachi-GE, 2016a). The total dose was 25 µSv/y, well below the dose constraint of 300 µSv/y, with almost all the dose associated with discharges of carbon-14. Direct radiation contributed between 0.3 and 1 µSv/y to the total dose. The cautious habits assumed for the representative person (for example that they get all their food from sources close to the reactor) means that no other individuals could receive higher exposures, including other members of the public or non-nuclear workers.

The independent assessment of doses from liquid discharges showed that doses are low (much less than 1 µSv/y), which is consistent with Hitachi-GE's outcome, despite the more restricted marine dispersion at the site used in the independent assessment.

The independent estimates of the collective radiation dose to populations (the UK, Europe and the world) were above the collective dose criterion proposed by the IAEA (IAEA 1988, 2004b) of 1 manSv/y of discharge. Doses to wildlife did not indicate any doses that would be of concern.

The dose calculations in this study are applicable to the GDA and apply to a single UK ABWR unit. The results indicate that more than one unit could be accommodated at a site and still meet the legal dose criteria (the dose constraint of 300 µSv/y and site constraint of 500 µSv/y; or the dose limit of 1000 µSv/y - allowing for radiation exposures from existing nuclear facilities).

Sensitivity analysis undertaken in the study shows that locating a UK ABWR at another site may lead to similar or lower environmental concentrations and lower doses than those calculated for a site similar to Oldbury - in this assessment.

If a site is selected for a new reactor of this design and a permit requested, then a site-specific assessment will be needed. This assessment will take account of site-specific factors and the number of UK ABWR units that will be operated.

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Glossary

Term	Details
Collective dose	The sum of the individual doses received by a specified population from exposure to a specified source of radiation in a given time period. Typically man-Sv truncated at 500 years from a discharge lasting for one year.
Direct radiation	Radiation emitted from fixed structures containing radioactivity and / or radioactive sources on a site, including the reactor circuit; source stores; spent fuel stores; radioactive waste stores.
Effective stack height (frequently used in the modelling of gaseous releases)	A representation of the release height of gases to atmosphere, which, where relevant, maybe affected by (or may take into account) the physical height of the release point; the wake effects or downdraught effects of nearby buildings of similar height to or higher than the stack the exit velocity of the discharged gases the temperature of the discharged gases geography / terrain (hills or valleys nearby)
Gaussian (plume) model	One of the oldest (circa 1936) and commonly used model types for atmospheric dispersion of pollutants. It assumes that the air pollutant dispersion has a Gaussian distribution, meaning that the pollutant distribution has a normal probability distribution. Gaussian (plume) models are most often used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Gaussian models may also be used for predicting the dispersion of non-continuous air pollution plumes (called puff models). The primary algorithm used in Gaussian modelling is the Generalised Dispersion Equation For A Continuous Point-Source Plume (Paraphrased from Wikipedia).
Pasquill stability category (related to modelling dispersion of discharges to atmosphere)	An historically common method of categorising the amount of atmospheric turbulence present (dating from 1961). Atmospheric turbulence was categorised into six stability classes (A, B, C, D, E and F) with class A being the most unstable or most turbulent class, and class F the most stable or least turbulent class. (Paraphrased from Wikipedia).
Physical stack height (sometimes used in the modelling of gaseous releases)	The height of the top of the stack from which gaseous releases may occur relative to the ground.
Radioactive Progeny	The radioactive isotope that is the product atom formed during the radioactive decay. Also called radioactive daughter. In some cases the product atom may not be radioactive.

Term	Details
Representative person	Characterised individual, either hypothetical or specific, whose dose can be used for determining compliance with the relevant dose constraint. The representative person is ‘an individual receiving a dose that is representative of the more highly exposed individuals in the population.’ This term is the equivalent of and replaces the average member of the critical group. In selecting the characteristics including habits of the representative person, 3 important concepts should be borne in mind: reasonableness, sustainability, and homogeneity.
Rounded (number)	In this report estimated doses may be calculated to several decimal places. This suggests the result is known to a high level of precision, which is not correct given the uncertainties in the calculation. Therefore the results may be rounded to one or 2 significant figures. The standard rounding rules for decimals have been followed.

List of abbreviations

Abbreviation	Details
ABWR	Advanced Boiling Water Reactor
ADMS	Atmospheric Dispersion Modelling System
DPUR	Dose per unit release
EU12	Countries in EU in 1986 (Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Portugal, Spain, United Kingdom).
EU25	Countries in EU in 2004 (as EU12 plus Austria, Cyprus, Czech Republic, Estonia, Finland, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia and Sweden).
GDA	Generic design assessment
ICRP	International Commission on Radiological Protection
IDA	Independent dose assessment
IRA	Initial radiological assessment
IAEA	International Atomic Energy Agency
IRAT	Initial radiological assessment tool
LLWR	Low Level Waste Repository
NDAWG	National Dose Assessment Working Group
ONR	Office for Nuclear Regulation
P&ID	Process and information document
PHE	Public Health England
REP	Radioactive Substances Regulation Environmental Principle
RIFE	Radioactivity in Food and the Environment
RQ	Regulatory Query
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

Abbreviation	Details
USDOE	United Stated Department of Energy
UK	United Kingdom

Appendix A: Verification of the radiological assessments of the UK ABWR design

A.1 Introduction

This appendix examines the dose calculations undertaken by Hitachi-GE in support of the Generic Design Assessment (GDA) of the UK ABWR (Hitachi-GE, 2016a). In it we seek to show whether the results can be reproduced independently. This is referred to as 'verification' of the radiological dose assessments.

Verification of the dose assessment provided by the requesting party (Hitachi-GE) is a key part of the GDA process (Environment Agency, 2013). Verification is part of the detailed assessment phase of the GDA. Detailed assessment involves close scrutiny of the underlying case that substantiates the assertions and commitments made.

Verification ensures that there have been no errors in the calculations performed by the requesting party and therefore builds confidence in the knowledge, expertise, and quality management systems used by the requesting party. Verification of the calculations has been undertaken by adopting the modelling techniques used by Hitachi-GE and the input data specified (Hitachi-GE, 2016a). These results are then compared with the reported values. The results should be similar or identical. Any differences may indicate:

1. an error has been made in the assessment
2. the calculations performed are not as described (possible systematic error)
3. the verification process itself has included errors or misinterpretations

Validation of Hitachi-GEs assessment is considered in Appendix B. This is a review of the appropriateness of the calculations performed by the requesting party. Validation can include checking that appropriate dose assessment guidance has been taken into account, and that the assumptions, models, data and other methods used in the dose assessment are well founded and appropriate to the purpose of the dose assessment.

The structure of this appendix mirrors the way that the dose calculations have been presented in Hitachi-GE's dose assessment report, as follows:

- the annual dose to the most exposed members of the public from the discharges from the facility
- the dose to the representative person from the facility
- potential doses from short-term discharges
- accumulation of radionuclides in the local environment
- the collective dose from discharges
- the potential radiation dose to non-human species

The verification of these calculations is discussed in turn in the following sections.

The results have been compared with those reported by Hitachi-GE. As Hitachi-GE has quoted the results to its calculations to 3 significant figures, discrepancies of up to ~1% can be attributed to rounding errors. Differences greater than this have been reported and the reasons for the differences have been identified where possible.

A.2 Annual dose to the most exposed member of the public

Hitachi-GE made a 3 Stage assessment. The first 2 Stages used the dose per unit release (DPUR) factors from the initial radiological assessment (IRA) system. The third stage was more detailed and used commercial modelling software.

A.2.1 Stage 1 assessment

The Stage 1 assessment follows the Environment Agency's guidance (Environment Agency, 2006a), in that the calculations use general conservative conditions that do not reflect the conditions assumed for the discharging site

Liquid discharges

The Stage 1 assessment uses the Environment Agency's dose per unit release (DPUR) values from IRAT system for liquid discharges (Environment Agency, 2006b). These are factors that have been calculated by the Environment Agency to relate radiation exposure of a hypothetical person to radionuclide discharges for a site. The DPUR values were calculated with cautious assumptions, are used in the IRAT system such that if the radiation dose to a person is below the recommended criterion, no further assessment in required. For the Stage 1 DPUR values are derived for liquid discharges into a local marine compartment (an area of sea immediately around the point of discharge, 1 km out to sea and 10 km wide). There is a low rate of seawater flow through it of 100 m^3/s. The assessment is made assuming that an exposed person eats seafood at rates that are representative of the highest anticipated consumption rates. A high proportion of seafood is assumed to originate from the local compartment - where radionuclide concentrations will be highest.

Where DPUR values were not available (for example tellurium-123m, antimony-122 and antimony-124) Hitachi-GE used caesium-137 as a surrogate, - which is cautious. The independently calculated results were the same as those reported by Hitachi-GE for its Stage 1 assessment (Hitachi-GE, 2016a) in Table A.1, allowing for rounding differences, except for tellurium-123m. An incorrect discharge rate is listed in Table A.1 for this radionuclide (3.4E-05 Bq/y rather than 49 Bq/y reported by Hitachi-GE in Table 6.3-3). When the correct discharge rate is used, a small difference in the calculated dose (7.25E-9 µSv/y compared with 7.14E-09 µSv/y by Hitachi-GE) remains. This is a small difference in a small dose, and does not affect the total.

Atmospheric discharges

The Stage 1 assessment uses the Environment Agency's DPUR values from IRAT system for discharges to atmosphere (Environment Agency, 2006b). These have been calculated with generic assumptions. The release of radioactivity to air is assumed to be at ground level. The assumed atmospheric conditions are representative of a site where Pasquill stability Category D conditions persist for 50 % of the time. Pasquill categories are a measure of atmospheric stability; Category D is associated with overcast and breezy conditions. In central England, Pasquill Stability Category D typically dominates for around 50% of the time. At coastal locations, it tends to be more frequent and might dominate for 65 - 75% of the time.

Consumption rates of potentially contaminated foodstuffs have been taken to represent the highest anticipated ingestion rates (based on food intake information presented in Smith and Jones (Smith and Jones, 2003). The local resident exposure group is conservatively assumed to live at a distance of 300 m from the point of discharge. The food they eat is assumed to be produced 500 m from the stack.

The results matched those presented by Hitachi-GE (Hitachi-GE, 2016a) in Table A.9.

A.2.2 Stage 2 assessment

Liquid discharges

The Stage 2 assessment follows the Environment Agency's guidance (Environment Agency, 2006a). The calculations have been modified to more closely reflect the conditions assumed for the discharging site. A generic site has been defined by Hitachi-GE (Hitachi-GE, 2014). Hitachi-GE consider that the volumetric flow of water through the local marine compartment defined in the generic site and used in Stage 2 is significantly higher than for Stage 1. Calculations were therefore adjusted to take this into account and the flow rate at the selected generic site was assumed to be 1300 m^3/s, (in comparison 100 m^3/s used in the Stage 1 assessment). This yields a factor of 0.077 for the generic site and used in the Stage 2 assessment.

In the verification of Stage 2 of the assessment when the results were adjusted by the increased exchange factor, the same doses as those presented by Hitachi-GE were calculated, except for tellurium-123m (where the difference was marginally greater than 1%). It was noted that Table A.2 of the Hitachi-GE submission (which lists the radionuclides and the discharges) includes an incorrect value for the discharge rate for tellurium-123m.

Atmospheric discharges

The Stage 2 assessment refines the Stage 1 calculations by allowing adjustment of the atmospheric concentrations and deposition fluxes - allowing for releases higher than ground level. This is more realistic and can allow representation of a release from a stack typical of the UK ABWR. The effective stack height was taken to be 19 m. This is one third of the likely physical stack height. This factor of a third has been introduced to take account of entrainment in the wake of the site buildings (Jones, 1983). Using the scaling factors presented in the IRAT, the net effect of assuming this stack height, rather than a ground level release, reduces doses from foods by a factor of 3, and internal inhalation doses and external doses by a factor of 0.045.

In our verification of the Stage 2 assessment, when the results were adjusted to allow for the higher stack, we obtained the same doses as those presented by Hitachi-GE.

A.2.3 Stage 3 assessment

Liquid discharges

The Stage 3 assessment calculated annual individual doses to a person from a continuous release of liquid effluent at the assumed discharge limits for a 60-year period (the estimated lifetime of the UK ABWR). The model assumptions were very similar to those underlying the Stage 2 assessment, insofar as a release was assumed to occur to the North Wales coast at the location chosen for the generic site. The most notable difference to the Stage 2 assessment, in terms of habits, was that seaweed ingestion (for example samphire) was included for adults in the Stage 3 assessment. Hitachi-GE calculated doses using local seafood ingestion at a rate equal to the 'high intake rates' (high intake rates correspond to the upper end of the distribution of food intake rates, based on national surveys). Hitachi-GE also present doses calculated for mean intake rates.

For our verification we used the model parameters specified in Appendix B of Hitachi-GE's Submission (Hitachi-GE, 2016a) with the current release of the PC-CREAM 08 dose assessment software (PC-CREAM 08 v1.5.1.85 using database Version 2.0.0) to calculate individual doses for both high rates and mean intakes (Smith and Jones, 2003).

The calculation results were compared with Tables A.3 - A.5 (high intake rates) and A.6 to A.8 (mean intake rates) of the Hitachi-GE report. For most results, we found that differences were at or below 1% for all radionuclides and foodstuffs, indicating that the results are the same, with the exception of small rounding differences. Our results for the inhalation of sea spray by adults were almost exactly half those presented by Hitachi-GE, and for the same pathway our results differed by about 2% for infants. This difference is likely to be related to the assumed inhalation rate or occupancy of the beach. The same differences were found for the high intake and mean intake results.

It was also found that the calculated doses for tellurium-123m was about 3-4% higher than presented by Hitachi-GE for all pathways and all age groups. The reason for this was not determined but is most likely to be related to a difference in the discharge rate or sorption coefficient for marine sediments.

Atmospheric discharges

The Stage 3 assessment involved calculating peak doses from a continuous gaseous release at the discharge limits for the 60-year operating period of the UK ABWR. The main difference in assumptions to the Stage 2 calculations was the adoption of '70% Category D' atmospheric conditions. These meteorological conditions are representative of an exposed coastal site in the UK, such as has been assumed for the generic site of the UK ABWR (Hitachi-GE, 2016b). The local resident was also assumed to live further away (270 m rather than 100 m) but still obtain food produced 500 m from the site. As in Stages 1 and 2, a uniform wind rose was assumed, which is not conservative.

The model parameters assumed were those specified in Appendix B of Hitachi-GE's Submission (Hitachi-GE, 2016a). The current release of the PC-CREAM 08 dose assessment code was used to calculate individual doses for both critical intake rates[1] and mean intakes. The results have been compared to those presented by Hitachi-GE in Tables A.11 to A.16.

The verified results for the exposure of adults are within 1% for all combinations of pathways and radionuclides, with the exception of inhalation by infants. These differed by 1-2%, indicating the reason is likely to be a rounding difference in the adopted inhalation rate.

Hitachi-GE has produced a simplified uncertainty analysis to estimate how much the calculated air concentrations rely on the assumed modelling input parameters. There are no specific results presented in relation to the frequency of Category D stability conditions. Reference is made to a report that introduced the R91 Model (Clarke, 1979). Hitachi-GE has cited a difference of around 2 for 50% and 80% Category D conditions, although this would clearly depend on the distance from the source (and the source height). It was not possible to match this factor of 2 from the tables cited by Hitachi-GE.

Hitachi-GE has also illustrated the effect of source height on ground level concentration (Figure 16.2-1 (Hitachi-GE, 2016a)) for a release during Category D conditions. While the figure may be intended for illustrative purposes, it was not possible to replicate the results in it using either ADMS or R91.

A.3 Annual dose the 'representative person'

The calculated dose to the most exposed individual provides an illustration of the highest dose that might be expected from a combination of human behaviours. It is, however, intentionally very conservative and is thus unlikely to be representative of the characteristics of real people. For example, the combination of high ingestion rates for many food pathways may not lead to a realistic diet, and there are aspects of double counting of exposures via other pathways. To address this, it is accepted practice to define conservative, but feasible and self-consistent, exposure groups for the purpose of assessing radiological discharges. These are referred to as 'representative persons' (see NDAWG, 2009, for further information this definition).

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[1] A 'top-two' approach (NDAWG, 2009) was used, with high rates taken for milk and milk products for infants and children, and root vegetables and milk products for adults, and mean rates for other foods.

The Hitachi-GE assessment considers 2 groups that are candidates for the 'representative persons': one exposed predominantly to liquid discharges (the fishing family) and the other predominantly to gaseous discharges (the local resident). The annual doses to these exposure groups have been calculated using the results calculated for the routine liquid and gaseous discharges, discussed in Sections A.2 and A.3. These have been combined by summing the relevant results for each pathway:

- the fishing family doses are the calculated from the results for exposure to marine pathways at critical rates to the terrestrial consumption pathways at mean rates
- the local resident doses are calculated from the "top two" doses from terrestrial foods with the addition of marine food pathways at mean intake rates

The calculated results agree with Hitachi-GE's results to within 1%, with the exception of those pathways where a difference was in the Stage 3 assessment described in A2.3.

A.4 Potential doses from short-term discharges to the atmosphere

Doses resulting from short-term releases of radionuclides have been estimated using the ADMS atmospheric dispersion software. ADMS is a Gaussian plume dispersion model, typical of most short-range dispersion models. The most likely cause of an enhanced short-term release to atmosphere has been quoted by Hitachi-GE as being due to pinhole to fuel-pin cladding (fuel pin failure). It has been further noted by Hitachi-GE that this would result in a release to the atmosphere of noble gases (isotopes of krypton and xenon) only, since it has been assumed that other radionuclides would be retained in the coolant. It is further noted that such a short-term discharge could constitute up to 90% of the annual discharge limit for theses radionuclides.

The main difference between ADMS and PC-CREAM 08 (used in the calculation of exposures from continuous atmospheric discharges) is how atmospheric stability is addressed. PC-CREAM 08 requires atmospheric stability to be described by the Pasquill Stability Class, whereas ADMS uses specific parameters. Pasquill Stability Class cannot be input directly into ADMS. However, there are various ways of using meteorological and other data in ADMS, so that the different Pasquill Stability Classes can be represented. They include specifying time of day / year and cloud cover (to determine insolation level), and wind speed. Hitachi-GE has assumed conditions stated to be representative of Pasquill Stability Category D in assessing the impact of a short-term release, on the principle that this would represent a realistically cautious rather than exceedingly cautious approach. Hitachi-GE has based this assumption on conclusions made in a published report on assessing short-term planned releases (Smith et al., 2004), although there are a number of factors that need to be considered when deciding whether the results in this report are applicable. The Hitachi-GE calculations involve a different release height, a critical group at a different distance from the source and non-depositing radionuclides. The report (Smith et al., 2004) cautions against the universal acceptance of Category D conditions being representative without further study for an individual location. Hitachi-GE has undertaken a sensitivity study and the applicability of the conclusions from the report (Smith et al., 2004) are discussed in the independent dose assessment (see Appendix H).

The ADMS input parameters specified by Hitachi-GE are:

- wind speed of 3 m/s
- 0 W/m solar radiation
- rainfall rate of 0.1mm/h
- boundary layer height of 800 m
- lateral spread of 21.7 degrees
- stack diameter of 1m
- efflux velocity of 0 m/s

- effective stack height of 19 m (i.e. one third of 57 m)

Hitachi-GE has assumed a short-term release would take place over 24-hours rather than the more likely timescale of 14 days. Hitachi-GE has stated this is a conservative assumption. However, it is only conservative in terms of the constancy of the wind direction (since it is the integrated dose that is important and Hitachi-GE has assumed Category D to be representative conditions). Calculations using ADMS confirmed the values of air concentration presented by Hitachi-GE in Table A.24 (note that the numbers here do not agree with those illustrated in Figure 16.2-1).

A.5 Accumulation of radionuclides in the local environment

Calculated results from PC-CREAM 08 were used by Hitachi-GE to estimate the peak concentrations in environmental media after a 60-year operating period. In these calculations, Hitachi-GE adopted the modelling assumptions specified by the Environment Agency's IRAT for Stage 1 assessment, rather than use those used in the Stage 3 assessment. The reasons for not using the more detailed calculation assumptions are not discussed by Hitachi-GE. The key differences relate to the initial dispersion of radionuclides. For liquid discharges, a lower local compartmental exchange rate of 100 m^3/s is used in the Stage 1 assessment. For gaseous releases, the Stage 1 assessment considers a release at ground level compared to an effective release height of 19 m in Stage 3. It can therefore be expected that environmental concentrations presented by Hitachi-GE are conservative and would be lower had the Stage 3 modelling assumptions been used.

A.5.1 Marine environment

Concentrations in seawater and seabed sediment were calculated using the DORIS model in PC-CREAM 08. The local compartment characteristics used were those specified for the Stage 1 assessment, taken from the IRA documentation (Environment Agency, 2006b). The calculated concentrations agreed to within 1% for both (Table A.28) for most radionuclides.

The largest discrepancies were found for americium, cobalt, caesium, lanthanum, niobium and ruthenium. For americium, cobalt and caesium, concentrations in sediment were found to be higher than those presented by Hitachi-GE, indicating that Hitachi-GE used a lower sorption coefficient. However, the opposite was true for ruthenium isotopes. The Hitachi-GE results for lanthanum and niobium, were lower in both water and sediments. These radionuclides include discharged parents and ingrown progeny, and this is expected to be the reason for the difference.

A.5.2 Terrestrial environment

Concentrations of radionuclides (Bq/kg) were calculated by combining the rate of deposition from the plume (using the PLUME component of PC-CREAM 08) with soil concentrations calculated for a unit deposition rate by the FARMLAND component. FARMLAND calculates soil concentrations for different crops. Hitachi-GE did not specify a crop type for the soil, so soil used for growing root vegetables was selected. This gives the highest soil concentrations. In both cases, a 60 year discharge was assessed. Concentrations of tritium and carbon-14 were calculated separately using a specific activity model.

The calculated soil concentrations agreed with Hitachi-GE results to within 1% for most radionuclides. The exceptions were caesium-135, lanthanum-140, niobium-95, neptunium-237, praseodymium-144, plutonium-238, tellurium-125m, uranium-234, uranium-235 and uranium-236. These are all present as radioactive progeny ingrown from other radionuclides (as well as being released in their own right in some cases). The discharge rates and other parameters for these radionuclides were checked and no discrepancies were identified that would lead to these differences. It was therefore concluded that the differences relate to the way in which the contributions from ingrown progenies have been assessed. A side-check calculation indicates that the values presented by Hitachi-GE are consistent with the expected amount of ingrowth and are therefore likely to be correct.

The total activity in soil is, however, dominated by other radionuclides (principally carbon-14) and is not affected by the differences in the soil concentrations noted above. Consequently, the total concentration calculated agrees with the summary results presented in the main report by Hitachi-GE (Hitachi-GE, 2016a).

A.6 Collective dose

Collective doses from discharges (a measure of the total dose to whole populations of people) were calculated by Hitachi-GE using the methods incorporated in PC-CREAM 08. For liquid discharges, doses were derived from the total consumption of fish and total beach occupancy in the relevant region (UK, Europe or world), integrated over an appropriate timescale (500 y is used). For gaseous discharges, the calculation is in two parts: a 'first pass' collective dose estimate to the UK and Europe, and a separate calculation of the collective dose to UK, Europe and the world populations from the 'global circulation' of radionuclides (truncated at 500 years). The first pass collective doses are calculated on the basis of inhalation, ingestion of foods and external irradiation, while ongoing exposures are calculated for gaseous radionuclides that remain in the atmosphere and continue to circulate and enter foods (global circulation collective dose). Hitachi-GE applied the standard PC-CREAM 08 models and data in assessing these doses.

A.6.1 Collective dose from liquid discharges

Collective dose calculations use the same local marine compartment assumptions made by Hitachi-GE (which correspond to those used in the Stage 1 IRA methodology). The results agree with those given by Hitachi-GE in Tables A.37 to A.39, to within 1% for most radionuclides for the UK, EU12 (countries in EU in 1986) and world populations. The calculated collective dose for cerium-141 and tellurium-123m differed by 2-3% across all pathways. The reason is unclear, but the differences are small and the dose itself is small.

A.6.2 Collective dose from gaseous discharges

The collective dose for gaseous discharges also adopts cautious Stage 1 assumptions, including a ground-level release. The collective dose from the first pass of the plume was calculated for both UK and European populations and compared to Hitachi-GE results in Tables A.40 and A.41. All results were found to agree to within 1%.

The collective dose from the global circulation of radionuclides was calculated with PC-CREAM 08 and also found to agree to within 1% for all radionuclides and populations presented in Table A.42 of Hitachi-GE's Submission (Hitachi-GE, 2016a).

A.7 Calculation of the potential radiation dose to non-human species

The radiation exposure of non-human species can be calculated using ERICA software (Beresford et al., 2007), developed as part of a European Commission project and now widely adopted. Using the input data as provided in Tables A.31, A.32 and A.33, and using the ERICA Version 1.2.1 code, the same calculated dose rates and risk quotients have been replicated to within 1% for the terrestrial biota presented in Table A.35 of Hitachi-GE's Submission (Hitachi-GE, 2016a). However, with respect to the marine biota it has not been possible replicate the values reported in Table A.34 of Hitachi-GE's Submission (Hitachi-GE, 2016a). This issue had been raised with Hitachi-GE, who subsequently re-issued the results (Hitachi-GE, 2016b), which were successfully verified. In verifying the noble gas calculations for potential radiation doses to terrestrial biota, the calculated air concentrations shown in Table A.30 have been used as the input to the update of the EA R&D128 tool (Vives i Batlle et al., 2015), downloaded from the CEH wiki website in June 2016. The same dose rates were calculated as those reported by Hitachi-GE in Table A.36.

A.8 References

Reference	Details
Beresford et al., 2007	Beresford N, Brown J, Copplestone D, Garnier-Laplace J, Howard BJ, Larsson C-M, Oughton O, Pröhl G, Zinger I (eds.) 2007. D-ERICA: An integrated approach to the assessment and management of environmental risks from ionising radiation. Description of purpose, methodology and application.
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Hitachi-GE, 2014	UK ABWR Generic Design Assessment - Generic Site Description. Document Number XE-GD-0095, Revision D.
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NDAWG, 2011	Short-term releases to the atmosphere. NDAWG 2/2011. National Dose Assessment Working Group
NDAWG, 2009	Acquisition and Use of Habits Data for Prospective Assessments. NDAWG/2/2009. National Dose Assessment Working Group
Smith and Jones, 2003	Smith KR and Jones AL (2003). Generalised Habit Data for Radiological Assessments. NRPB-W41, Chilton, March 2003.

Reference	Details
Smith et al., 2004	Smith JG, Bedwell P, Walsh C and Heywood SM (2004), A methodology for assessing doses from short-term planned discharges to the atmosphere, NRPB-W54, Chilton, March 2004.
Vives I Batlle et al., 2015	Vives i Batlle J., Jones S.R. and Copplestone D. (2015). A methodology for Ar-41, Kr-85, 88 and Xe-131m and133 wildlife dose assessment. Journal of Environmental Radioactivity. Volume 144 (152-161).

Appendix B: Validation of the radiological assessment of the UK ABWR design

B.1 Introduction

This appendix presents our detailed review of the approach, methods and parameters used in the dose assessments presented for consideration by Hitachi-GE (Hitachi-GE, 2016a). We refer to this as 'validation'.

It involved firstly scrutinising the overall approach to the radiological assessment, with particular reference to its consistency with the Environment Agency's principles for assessing doses from discharges (Environment Agency et al., 2012). This part focused on the extent to which the key principles have been addressed and the associated guidance has been applied. It is reported in Section B.2 of this appendix.

Each part of the dose assessment is considered in turn in Section B.3. Hitachi-GE has calculated radiation doses for each discharge route (liquid and gaseous) and for a selection of receptors (annual individual dose and collective dose to people, and dose to non-human species). We therefore examined the approach taken to calculate:

- the annual dose from routine liquid discharges
- the annual dose from routine gaseous discharges
- potential doses from short-term discharges
- the collective dose from discharges
- the potential radiation dose to non-human species

The aggregation of the calculated doses was also considered. Aggregation of doses allows an estimate to be made of the exposure of a 'representative person' to all radioactive discharges and from direct radiation. Direct radiation is not part of the Environment Agency's regulatory responsibilities. A detailed review of direct radiation calculations was not undertaken, although the consistency of the approach with other pathways was reviewed to ensure they are appropriate.

The following has been reviewed for each calculation:

- the methodology or approach
- the models and computer codes used
- the selected parameter values
- the interpretation of the results

The review is documented in matrix form each of the assessment calculations. These calculations are presented in Tables B.1 to B.6 and the main points are described in Section B.3.

The rationale and justification presented by Hitachi-GE has been examined, taking account of the latest regulatory guidance and guidance from the main UK advisory group on dose assessments (the National Dose Assessment Working Group, (NDAWG)). Values have been checked against the information sources cited, wherever possible. The review was undertaken by specialists with considerable experience in radiological assessments. We have not commented on the validity of the calculated results here, as this is discussed in Appendix A.

B.2 The Environment Agency's requirements

B.2.1 Regulatory requirements and guidance

The Environment Agency's Process and Information Document (P&ID) for the generic assessment of nuclear power plant designs (Environment Agency, 2013) describes the information requirements for the GDA. The information requirements are founded on and guided by the Radioactive Substances Regulation Environmental Principles (REPs) (Environment Agency, 2010). The REPs clarify regulatory expectations and provide the basis for decisions relating to radioactive substances regulation. They draw on the ONR's Safety Assessment Principles, so as to ensure consistency in the regulation of nuclear sites.

One of the eight items required in the P&ID is a prospective radiological assessment of discharges from the site at the proposed limits. As the REPs have a broad scope of application, additional guidance in the form of the 'Principles for the Assessment of Prospective Public Doses' has been developed (Environment Agency et al., 2012). This provides additional information on appropriate methods of conducting public dose assessments, and the regulator's expectations of them. All 3 documents - the P&ID, the REPs and the 'Principles' have been used in the validation process, but most use is made of the 'Principles', as it is most specific to the dose assessment process and is the most detailed.

B.2.2 Process and information requirements

Taking account the REPs RPDP2, 3 and 4, (see below) and the more specific guidance in the 'Principles for the Assessment of Prospective Public Doses', the P&ID requires that the requesting party:

- describes models used to calculate doses and why they are appropriate
- sets out the data and assumptions (with reasoning) used as input to the models

The following aspects must be evaluated in the dose assessment:

- the annual dose to the most exposed members of the public for liquid discharges*
- the annual dose to the most exposed members of the public for gaseous discharges*
- the annual dose to the most exposed members of the public for all discharges*
- the annual dose from direct radiation to the most exposed member of the public
- the annual dose to the representative person for the facility
- the potential short-term doses, including those via the food chain, based on the maximum anticipated short-term discharges from the facility in normal operation
- a comparison of calculated doses with the relevant dose constraints
- an assessment of the build-up of radionuclides in the local environment of the facility, based on the anticipated lifetime discharges
- the collective radiation dose, truncated at 500 years, to the UK, European and world populations
- the dose-rate to non-human species*

For those items marked with an asterisk (*), the initial radiological assessment (IRAT) methodology (Environment Agency, 2006a, b) is recommended to be used by the Environment Agency and Natural Resources Wales, refining the default data to reflect the characteristics of the facility and generic site.

B.2.3 Regulation environmental principles

The assessment is required to address 3 of the environmental principles (Environment Agency, 2010).

- Principle RPDP2 - 'Dose Limits and Constraints': Radiation doses to individual people shall be below the relevant dose limits and in general should be below the relevant constraints.
- Principle RPDP3 – 'Protection of Non-Human Species': Non-human species should be adequately protected from exposure to ionising radiation.
- Principle RPDP4 – 'Prospective Dose Assessments for Radioactive Discharges into the Environment': Assessments of potential doses to people and to non-human species should be made prior to granting any new or revised permit for the discharge of radioactive wastes into the environment.

To adequately address these principles, the dose assessment must satisfy the principles for the assessment of radiation doses from discharges of radionuclides (Environment Agency et al., 2012). An assessment of the consistency of the Hitachi-GE dose assessment (Hitachi-GE, 2016a) with these principles is presented in the next sub-section

B.2.4 Principles for assessing doses from discharges

There are 13 principles and associated guidance presented by the Environment Agency and others (Environmental Agency et al., 2012). These guide the evaluation of dose assessments, ensuring that it is consistent and transparent. They also inform those submitting the assessments, as well as members of the public, of the recommended approach and regulatory expectations. The Hitachi-GE assessment has been reviewed with respect to the 13 principles, and the outcomes and observations are described in the following sub-sections.

Documentation

Principle 1 states that:

> Prospective dose assessment methods, data and results should be transparent and made publicly available.

Hitachi-GE has presented a dose assessment for the UK ABWR as part of its GDA submission (Hitachi-GE, 2016a). The dose assessment for the UK ABWR is the focus of our verification and validation exercise. As such, all of the observations and findings collectively provide a commentary on the extent to which the document achieves Principle 1. Notwithstanding this, some general comments can be made.

The dose assessment methods used by Hitachi-GE have been documented clearly and are appropriate to the current stage of the GDA. For the main calculations, a 3 stage assessment was made by Hitachi-GE, with our IRA methodology being used for Stages 1 and 2, and other codes for Stage 3 and supplementary calculations. The use of IRA is consistent with the guidance described in preceding section. The code used for the Stage 3 assessment of routine discharges to air and water, the assessment of collective doses, and the calculation of environmental concentrations was PC-CREAM 08 Version 1.5.1.85 and database Version 2.0.0. Short-term discharges to atmosphere were assessed with the atmospheric dispersion code ADMS version 5.1. The exposure of non-human species was evaluated with the ERICA methodology, version 1.2.0 (Beresford et al., 2007) and the EA R&D 128 approach for assessing impacts associated with noble gases, (Vives i Batlle et al., 2015). These tools are recognised as being potentially suitable for the assessment of radioactive discharges (Environment Agency et al., 2012). Prior to presenting data and results, Hitachi-GE present an explanation and rationale for using these tools.

The explanation of the selection of the ADMS code used to assess short-term releases is given separately, later in the document along with a basic uncertainty analysis. Although guidance from NDAWG suggests this detailed atmospheric dispersion code may be needed to assess short-term releases (NDAWG, 2011), Hitachi-GE has defined a very simple atmospheric dispersion scenario, for which the use of a simpler model (for example R91 (Clarke, 1979)) might be sufficient.

As regards the transparency of the data and results, we have found that the information provided by Hitachi-GE has been generally sufficient to undertake verification calculations, which are presented in Appendix A. The source of these data has also been clearly recorded.

Workers Not Normally Working with Radiation

Principle 2 states that:

> Workers, who are exposed to discharges of radioactive waste, but who do not work directly with ionising radiation and are therefore not normally exposed to ionising radiation, should be treated as if they are members of the public for the purpose of determining discharge permits or authorisations.

The dose assessment made by Hitachi-GE does not refer to workers not normally exposed to ionising radiation. The dose assessment does, however, consider exposure groups that have habits that cover those expected of workers. The dose calculations for atmospheric discharges consider permanent residence close to the point of discharge (270 m distance), which can reasonably be expected to be a longer-duration exposure close to the site than farmers, fishermen, or other non-nuclear workers.

The representative person

Principle 3 states that:

> When determining discharge permits or authorisations, the dose to the representative person should be assessed.

Hitachi-GE has calculated the radiation dose to representative person exposure groups using IRA Stage 1 and 2 calculations, and a Stage 3 dose assessment using PC-CREAM 08. Two representative persons were defined:

- A local resident family principally exposed to gaseous discharges, who also consume locally sourced seafood at an average rate; and
- A fisherman family principally exposed to liquid discharges, who also consume locally sourced terrestrial foods at an average rate.

The local resident and fisherman families are the reference exposure groups defined in the IRA methodology (Environment Agency, 2006a). These exposure groups were designed to ensure full coverage of possible pathways arising from discharges using reasonable habit patterns. The assumed location and habits (Environment Agency, 2006b) are such that doses from each type of discharge scenario will be maximised (but not unrealistically so).

The Environment Agency (Environment Agency, 2006b) notes that in general an exposure group can be assumed to be most exposed to either liquid or gaseous discharges and that there is some cross-over of habits (and therefore exposure). A prudent first approximation would be to sum the estimated doses calculated for the group in question. Hitachi-GE (Hitachi-GE, 2016a) has taken the approach of adding doses from mean intakes of seafood to the local resident, and mean intakes of terrestrial foods to the fisherman exposure group, which appears reasonable.

The exposure of groups defined by Hitachi-GE appears sufficiently cautious to provide the basis for determining the representative person, given that the assessment relates to a generic site. Hitachi-GE do not describe why the groups were considered to be suitable. The implication is that as they have been assessed in the IRA methodology and it is not possible to define site-specific characteristics for a generic assessment. This appears a reasonable position to adopt.

Age Groups

Principle 4 states that:

> Doses to the most affected age group should be assessed for the purpose of determining discharge permits or authorisations. Assessment of doses to 1 year old, 10 year old and adults (and foetus when appropriate) is adequate age group coverage.

Hitachi-GE has calculated doses to adults, children (nominally 10 y) and infants (1 y) for liquid and gaseous discharges. They also refer to guidance from the Health Protection Agency (now Public Health England) that indicates that doses to the foetus need only be considered where one or more of four radionuclides (phosphorus-32, phoshorus-33, calcium-45 and strontium-89) form a significant part of the release to the environment. Only strontium-89 is included in the proposed discharge limits, and it is expected to account for much less than 0.1% of the release to the environment. On this basis, Hitachi-GE concluded that detailed consideration of foetal exposure is not necessary. This appears a reasonable conclusion.

Exposure Pathways

Principle 5 states that:

> The dose to the representative person which is assessed for comparison with the source constraint and, if appropriate, the site constraint, should include all reasonably foreseeable and relevant future exposure pathways.

As discussed in relation to Principle 3, the 'representative persons' used for the Hitachi-GE dose assessment are based on the exposure groups specified in the IRA methodology for liquid and gaseous discharges.

The exposure group for liquid discharges includes ingestion pathways for seafood (fish and shellfish), external and inhalation exposures from contaminated beach sediment, and external exposure from handling contaminated fishing gear. Hitachi-GE has also added the ingestion of seaweed as an exposure pathway for the fisherman.

The exposure group for atmospheric discharges eats food grown on soil contaminated by atmospheric discharges, including vegetables (green and root vegetables and fruit), meat (cow and sheep meat, and liver), milk and milk products. External irradiation from the plume and radionuclides deposited on the ground is assessed, as is exposure by inhalation of the plume or contaminated soil that has been resuspended.

These exposure pathways are representative of those usually included in radiological assessments. The selection and parameterisation of the exposure pathways is consistent with the NDAWG recommendations (NDAWG, 2009). The exposure pathways assessed include all of those included in the IRA methodology and PC-CREAM 08, and on this basis it is concluded that the assessment should be sufficiently comprehensive. However, there is no detailed description and justification of the derivation of the candidate exposure groups or justification of the exposure pathways, and their parameterisation. For example, some perspective on what might be 'reasonably foreseeable' (Environment Agency et al., 2012) exposure pathways might be gained by reviewing the exposure pathways adopted in discharge assessments for existing nuclear sites. Information in the 'Radioactivity in Food and the Environment' (RIFE) series of reports (Environment Agency et al., 2014) provides a summary of site-specific habits data and their use in the definition of representative persons.

Other Sources of Exposure

Principle 6 states that:

> Significant additional doses to the representative person from historical discharges from the source being considered and doses from historical and future discharges and direct radiation from other relevant sources subject to control should be assessed and the total dose compared with the dose limit of 1 mSv/y.

The prospective dose assessment presented by Hitachi-GE does not take account exposure from other sources of radiation. This is presumably because the site is generic. Nevertheless, a cautious approach would include the highest anthropogenic radiation background from existing nuclear sites to illustrate a 'worst case' situation.

Refinement of the Assessment

Principle 7 states that:

> Where a cautious estimate of the dose to the representative person exceeds 0.02 mSv/y, the assessments should be refined and, where appropriate, more realistic assumptions made. However, sufficient caution should be retained

> in assessments to provide confidence that actual doses received by the representative person will be below the dose limit.

Hitachi-GE calculated a total dose to the most exposed person of 144 µSv/y using the Stage 1 IRA, indicating that the dose assessments should be refined. The main contributor was atmospheric discharges (143 µSv/y). Even with the very cautious Stage 1 assumptions, the contribution from liquid discharges is very low indeed (0.003 µSv/y). Nevertheless, the Hitachi-GE approach has been to refine the assessment of both liquid and gaseous discharges. The refinements made to the assessments by Hitachi-GE in Stage 2 primarily relate to the initial rate of dispersion in the marine environment or atmosphere, as suggested by the Environment Agency (Environment Agency, 2006a).

The refinements made for the marine environment involve increasing the volumetric exchange rate of the local compartment into which aqueous discharges occur. The rate was increased by a factor of 13, on the basis that this was more representative of the North Wales coast. Similarly, the specific characteristics of the Wylfa site were used in a PC-CREAM 08 calculation for the Stage 3 assessment. Hitachi-GE note that other locations may have a lower exchange rate, but that these were bounded by the Stage 1 assessment. While this approach is reasonable, it may be misleading for the Stage 2 and 3 assessments to be considered to be a cautious assessment of a generic site. A generic assessment should adopt assumptions that are sufficiently cautious to cover all potential locations. The site description adopted for the GDA has particular characteristics that might not necessarily be cautious for a given site, and it is not clear how generally applicable it is.

In relation to atmospheric discharges, the main refinement for the Stage 2 calculation was to adopt a higher effective stack height (19 m), which is a third of the lowest stack at an existing ABWR. This height is also included in the Stage 3 calculation with PC-CREAM 08, but different meteorological conditions have been assumed (70% Category D rather than the 50% Category D in the IRA methodology, although for the distances and stack height concerned, the difference is unimportant). 70% Category D conditions are most likely to be experienced at a coastal site. The Stage 3 assessment also assumed that the exposed person lives further from the point of discharge (270 m compared with 100 m), since this represents the distance of the perimeter from the discharge point. It should be noted that as with the marine discharges, these characteristics are representative of the Wylfa site, but they are not sufficiently conservative to cover all conditions experienced elsewhere.

Accumulation in the Environment

Principle 8 states that:

> The assessment of dose to the representative person should take account of accumulation of radionuclides in the environment from future discharges.

The UK ABWR has a planned operating life time of 60 years. The Hitachi-GE dose assessment has taken account of the environmental accumulation of discharges over this period by:

- modelling the accumulation of radionuclides in the marine environment with the PC-CREAM 08 module DORIS, assuming 60 years of discharges at the discharge limits
- modelling the accumulation of radionuclides in terrestrial media, with the PC-CREAM 08 modules GRANIS and FARMLAND, assuming 60 years of discharges at the discharge limits

- calculating the radiation dose to representative persons after 60 years of operation, so as to include the contribution from the environmental accumulation of radionuclides

Such an approach would appear to be appropriate.

Assumed Habits

Principle 9 states that:

> The realistic habits adopted for the representative person should be those which have actually been observed at the site within a period of about 5 years. Changes to habits which are reasonably likely to occur should be taken into account.

The dose assessment that supports the GDA relates to a generic location for the UK ABWR, therefore current human habits cannot be observed and there is no basis for identifying reasonably foreseeable changes to habits. Although it is not explicitly stated, this is the reason that Hitachi-GE bases the habits of its representative persons on those defined in the IRA methodology. These characteristics are conservative, as exposure durations and ingestion rates are generally greater than observed in habits surveys for existing nuclear sites.

Capacity of the environment to Support the Habits

Principle 10 states that:

> Land use and infrastructure should have sufficient capacity to support the habits of the representative person. Any changes to land use and infrastructure should be reasonably likely to occur over a period of about 5 years and be sustainable year on year for them to be considered.

Hitachi-GE do not evaluate the amount (and type) of farmland required to provide the amounts of food consumed by the representative person. Given that the assessment is for a generic site and the intake rates themselves are generalised and conservative, this is reasonable. This is because such an approach maximises the calculated dose and does not lead to an underestimate of the potential radiation exposure. It would nevertheless be useful to state that the assumption a single family group derives all of its food, including all food types, from a single location is deliberately cautious and highly unlikely to occur in practice.

Short-term Releases

Principle 11 states that:

> The dose assessed for operational short-term release at proposed notification levels or limits should be compared with the source constraint (maximum of 0.3 mSv/y) and the dose limit (1 mSv/y), taking into account remaining continuous discharges during the remainder of the year and contributions from other relevant sources under control.

Hitachi-GE has made an assessment of the potential dose from a short-term release of radioactivity. The scenario considered was a release of gaseous radionuclides following a fuel pin failure. The highest calculated dose is to an adult, and is only 0.02 µSv/y. Our detailed comments on the appropriateness of the assumptions used in this calculation follow in Section B.3. Furthermore, although Hitachi-GE has calculated the potential exposure from a short-term release, they have not added the exposure from contemporaneous continuous discharges, as required (Environment Agency et al., 2012). The total dose can readily be calculated and will remain well below the dose limit criterion.

Collective Exposure

Principle 12 states that:

> For permitting or authorisation purposes, collective doses to the populations of UK, Europe and the World, truncated at 500 y, should be estimated.

Although the dose assessment does not at this stage support a permit application, Hitachi-GE has calculated collective doses for the UK ABWR discharges using PC-CREAM 08. Collective doses were presented for both liquid and gaseous discharges for UK, European and World populations. Both 'first pass' and global circulation doses have been presented. The former relates to the potential exposures occurring to a population on the initial passage of a plume over the countries of interest. The global circulation of radionuclides refers to the fact that certain long-lived radioactive gases can remain present in the atmosphere for many years, providing an ongoing source of exposure to the world's population through their inhalation, albeit at a very low rate to any one individual.

For liquid discharges, the collective dose was calculated to the 'EU12' nations as well as the UK and world population. For atmospheric discharges the global circulation collective dose was calculated to the EU12 (countries in EU in 1986) and EU25 (countries in EU in 2004) nations, while the first pass dose was calculated to European population grids. The different ways of measuring the European population reflect the models and data available in the PC-CREAM 08 code.

Uncertainty and Variability

Principle 13 states that:

> Where the assessed mean dose to the representative person exceeds 0.02 mSv/y, the uncertainty and variability in the key assumptions used for the dose assessment should be reviewed.

The dose assessment by Hitachi-GE included investigation of some uncertainties. Hitachi-GE identify several areas for discussion in relation to uncertainties in the dose assessment. These include the estimates of discharges, dispersion in the atmosphere and the marine environment, environmental transfer of radionuclides and dose coefficients for inhalation and ingestion. The uncertainty in discharges is considered to be around 5%, based on comparisons between operational plants.

The sensitivity of the atmospheric dispersion to stack height is described with reference to the IRA methodology. The dependence on meteorological conditions is also discussed, noting that atmospheric concentrations range over about a factor of 2 depending on the conditions assumed. A similar uncertainty of about a factor of 2 is noted in relation to dependence of air concentrations on distance from the stack. In relation to marine dispersion, Hitachi-GE note that the marine model used has been found to report concentrations in water to within a factor of 2 of measured values.

Hitachi-GE consider the environmental transfer aspect of the modelling is not deemed to have significant levels of uncertainty. This does not reflect the sometimes considerable variability in reported soil-plant and animal transfer factors. In relation to dose coefficients, Hitachi-GE refer to work undertaken in the past by Public Health England (PHE) which indicated uncertainty of a factor of a few in the dose coefficients for commonly assessed radionuclides.

Variation in air concentration according to short-term meteorological conditions have also been discussed by Hitachi-GE. It includes a sensitivity study to investigate the impact of cloud cover on the dispersion of short-term discharges. This has been done for a release commencing at noon on 1 July 2015. Hitachi-GE has explained the choice of date as being a conservative one because this is when most foodstuffs are grown. However, the radionuclides released from a short-term discharge (krypton and xenon) are non-depositing and so dose via food consumption is not relevant (Hitachi-GE acknowledge this elsewhere). The sensitivity study involves ascribing 2 wind speeds (5 m/s during the day and 2 m/s at night) to determine an average concentration for a unit release. Hitachi-GE has also designated a level of lateral spread due to meandering, which is dependent on the Pasquill Stability Class. Unfortunately, there is no definition of 'night' and 'day' and it has not been explained how the stability class has been determined (note also that Hitachi-GE has listed typical solar radiation levels and stability classes incorrectly in Table F6.1). Because Hitachi-GE has not specified the exact input data for the calculations in the sensitivity study, it is not possible to reproduce the calculations.

B.2.5 Summary of consistency with Environment Agency requirements

The extent to which Hitachi-GE's dose assessment (Hitachi-GE, 2016a) has addressed the principles for prospective dose assessment is summarised below.

- Principle 1: Documentation - the documentation is sufficiently clear to understand the dose assessment and its outcomes, although there is limited explanation to support some modelling and parameter decisions.
- Principle 2: Workers not normally working with radiation - the dose assessment did not refer to this exposure group, although the exposure groups used in the assessment can be reasonably expected to cover worker exposures.
- Principle 3: The representative person - the exposure groups selected by Hitachi-GE as candidates for the representative person were based on suitably cautious assumptions.

- Principle 4: Age groups - Hitachi-GE has assessed doses to adults, children and infants and provided a sound reason for not assessing foetal exposure.
- Principle 5: Exposure pathways - the exposure pathways assessed include all of those included in the IRA methodology and PC-CREAM 08, and on this basis it can be concluded that the assessment was sufficiently comprehensive.
- Principle 6: Other sources of exposure - the prospective dose assessment did not take account the contribution of other sources of radiation exposure, including past discharges from other nuclear sites because the site is generic. Nevertheless, a cautious approach would be to present a 'worst case' situation that could also consider the presence of 2 or more reactors.
- Principle 7: Refinement of the assessment - assessments of both liquid and atmospheric discharge pathways have been refined. The approach was to adopt environmental characteristics more representative of the Wylfa site. The assessment is intended to relate to a generic site, however, and using environmental conditions at Wylfa may not be sufficiently conservative to cover all potential sites for the UK ABWR.
- Principle 8: Accumulation in the environment - the Hitachi-GE dose assessment took account of the environmental accumulation of discharges over a 60 year operating lifetime of the UK ABWR.
- Principle 9: Assumed habits - the dose assessment relates to a generic location for the UK ABWR, therefore assessment assumptions cannot be related to observed human habits. Hitachi-GE's assumptions are regarded as conservative.
- Principle 10: Capacity to support the habits - as the assessment relates to a generic site, and the intake rates themselves are generalised and conservative, it is reasonable not to examine the capacity of land to support the habits.
- Principle 11: Short-term releases - Hitachi-GE make an assessment of the potential dose associated with a short-term release, but do not take into account the additional exposure from continuous discharges. The assumptions used for the atmospheric conditions for a short-term release are reliant on a statement made by Smith et al. (Smith et al., 2004) that assumes Category D stability conditions are realistically cautious for a planned short-term release. It should be noted that the validity of this statement is dependent on stack height and exposure distance, and it is not obvious whether a fuel pin failure can be regarded as a planned release).
- Principle 12: Collective exposure - collective exposure to UK, EU and world populations has been addressed for the UK ABWR discharges.
- Principle 13: Uncertainty and variability - the assessed dose from atmospheric discharges exceeded 0.02 mSv/y, therefore Hitachi-GE has provided a discussion of the potential uncertainty in the dose assessment assumptions for key aspects of the models and data.

B.3. Main findings of the validation review of the radiological assessment calculations

B.3.1 Method for the calculation of annual doses from routine liquid discharges

Our review of the approach to calculating the annual dose from routine liquid discharges is summarised in Table B.1. The approach is consistent with guidance and accepted practice, and at a suitable level of detail for the generic site assessment. The assessed doses from liquid discharges appear to be very low and well below the level of dose that necessarily requires a Stage 3 assessment, although Hitachi-GE has undertaken such a calculation.

The justification of the selection of the generic site is presented in a separate report. This is important, as the adoption of the local marine compartment for Wylfa may not be conservative in the context of a generic dose assessment. It would be informative to compare local marine compartment characteristics for all existing UK nuclear sites where new nuclear power stations may be built in future, for example.

Summary results are reported clearly and succinctly. The detailed results are comprehensive.

B.3.2 Method for the calculation of annual doses from routine gaseous discharges

Comments on the assessment of routine discharges to air are summarised in Table B.2.

Hitachi-GE has appropriately used the IRA DPUR method for Stage 1 and 2 calculations, before applying PC-CREAM 08 at Stage 3. The DPUR values published by the Environment Agency (Environment Agency, 2006a) rely on a Gaussian plume model to predict atmospheric dispersion. Such models are appropriate for predicting air concentrations from continuous releases over the required distance scales. An estimate of atmospheric stability is required when using these dispersion models and the DPUR values calculated in the IRA methodology assume Pasquill Stability Category D (i.e. conditions when thermal buoyancy or damping effects are not apparent) on 50% of occasions, as defined and calculated by Clarke (Clark, 1979). This would be representative of Central England. Hitachi-GE has adopted a figure of 70 % Category D in the Stage 3 calculations, on the basis this is more representative of a likely reactor site. The extent to which this is a conservative approach will depend on the specific location, including possible local effects, and these cannot be evaluated in a generic sense. Nevertheless, the choice of frequency of Category D conditions is unlikely to be of major importance for the stack height and distance scales concerned.

Key factors in Stage 1 of the IRA methodology are that a ground-level release is assumed and dose calculations are for a local resident living 100 m from the source and consuming food produced 500 m from the source. Noble gases have been regarded as non-depositing, while fixed dry deposition velocities have been assumed for particulate radionuclides (0.1 cm/ s) and reactive iodine (1 cm/s). A fixed wet deposition removal rate (0.0001/s) has been assumed for both. These are commonly adopted parameter values, although the value for particulate radionuclides assumes a filtered discharge (and thus low levels of radioactivity and only material associated with a small particle size would be released). Different values for the deposition parameters might be more appropriate for other release scenarios (for example unfiltered outlets, including filter breaches and fugitive emissions). Tritium and carbon-14 are represented in the DPUR by assuming an equilibrium concentration approach. This is appropriate (although quite complex and subject to potential errors).

The calculated DPUR values assume a symmetrical windrose and an even distribution of atmospheric stability according to wind direction. This is unlikely in practice, meaning the approach is not conservative for a person living downwind of the release. Consumption rates of foodstuffs in the DPUR calculations are representative of the 97.5 percentile consumption rates presented in Smith and Jones (Smith and Jones, 2003), which is a conservative approach.

The IRA Stage 2 assessment refines the generic calculations made in Stage 1 by assuming a representative discharge height. This was assumed to be equal to 19 m, based on scaling factors recommended by Jones (Jones, 1983), and the corresponding DPUR values were adjusted in accordance with the methodology described by the Environment Agency (Environment Agency, 2006a). This is an appropriate refinement. Also, the release height is appropriate for an UK ABWR design.

The Stage 3 assessment involves using PC-CREAM 08 to calculate the dose for a 60-year period that would result from continuous atmospheric releases at the authorised discharge limits. This is an accepted approach for routine discharges from a nuclear site. The main refinement over Stages 1 and 2 is that Pasquill Stability Category D is assumed to prevail for 70% of the time (rather than 50%). This makes the assessment more appropriate for exposed coastal locations in the UK. The local resident was also assumed to live further away (at 270 m), reflecting the assumed site layout for an UK ABWR). The ingestion rates are also changed so that only the 2 most significant foodstuffs are consumed at high rates, which is consistent with the discussion by NDAWG (NDAWG, 2009). As with the liquid discharge assessment, there is no discussion of whether this is the most conservative set of conditions that are reasonable for a generic site.

Results are presented clearly. There is an analysis of uncertainties, as required for pathways in which assessed doses exceed the criterion of 0.02 mSv/y.

B.3.3 Method for the calculation of potential doses from direct radiation

The scope of this review does not extend to evaluating the calculation of direct radiation exposures from the UK ABWR. However, the contribution of this pathway is relevant when the total dose from the site is considered. The focus has therefore been on to review Hitachi-GE's assessment, in terms of its consistency with the assessment of other pathways. This is summarised in Table B.3. It should be noted how the exposure is assessed at a variety of distances that correspond to those at which other pathways are assessed. The exposure durations and other considerations are also consistent with other dose calculation assumptions.

B.3.4 Method for the calculation of potential doses from short-term discharges

A summary of the observations relating to the calculation of the dose due to short-term releases is presented in Table B.4.

Only isotopes of xenon and krypton were judged by Hitachi-GE to have been a potential source of exposure from a short-term release, since it was regarded that other radionuclides would be retained in the coolant. It is beyond the scope of this review to evaluate the accuracy of this assumption.

PC-CREAM 08 does not readily provide a facility for calculating the consequences of short-term releases, so Hitachi-GE has used ADMS (a Gaussian plume dispersion model like PLUME, the model embedded in PC-CREAM) to calculate atmospheric concentrations and deposition levels. ADMS is an accepted and well-documented dispersion model and it is appropriate for use in such a task. The main difference between ADMS and PLUME (used in the Stage 1 to 3 assessments) is in how the atmospheric boundary layer is described. PLUME assumes atmospheric stability to be represented by a Pasquill Stability Class, whereas ADMS uses more detailed input data (which can be equated to a Pasquill Stability Class if required). This makes the definition of a generic short-term release complicated, since a combination of time of day/year and cloud cover (to determine insolation levels) and wind speed are needed. Hitachi-GE has assumed conditions representative of Pasquill Stability Category D to be appropriate. While it can be argued that this stability class is the most frequent, it has not been demonstrated that it is a conservative choice.

Hitachi-GE has undertaken a sensitivity analysis by looking at the impact of cloud cover on dispersion rates over 24 hours beginning at noon on the 1st July 2015. Hitachi-GE concluded that increasing cloud cover decreased the dispersion rate by a factor of up to around 2 (between $1.23\ 10^{-5}$ and $2.50\ 10^{-5}$ s/m^3 at 300 m). It was also concluded that the assumption of Category D conditions, as suggested by Smith et al. (Smith et al., 2004), was within this range ($1.93\ 10^{-5}$) and was realistically conservative. Notwithstanding, there are limitations to the recommendations made by Smith et al. (Smith et al., 2004), in that further testing is also recommend in the study and that the guidance relates to release scenarios (including stack height) not directly comparable to the generic study. In addition, it should be stressed that the Hitachi-GE study covers only a single day.

Doing a comprehensive sensitivity study is potentially an endless task given the large number of variables and because some of the variables are correlated (for example plume buoyancy and time of year / outside temperature). Hitachi-GE has provided one such estimate of a range of uncertainty. Another estimate has been given in Appendix H, where the calculations have been undertaken for different times of year and cloud cover. This indicates a larger range than that reported by Hitachi-GE ($0.83\ 10^{-5}$ s/m^3 to $3.15\ 10^{-5}$ s/m^3 at 300 m).

Another way to address uncertainty might be to look at a range of representative stability conditions. In this case, it should be noted that Pasquill Categories A and B are restricted to daytime summer, while Categories F and G are restricted to night-time (the latter implying a strong inversion and a cold ground). Example calculations were undertaken giving a range of hourly dispersion coefficients between 0.01 10^{-5} s/m^3 (Category G) and 5.04 10^{-5} s/m^3 (Category E), neglecting plume meander. The range is understandably greater than the daily mean values, but it can be seen that the assumption of a dispersion coefficient of around 2 10^{-5} s/m^3 would be unlikely to underestimate concentrations by more than a factor of 2 at most. This would not increase the overall dose from the site significantly.

B.3.5 Method for the calculation of collective doses from discharges

Hitachi-GE has used a well-accepted approach to calculating collective dose from discharges to air and water, involving the PC-CREAM 08 code and its inbuilt assumptions of population distribution, beach occupancy and fish catch. A summary of the review is given in Table B.5. The only important assessment assumptions for this calculation are the discharge rates, location of the liquid discharges, and the location, stack height and atmospheric conditions for the gaseous discharges. The review comments on these pathways, as presented in Sections B.3.1 and B.3.2. Nevertheless, it is noted that as collective doses relate to the exposure of large numbers of people, widely distributed, they cannot be expected to be as sensitive to the specific assessment assumptions as individuals living very close to the point of discharge.

B.3.6 Method for the calculation of potential radiation doses to non-human species

The overall approach is consistent with guidance and accepted practice, and at a suitable level of detail for a generic site assessment.

With respect to atmospheric releases, the calculation of potential radiation doses to non-human species from non-noble gases has been undertaken using the ERICA tool, Version 1.2.0. For noble gases, the latest version of the EA R&D128 tool has been used (Vives i Batlle et al., 2015). The data used for terrestrial biota that are the non-human receptors for atmospheric releases is clearly presented in Tables A.29, A.30 and A.33, though there is no wider discussion to justify these values. Within the two tools, default parameter values were adopted when available. Only for certain radionuclides (iron, praseodymium, rubidium and yttrium), was gap-filling required for the terrestrial biota concentration ratios. An explanation of the assumed values for carbon is not discussed, but they are obviously reasonably cautious.

With respect to liquid discharges, the calculation of potential radiation doses to non-human species has again been undertaken using the ERICA tool, Version 1.2.0. Most of the parameter values used in the marine assessment are the default values in ERICA, with only data for iron not included in the tool. The gap-filling of sediment Kd and concentration ratios for marine biota was undertaken in a manner consistent with the ERICA approach, which is considered as reasonable. It should be noted, however, the sediment concentration factors are not the same as those used in PC-CREAM 08, which are used to calculate the water and sediment concentrations inputted into ERICA.

B.4 References

Reference	Details
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Hitachi-GE, 2016a	UK ABWR Generic Design Assessment - Prospective Dose Modelling. Document Number HE-GD-0005, Revision E.
Hitachi-GE, 2016b	UK ABWR Generic Design Assessment - Non-human Doses from Liquid Discharges (Response to RQ-ABWR-0858), Document Number HE-GD-0202, Revision 0.
IAEA, 2004	Sediment distribution coefficients and concentration factors for biota in the marine environment. Technical report series 422.
Jones, 1983	Jones J.A. (1983) Models to allow for the effects of Coastal Sites, Plume Rise and Buildings on Dispersion of Radionuclides and Guidance on the value of Deposition Velocity and Washout Coefficients, Fifth report of a working group on Atmospheric Dispersion. National Radiological Protection Board (NRPB) R-157.
NDAWG, 2009	Acquisition and Use of Habits Data for Prospective Assessments. NDAWG/2/2009. National Dose Assessment Working Group

Reference	Details
NDAWG, 2011	Short-term releases to the atmosphere. NDAWG 2/2011. National Dose Assessment Working Group
Smith et al., 2004	Smith, JG, Bedwell, P, Walsh,C and Heywood, SM (2004), A methodology for assessing doses from short-term planned discharges to the atmosphere, NRPB-W54, Chilton, March 2004.
Smith and Jones, 2003	Smith KR and Jones AL (2003). Generalised Habit Data for Radiological Assessments. NRPB-W41, Chilton, March 2003.
Smith and Simmonds, 2009	Smith J G and Simmonds J R (2009). The Methodology for assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08, October 2009.
Vives I Batlle et al., 2015	Vives i Batlle J., Jones S.R. and Copplestone D. (2015). A methodology for Ar-41, Kr-85, 88 and Xe-131m and133 wildlife dose assessment. Journal of Environmental Radioactivity. Volume 144 (152-161).

B.5 Tables

Table B.1: Summary and review of Hitachi-GE's approach for assessment of individual dose - liquid discharges

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE's approach	Comments on Hitachi-GE's approach
6.3.1.1: Stage 1 liquid discharge assessment	Habits data	Reference values from the IRAT are used.	Values given in Table 6.3-5 were checked against Table E.1 in the IRA (Environment Agency, 2006b) and agree.
6.3.1.1: Stage 1 liquid discharge assessment	DPUR values	Reference values from the IRAT are used.	Values from Table 3 of IRAT are given in Table A.1. Values were not checked directly (this was done in the verification exercise, see Appendix 1). Use of caesium-137 as a conservative surrogate for other fission products is considered to be reasonable.
5.2.1.1 and 6.3.1.3: Stage 2 liquid discharge assessment	Methodology	The marine exchange rate of the local box is changed from 100 m^3/s to 1300 m^3/s which is considered to be more appropriate as it is representative of North Wales.	The increased exchange rate should refer to the generic site report (Hitachi-GE, 2014). As the assessment is for a generic site there should be some justification of the use a value that is significantly less conservative and specific to a particular location. Some commentary on the fact that the exchange rate corresponds to a much larger local marine compartment would also be appropriate.
5.2.3.1: Stage 3 liquid discharge assessment	Approach	The reason for a Stage 3 assessment is not stated.	The justification for the selection of the dose assessment method could refer more closely to the advice by the Environment Agency.
Appendix B: Stage 3 liquid discharge assessment	Input data	Site characteristics are based on Wylfa. Generic habit is used.	There is no discussion of the choice of generic site parameters, and whether they represent a suitably cautious (but 'realistic') set of assumptions. (Further discussion of specific parameter values is described in relation to the review of Appendix B included later in this table).
5.2.3.1: Stage 3 liquid discharge assessment	Methodology	The assessment modelling approach is to use PC-CREAM 08 to calculate doses. A sensitivity analysis is included.	The arguments for not assessing strontium-89 dose to foetus appear to be reasonable. Given the very low doses for this pathway, it is questionable as to whether a sensitivity analysis is merited.

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE's approach	Comments on Hitachi-GE's approach
Appendix B: Input data for Stage 3 liquid discharge assessment	Definition of input data	Input data for PC-CREAM 08 are based on the Wylfa site and generic habits.	Generally, there is very limited discussion of the selection of parameter values and data as well as ranges and their applicability to different sites. Some more description of where and how each parameter is used would be helpful, for example is it appropriate to use annual total inhalation rates for exposures in specific situations (for example walking on beach)?
B4.1: Input data	Local marine compartment	Marine model assumptions for Stage 3 assessment are based on data defined in PC-CREAM 08 for Wylfa	It would be useful to refer to the source of the marine model data (HPA-RPD-058 and EC report RP 132). Values are consistent with these references.
B4.2: ASSESSOR input	Habits data	Assumed habits data (critical rates) are taken from the IRA methodology and seaweed consumption is based on generic habits data.	The critical group assumptions are the same as for the Stage 2 assessment, but with the addition of a seaweed pathway. For seaweed, a published report (Smith and Jones, 2003) indicates a mean rate of 5kg/y in a survey of South Wales. No value is recommended, but it seems that 5 kg/y might be a more appropriate cautious rate.
B4.2: ASSESSOR input	Habits data	Assumed habits data (inhalation and external pathways) are based on various references including IRAT and PC-CREAM 08.	Values have been checked against source references. It might be noted that the inhalation rates are appropriate for year-round exposure situations as they include periods sleeping; for shorter-term exposure higher rates are more appropriate as discussed by Smith and Jones (Smith and Jones, 2003). The value for the distance from the sea was not found in Smith and Simmonds (Smith and Simmonds, 2009). It is presumed that this is used to calculate sea spray deposition, but this is not stated. If this is the case, Smith and Simmonds (Smith and Simmonds, 2009) assume deposition within 300 m from the coast.

Table B.2: Summary and review of Hitachi-GE's approach for assessment of individual dose - atmospheric discharges

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE approach	Comments on Hitachi-GE's approach
5.2.1.2: Stage 1 atmospheric discharge assessment	Initial dose assessment	DPUR values specified by the Environment Agency used to calculate dose, assuming discharges at the authorisation limits, a ground level source and exposure of a critical group defined by the Environment Agency (at distances of 100m for exposure and 500m for food).	The use of DPUR values is an accepted technique. However, DPUR values assume deposition parameters based on a filtered source, a uniform wind rose and an even distribution of atmospheric stability conditions according to wind direction. The latter two are unlikely to be representative, although this will be highly site-dependent. The assumption of a uniform wind rose is not conservative.
5.2.2.2: Stage 2 atmospheric discharge assessment	Refined dose assessment	Stage 2 assessment undertaken because the dose calculated in Stage 1 exceeded 20 µSv/y. A similar procedure to Stage 1 undertaken except a source height of 19 m was adopted (based on third of stack height) and scaling factors provided by the Environment Agency used.	This is an accepted assessment procedure. The stack height is consistent with the current existing design assumptions.
5.2.3.2: Stage 3 atmospheric discharge assessment	Further refined dose assessment	Stage 3 assessment undertaken since dose calculated in Stage 2 exceeded 20 µSv/y. PC-CREAM 08 used for specific age groups and to determine whether a site-specific study is necessary. Exposure of critical group increased from 100 to 270m. A uniform wind rose is assumed.	Assumed that 70% of atmospheric stability conditions are Pasquill stability category D (Appendix B, section 5.2), which would be appropriate for coastal locations. This is not necessarily conservative for a generic site. PC-CREAM 08 is an accepted and recommended assessment technique. The assumption of a uniform wind rose is not conservative. Further investigation could be made of the effect of greater stack heights in reducing dose.

Table B.3: Summary and Review of Hitachi-GE's approach for assessment of individual dose - direct radiation

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE Approach	Comments on the Hitachi-GE Approach
5.2.4: Methodology	Dose rate calculation	The MCNP code to assess dose rates at various distances. Supporting report describing dose modelling.	There is reference to the supporting dose calculations but no details of the nature of the calculation are presented. It is assumed scattered radiation ('sky shine') is included but it is not discussed.
5.2.4.1: Occupancy pattern	Location factor	Shielding by the resident's house is represented by reducing dose rates by 90%.	A 'location factor' of 0.1 is commonly applied in assessments, but the attenuation is related to the photon energy. In this case the principal emissions are 6.1 MeV - this is a high energy and penetrating photon, for which the 0.1 value may not be appropriate.
7.2: Discussion	Doses to children and infants	Adult doses scaled by 50% and 34% respectively.	No details are given of the derivation of the scaling factors for infants and children.

Table B.4: Summary and review of Hitachi-GE's approach for assessment of individual dose - short-term atmospheric discharges

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE Approach	Comments on the Hitachi-GE Approach
6.3.4.1: Short-term discharge source term	Source term	Source assumed to be a by pin failure and that all particulate radionuclides retained in coolant. Dose limited to only xenon and krypton isotopes released. Release assumed to occur over 24 hours.	Source term is assumed to be accurate and release duration is assumed conservative.
6.3.4.2: Atmospheric dispersion	Atmospheric dispersion	ADMS used to calculate air concentrations for assumed Category D stability conditions.	ADMS is a proven and acceptable model. Calculations are stated to have been done for Pasquill stability category D. However, it was not demonstrated clearly how this assumption was sufficiently conservative (an independent assessment shows it is probably reasonable, given the release height and critical group distance).

Table B.5: Summary and review of Hitachi-GE's approach for assessment of collective doses

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE Approach	Comments on the Hitachi-GE Approach
6.3.6: Input data	Meteorological Conditions	'70% Category D' conditions have been assumed.	It was not demonstrated how this was conservative, although an independent analysis shows that the frequency of Category D conditions does not impact strongly on air concentrations, given the release height critical group distance .

Table B.6: Summary and review of Hitachi-GE's approach for assessment of potential dose to non-human species

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE Approach	Comments on the Hitachi-GE Approach
14.1: Methodology	Source term	Accumulated concentrations in soil, sea water and seabed sediment over 60 years.	As this calculation is part of the detailed assessment, it may have been appropriate to use Stage 3 assessment assumptions, although Stage 1 parameters will be cautious. A 60 year period is used as that is the planned operating lifetime of the UK ABWR.
14.1: Methodology	Source term	Airborne activity concentrations of noble gases at 100 m due to a ground level discharge, based on a Bq/y discharge rate.	The use of 100 m is not discussed in this case, but is consistent with the Stage 1 and 2 IRA assumptions.
14.1: Methodology	Methodology	The ERICA Tool has been used for the majority of radionuclides, with the EA R&D128 tool used for noble gases. Krypton-88 has been used as a surrogate for all noble gases not included in R&D128 except krpton-85.	This has been checked and confirmed that krypton-88 is the most cautious choice. These are the tools typically used in such assessments. It is noted that a new version of the ERICA tool was released in February 2016 (Version 1.2.1) but Hitachi-GE used the previous version of the tool released in November 2014.
A.31 Parameters	Parameters for the marine ERICA assessment	Dose rate screening value of 10 µGy/h used. Uncertainty factor of 5 used.	10 µGy/h is the ERICA default dose rate screening value. An uncertainty factor of 5 corresponds to the ERICA default value to test for 1% probability of exceeding the dose screening value, assuming that the

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE Approach	Comments on the Hitachi-GE Approach
		Marine sediment Kds defined. Occupancy factors, radiation weighting factors and percentage dry weight value set to the default values of ERICA 1.2.0.	risk quotient distribution is exponential. The marine sediment Kd values used in ERICA differ from those used in PC-CREAM 08.
A.29: ERICA input	Activity concentration in soil after 60 years continuous discharge	Based on calculations using the PLUME and FARMLAND modules within PC-CREAM 08.	This is consistent with other aspects of the dose assessment, and has been evaluated at 100 m from the discharge.
A.31: ERICA input	Distribution coefficients in ocean margin sediment.	Either default ERICA values used, or else data taken from IAEA TRS-422 (IAEA, 2004).	Use of ocean margin data consistent with the data source underlying ERICA 1.2.0.
A.32: ERICA input	Marine biota concentration ratios	Values taken from ERICA V1.2.0 database where available. Otherwise marine biota taken from IAEA TRS-422 (IAEA, 2004). Where no data is reported in IAEA TRS-422 (IAEA 2004), maximum across all elements for that biota is used. Surrogates are used for iron.	The selection of surrogate values for iron is considered to be reasonable. Where no IAEA TRS-422 (IAEA, 2004) values are available (wading birds, reptiles, sea anemones, vascular plants), the values are the maximum of the ERICA data.
Table A.33: ERICA input	Terrestrial biota concentration ratios	Default values were used with the exception of iron, praseodymium, rubidium and yttrium, which used the highest concentration ratio value for each species (which is the concentration ratio for carbon).	Approach is consistent with that used within ERICA for gap-filling. The reason for selecting carbon as the surrogate is not explained, although it is considered to be a reasonably cautious surrogate.
14.3: Results	Results	Results are presented in Tables A.34, A.35 and A.36 (Hitachi-GE, 2016a) for marine biota, terrestrial biota, and terrestrial biota	Using the input data provided in Tables A.28 to A.33 (Hitachi-GE 2016a), it was initially only possible to verify the results presented in Table

Section (Hitachi-GE, 2016a)	Criteria	Hitachi-GE Approach	Comments on the Hitachi-GE Approach
		following exposure to noble gases respectively.	A.35 (Hitachi-GE, 2016a) the terrestrial biota. It was not possible to replicate the results presented in Table A.34 (Hitachi-GE, 2016a), the marine biota. This issue was raised with Hitachi-GE, who subsequently re-issued the results (Hitachi-GE, 2016b), which were successfully verified.

Appendix C: Approach to the independent dose assessment

C.1 Requirements

The requirements for the generic design assessment (GDA) (Environment Agency, 2013) specify the need for a dose assessment that calculates:

- the annual dose to the most exposed members of the public liquid discharges
- the annual dose to the most exposed members of the public resulting from atmospheric discharges
- the annual dose to the most exposed members of the public from both liquid and atmospheric discharges
- the annual dose to the representative member of the public local to the site
- potential short-term doses, including those received via the food chain, based on anticipated short-term discharges from the facility in normal operation
- a comparison of the calculated doses with the relevant dose constraints
- an assessment of the build-up of radionuclides in the environment, over the anticipated lifetime of the facility
- the collective radiation dose, truncated at 500 years, to the UK, European and world populations
- the dose to non-human species

An estimate of the annual dose from direct radiation also needs to be included when calculating total exposures that are compared with dose constraints. However, the assessment of direct radiation exposures is not within the Environment Agency's remit (it is the responsibility of ONR so we have used values calculated by Hitachi-GE (Hitachi-GE, 2016) for this component of the assessment. Direct radiation is discussed in Appendix K.

The independent dose assessment provides an independent view of the potential radiological impacts of a single UK ABWR located at a generic site in England or Wales. The independent dose assessment must therefore address the requirements presented above, applying best-practice guidance.

This appendix describes key aspects: our approach to defining a generic site and our assessment approach. Details that are specific to each particular assessment are discussed in the remaining appendices (Appendix D to J) which cover each of the aspects described above in turn.

C.2 Characteristics of a generic site

The choice of the site at which the assessment is made is important because its characteristics influence the dispersion of discharged radioactivity. This determines the environmental concentrations and associated doses.

For the GDA, it is necessary to make assumptions about the site that are cautious but realistic so as to ensure that all potential site conditions have been encompassed. In previous independent dose assessments (for other reactor designs in the GDA process) this has involved prudently basing the site characteristics on an existing nuclear site with the lowest environmental concentrations for the anticipated discharges (Environment Agency, 2010). The same approach has been taken here. Because the discharges associated with each reactor design might differ in their key environmental pathways, it has been necessary to review the selection of the site.

In relation to liquid discharges, the coastline and near-shore currents determine amount of dispersion that occurs to effluents containing radioactivity. The assumed marine dispersion characteristics of existing nuclear sites (Table C.1, from Smith and Simmonds (Smith and Simmonds, 2009)) have been used to identify the site with the lowest dispersion. As a guide, the longer the residence time, the higher the accumulated concentrations of radionuclides. Figure C.1 shows the calculated seawater concentrations for nominal discharges at Sellafield or other existing English and Welsh reactor sites (note that these are not the discharge limits given in Hitachi-GE's report (Hitachi-GE, 2016), but will scale with them). The highest concentrations depend on the radionuclide in question, but are found at either Oldbury or Bradwell whilst Berkeley and Hartlepool also have high concentrations related to a long residence time.

Table C.1: The marine model compartment used for nuclear sites in England and Wales

Site	Volume (m^3)	Volumetric exchange rate (m^3/y)	Mean residence time of seawater (days)
Berkeley	2 10^8	4$10^9$	18
Bradwell	2 10^8	4 10^9	18
Dungeness	2 10^8	8 10^{10}	0.91
Hartlepool	2 10^8	4 10^9	18
Heysham	1 10^8	8 10^9	4.6
Hinkley Point	5 10^9	1 10^{11}	18
Oldbury	2 10^8	4 10^9	18
Sellafield	2 10^9	5 10^{11}	1.5
Sizewell	3 10^8	1.1 10^{10}	10
Wylfa	2 10^8	4 10^{10}	1.8

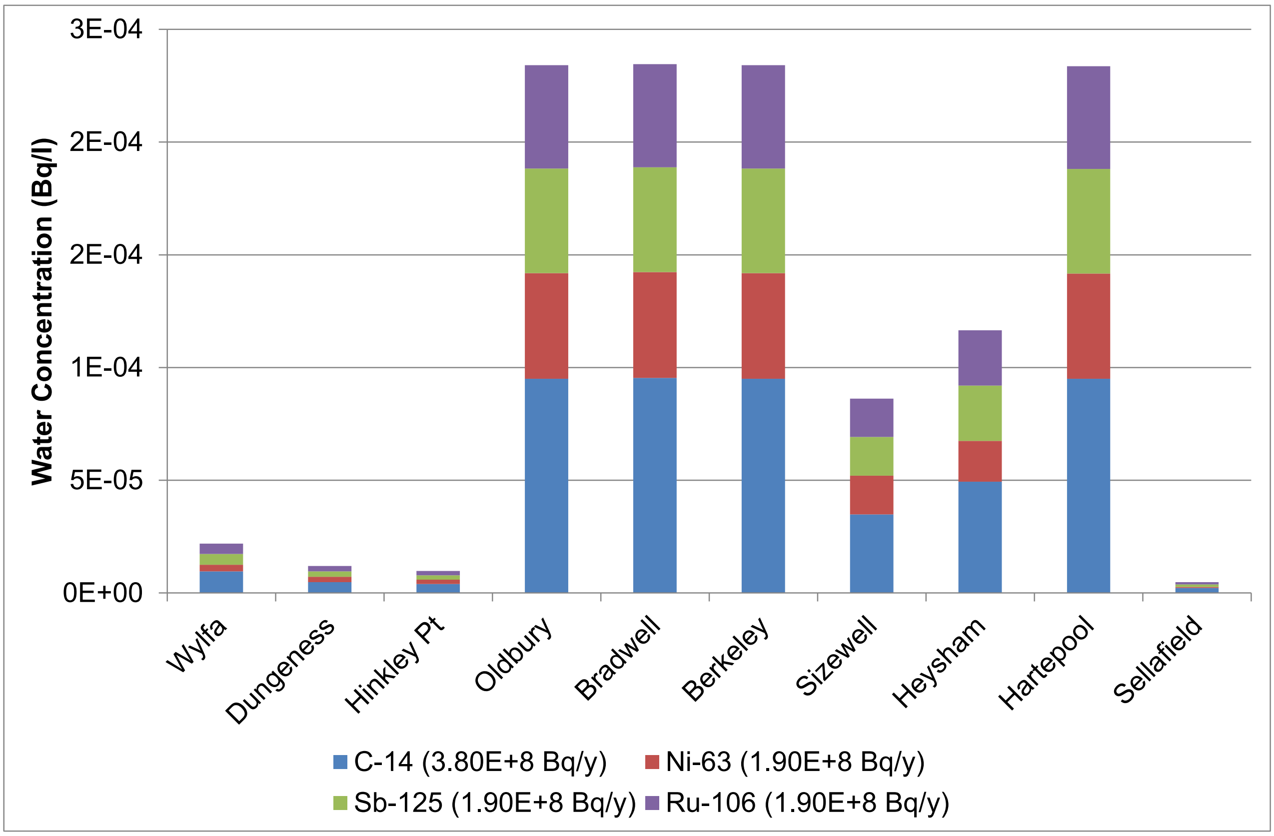

Figure C.1: Concentrations of radionuclides in seawater calculated by assuming the UK AWBR discharge occurs at existing nuclear sites in England and Wales

For discharges to the atmosphere, all but one of the existing nuclear sites in England and Wales is located on the coast or a coastal environment. Figure C.2 shows the long-term average meteorological conditions according to the Pasquill stability scheme for the UK. Taking the atmospheric conditions for each existing nuclear site, and applying the atmospheric discharge rates assumed for the UK ABWR, enables estimates to be made of ground level atmospheric concentrations of radioactivity. Figure C.3 suggests that the highest concentrations can be expected at Berkeley, Hinkley Point and Oldbury (as previously, these are for nominal discharge rates that will scale to those assumed by Hitachi-GE (Hitachi-GE, 2016)).

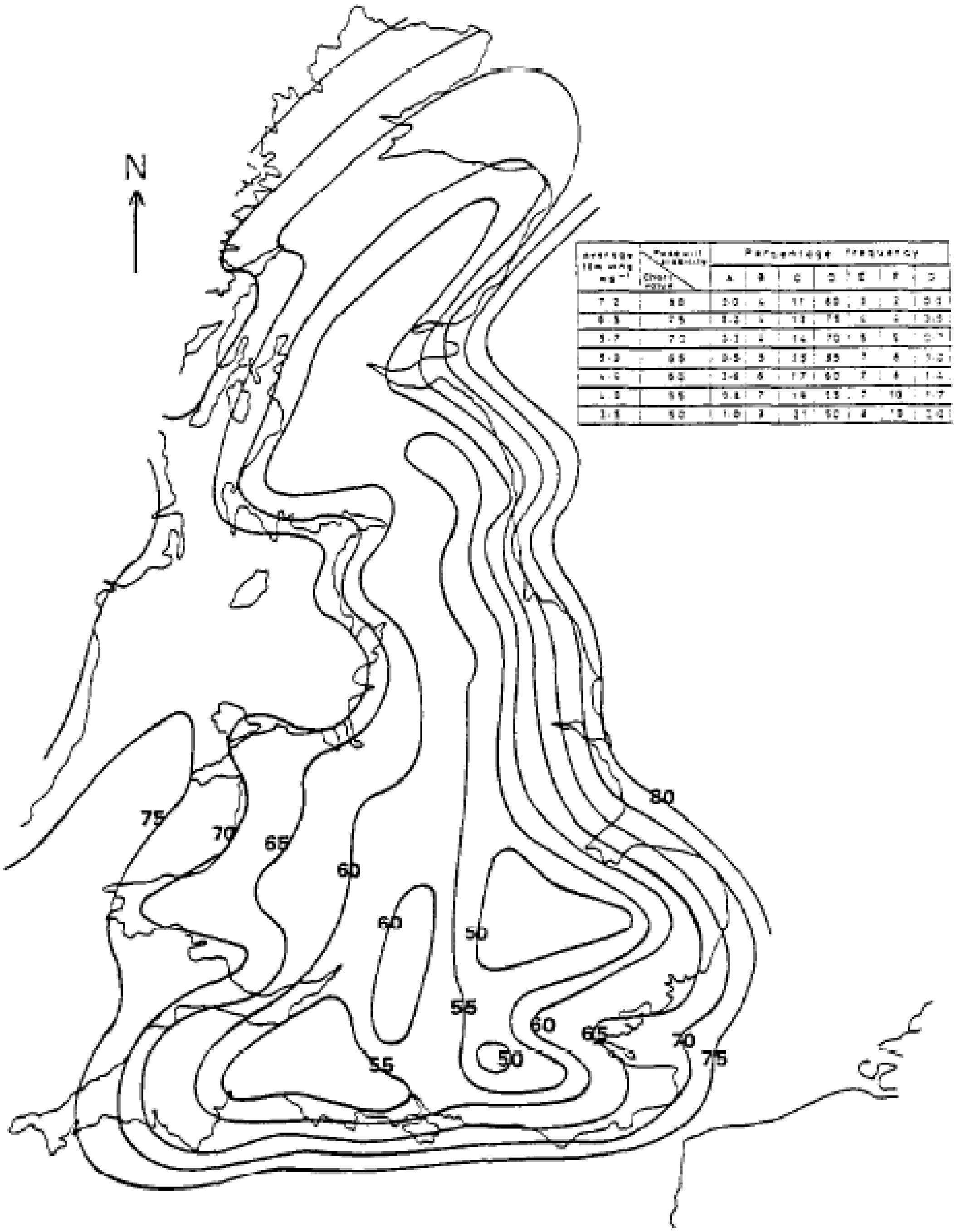

Figure C.2: Long-term average meteorological conditions in the UK according to Pasquill stability scheme (Clarke, 1979)

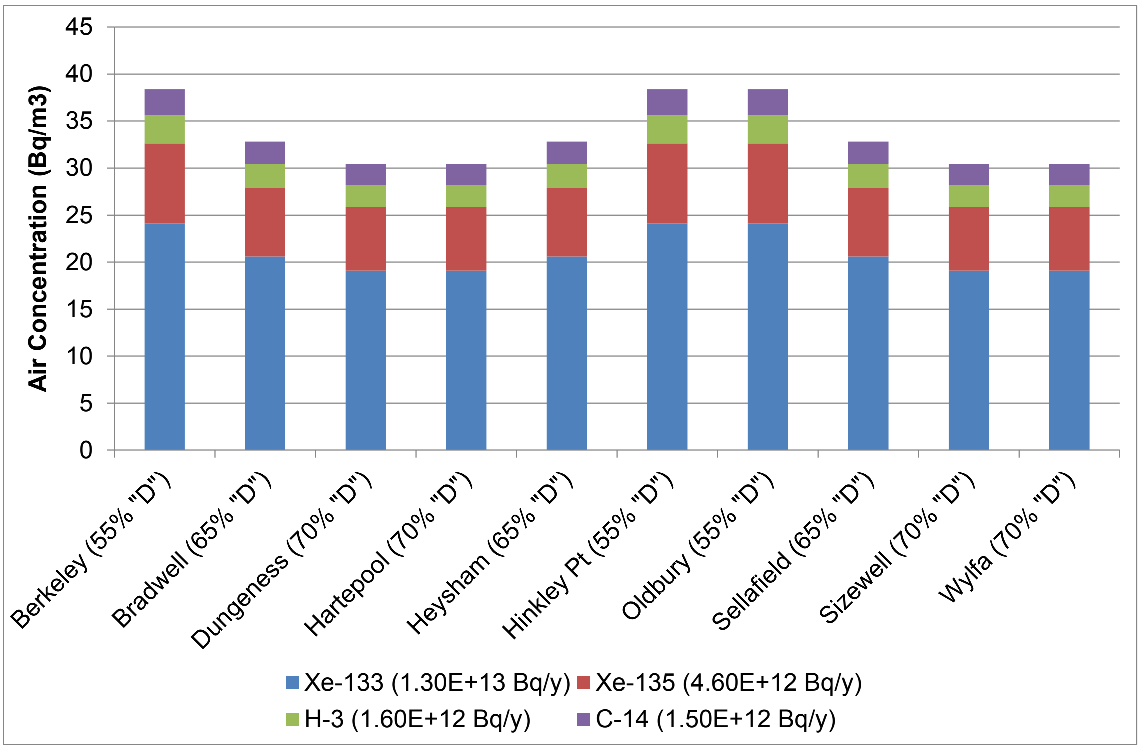

Figure C.3: Concentrations of radionuclides in air for continuous releases, calculated assuming the UK AWBR discharge occurs at existing nuclear sites in England and Wales (using Pasquill atmospheric stability categories)

On the basis of this analysis, we have adopted site characteristics based on those at Oldbury for the generic site used in the independent dose assessment. The assessment is generic and should not be interpreted as relating to any particular site. Data for the site are presented Appendix E and F for the dose assessment of atmospheric and marine discharges respectively. Model data are taken primarily from information presented in Smith and Simmonds (Smith and Simmonds, 2009).

Suitably cautious (but not unrealistic) assumptions are also needed for people's behaviours when assessing doses. At each existing nuclear site there are specific groups of people that can be characterised as most exposed on the basis of their actual places of home and work and related exposure pathways. These details are dependent on particular individuals and can readily change, particularly over the course of more than half a century during which the UK ABWR is anticipated to operate. For this reason, it the assumptions of human behaviour in the independent dose assessment are based on generic sources of data.

The independent dose assessment therefore uses the land and water use assumptions and habits of people described in the IRA methodology (Environment Agency, 2006a, b) and supporting studies (for example Smith and Jones (Smith and Jones, 2003)). The derivation of suitable human exposure assumptions is presented in relation to each dose assessment in the following appendices as part of the description of the specific dose assessment.

C.3 Assessment approach

The discharges to be assessed include releases to air and water, and the receptors include environmental media, humans (individual and collective doses) and non-human species. In relation to the doses to people, the 'Principles for the Assessment of Prospective Public Doses'" (Environment Agency et al., 2012) describe a staged approach to the assessment of radiation doses which has been applied in this study.

The first step of the initial dose assessment involves a simple and cautious assessment of the dose. There are two stages to the initial dose assessment.

- Stage 1 – initial radiological assessment using default data in the IRA methodology, and
- Stage 2 – initial radiological assessment using refined data.

If the resulting dose to the representative person is less than 20 μSv/y then no further assessment is necessarily warranted. Where the initial dose assessment outcome exceeds 20 μSv/y, then a further assessment, with suitable refinements to reflect the site, is needed. The methodology describes how the assessment can be refined at Stage 2; this involves scaling the dose to take account of local dispersion in the air or water.

If the doses calculated for the Stage 2 assessment remain above 20 μSv/y then a detailed assessment is needed using site-specific models.

C.3.1 Initial dose assessment (Stage 1 and 2)

Our independent initial dose assessment (stage 1 and 2) is presented in Appendix D

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C.3.2 Stage 3 (detailed) assessment

The dose assessment guidance (Environment Agency et al., 2012) does not specify models to be used in a Stage 3 detailed dose assessment. However, as a refinement of the dose assessment from Stage 1 and 2, it is reasonable to adopt an approach that involves using the same models. In the case of routine discharges, this is the PC-CREAM 08 dose assessment code, which is widely used for the assessment of releases from nuclear sites in the UK and Europe.

PC-CREAM 08 is a well-established system that was specifically designed for the assessment of the effects of continuous discharges of radioactivity on people. It was originally based on EC guidance (Simmonds et al., 1995) and has been developed further since then (Smith and Simmonds, 2009). It is suitable for the purpose of assessing individual doses and collective doses to people from liquid and gaseous discharges. The main limitations of PC-CREAM 08 are:

- the atmospheric dispersion module, PLUME embedded in PC-CREAM 08 is for continuous releases, and it is implementation means that it is not suitable for the assessment of short-term releases (as discussed by NDAWG (NDAWG, 2011)); and
- PC-CREAM 08 does not include algorithms for the calculation of radiation doses to non-human species.

For short duration releases to air our approach follows the NDAWG guidance, which recommends the use of the ADMS code to evaluate atmospheric dispersion. ADMS is a significantly more sophisticated model than the PLUME model and enables more specific atmospheric conditions, such as might be encountered during a short-term discharge, to be defined. ADMS calculates air concentrations and deposition rates at a given location.

Regarding the assessment of doses from non-human biota, PC-CREAM 08 can be used to estimate environmental concentrations. The exposure of non-human species can then be assessed using the ERICA approach (Beresford et al., 2007). This is widely used and can be readily applied to the predicted environmental concentrations. ERICA provides models and data that provide estimates of radiation doses to a range of non-human species. ERICA does not include models for the exposure of non-human species by noble gases, for which an alternative approach has been used (Vives i Batlle et al., 2015).

C.4 Assessment model data

PC-CREAM 08 has an extensive database of values required for the calculation of radionuclide transport, accumulation, uptake and exposure. Many parameters are not site-specific and therefore default values are routinely used in dose assessment calculations. The reference data are presented by Smith and Simmonds (Smith and Simmonds, 2009). Most non-site-specific data are based on international compilations of peer-reviewed data, and can be used without modification.

These compilations are periodically updated or revised to incorporate the outcomes of new work on the environmental and biological behaviour of radionuclides. In the last decade, IAEA (IAEA, 2004, 2010) has issued updated compilations of key data which are significantly more recent than the data used in PC-CREAM 08 (some of which dates to the 1980s). There are two key sets of parameters that have been superseded – environmental concentration factors for the foodchain and sorption coefficients between water and sediment. Dose calculations can be sensitive to these parameters, which determine the environmental accumulation of radionuclides and uptakes to plants and animals. Taking these issues into account, we have used the most recent values recommended by IAEA in the independent dose assessment. Further detail of the values used for gaseous discharges are given in Appendix E while Appendix F presents further detail for liquid discharges to the marine environment.

C.5 References

Reference	Details
Beresford, et al., 2007	Beresford N, Brown J, Copplestone D, Garnier-Laplace J, Howard B, Larsson C-M, Oughton D, Pröhl G and Zinger I (2007). D-ERICA: An INTEGRATED APPROACH to the assessment and management of environmental risks from ionising radiation. Euratom 6th Framework Programmes, Contract Number FI6R-CT-2004-508847.
Clarke, 1979	Clarke R H (1979). A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere. NRPB-R91.
Environment Agency, 2006a	Initial radiological assessment methodology – part 1 user report, Science Report: SC030162/SR1, May 2006
Environment Agency, 2006b	Initial radiological assessment methodology – part 2 methods and input data, Science Report: SC030162/SR2, May 2006.
Environment Agency et al., 2012	Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment. Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), August 2012.
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F
IAEA, 2004	Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment Technical Reports Series No. 422, April 2004

IAEA, 2010	Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments. IAEA Technical Report Series 472.
NDAWG, 2011.	Short-term Releases to the Atmosphere. National Dose Assessment Working Group - Short-term Release Sub-group. NDAWG/2/2011 (Updated version of NDAWG/1/2010).
Simmonds, et al., 1995	Simmonds J, Lawson G and Mayall A (1995). Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment. European Commission Report RP-72, 1995
Smith and Jones, 2003	Smith KR and Jones AL (2003). Generalised Habit Data for Radiological Assessments, National Radiological Protection Board Report NRPB-W41, May 2003.
Vives I Batlle et al., 2015	Vives i Batlle J., Jones S.R. and Copplestone D. (2015). A methodology for Ar-41, Kr-85, 88 and Xe-131m,133 wildlife dose assessment. Journal of Environmental Radioactivity. Volume 144 (152-161).

Appendix D: Initial dose assessment

D.1 Introduction

This appendix presents the initial dose assessment of the radioactive discharges from the UK ABWR. We have used the initial radiological assessment tool (IRAT) methodology (Environment Agency, 2006a, b). This recommends two stages to the assessment.

- Stage 1 – initial radiological assessment using default data
- Stage 2 – initial radiological assessment using refined data

The guidance describes how the assessment can be refined at Stage 2; this involves scaling the dose to take account of local dispersion in the air or water.

Both assessments use the estimated proposed annual discharge limits presented in Table 1 and Table 2 (see the main report) with the default dose per unit release factors presented in the IRA documentation (Environment Agency, 2006b).

D.2 Stage 1 Initial Radiological Assessment

The IRA methodology presents dose per unit release values (Sv/y per Bq/y) for atmospheric releases and for liquid discharges to a marine environment.

In Stage 1 of the methodology, the atmospheric releases are very conservatively assumed to be discharged at ground level. Liquid discharges are assumed to occur into a local marine compartment with low dispersion. This is represented with volumetric exchange rate of seawater of 100 m^3/s, which is at the low end of the rates found at existing nuclear sites in England and Wales (presented in **Error! Reference source not found.**).

The results calculated using the Stage 1 dose per unit release values for the proposed annual discharge limits for the UK ABWR are presented in Table D.1 and Table D.2.

The total dose from atmospheric discharges is well above the 20 µSv/y criterion, indicating a Stage 2 assessment is required. Carbon-14 is the dominant radionuclide contributing to dose (via inhalation and ingestion). The doses for liquid discharges are far below this criterion, but in order to provide a point of comparison with Hitachi-GE dose calculations, the subsequent stages of assessment have been undertaken. The dominant radionuclides for liquid discharges are cobalt-60 (external radiation) followed by tritium (ingestion).

Table D.1: Estimated Stage 1 doses (in µSv/y) from atmospheric discharges from a single UK ABWR

Radio-nuclide	Food ingestion	External irradiation	Inhalation	Total	% of total	Age group
Ar-41	<0.1	16.6	<0.1	16.6	11.6%	Adult
C-14	56.1	<0.1	59.5	115.6	80.7%	Infant
H-3	2.7	<0.1	6.9	9.6	6.7%	Offspring
I-131	1.3	<0.1	0.1	1.4	1.0%	Infant
Total	60	17	67	143		

Note: Only radionuclides contributing more than 0.1% of the total dose and only doses greater than 0.1 µSv/y are shown

Table D.2: Estimated Stage 1 doses (in μSv/y) from liquid discharges to the marine environment from a single UK ABWR

Radionuclide	External	Seafood ingestion	Total	% of total	Age group
Ce-144	3.4E-06	3.1E-07	3.7E-06	0.1%	Adult
Co-58	4.4E-06	1.2E-06	5.7E-06	0.2%	Adult
Co-60	2.2E-03	6.2E-05	2.3E-03	65.9%	Adult
H-3	0.0E+00	6.8E-04	6.8E-04	19.6%	Offspring
Mn-54	8.8E-05	2.0E-06	9.0E-05	2.6%	Adult
Nb-95	4.0E-06	3.6E-08	4.0E-06	0.1%	Adult
Sb-124	6.4E-06	1.5E-06	7.8E-06	0.2%	Adult
Zn-65	8.8E-06	3.6E-04	3.7E-04	10.8%	Adult
Zr-95	7.1E-06	5.3E-08	7.1E-06	0.2%	Adult
Total	2.3E-03	1.1E-03	3.5E-03		

Note: Only radionuclides contributing more than 0.1% of the total dose are shown.

D.3 Stage 2 initial radiological assessment

Stage 2 of the IRA involves simple refinements to the assessment to reflect site-specific characteristics. We have used the guidance in the methodology (Environment Agency, 2006b) which involves applying scaling factors. These factors relate to site-specific conditions that determine the initial dispersion of radionuclides in the air and in the marine environment, and consequently the environmental concentrations and associated doses.

Scaling factors for inhalation / external radiation and food ingestion are provided in the IRA methodology for atmospheric releases. Using an effective release height of 19 m (see Section **Error! Reference source not found.** in the main text) we have determined the following scaling factors:

- 0.0594 for inhalation/external radiation, and
- 0.357 food ingestion.

These have been applied to give the Stage 2 results shown in Table D.3.

For the liquid discharges, the main factor is the seawater exchange rate in the local marine environment. The Stage 1 calculations adopt a value of 100 m^3/s. Using data from Smith and Simmonds (Smith and Simmonds, 2009), a value appropriate for the generic site discussed in Appendix C is 130 m^3/s. The Stage 1 liquid discharge doses have therefore been scaled by a factor of 100/130. The Stage 2 results are shown in Table D.4.

The total dose from atmospheric discharges remains slightly above the 20 μSv/y criterion indicating a detailed (Stage 3) assessment is required. The dominant radionuclide remains carbon-14 in foods. The doses for liquid discharges remain well below this criterion. The dominant radionuclides for liquid discharges remain tritium and cobalt-60, and the dominant pathway is still the external irradiation (for cobalt-60).

The Stage 3 assessment of individual doses from atmospheric discharges is presented in Appendix E. A Stage 3 assessment of liquid discharges is presented in Appendix F.

Table D.3: Estimated Stage 2 doses (in µSv/y) from atmospheric discharges from a single UK ABWR

Radio-nuclide	Food ingestion	External irradiation	Inhalation	Total	% of total	Age group
Ar-41	<0.01	0.99	<0.01	0.99	3.7%	Adult
C-14	20.01	<0.01	3.53	23.54	89.2%	Infant
H-3	0.96	<0.01	0.41	1.37	5.2%	Offspring
I-131	0.47	<0.01	0.01	0.48	1.8%	Infant
Total	21	1	4	26		

Note: Only radionuclides contributing more than 0.1% of the total dose and only doses greater than 0.1 µSv/y are shown.

Table D.4: Estimated Stage 2 doses (in µSv/y) from liquid discharges to the marine environment from a single UK ABWR

Radio-nuclide	External	Seafood ingestion	Total	% of total	Age group
Ce-144	2.6E-06	2.4E-07	2.8E-06	0.1%	Adult
Co-58	3.4E-06	9.5E-07	4.4E-06	0.2%	Adult
Co-60	1.7E-03	4.7E-05	1.8E-03	65.9%	Adult
H-3	0.0E+00	5.2E-04	5.2E-04	19.6%	Offspring
Mn-54	6.8E-05	1.5E-06	6.9E-05	2.6%	Adult
Nb-95	3.0E-06	2.8E-08	3.1E-06	0.1%	Adult
Sb-124	4.9E-06	1.1E-06	6.0E-06	0.2%	Adult
Zn-65	6.8E-06	2.8E-04	2.9E-04	10.8%	Adult
Zr-95	5.4E-06	4.1E-08	5.5E-06	0.2%	Adult
Total	1.8E-03	8.6E-04	2.7E-03		

Note: Only radionuclides contributing more than 0.1% of the total dose are shown.

D.4 References

Reference	Details
Environment Agency, 2006a	Initial radiological assessment methodology – part 1 user report, Science Report: SC030162/SR1, May 2006.
Environment Agency, 2006b	Initial radiological assessment methodology – part 2 methods and input data, Science Report: SC030162/SR2, May 2006.
Smith and Simmonds, 2009	Smith JG and Simmonds JR (2009). The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08, Health Protection Agency Report HPA-RPB-08, October 2009.

Appendix E: Detailed independent dose assessment of atmospheric discharges

E.1 Introduction

This appendix describes the detailed (Stage 3) assessment of radiation doses from the atmospheric discharges from a UK ABWR nuclear power plant. A detailed assessment is required as the Stage 1 and 2 dose assessment for atmospheric discharges (Appendix D) gave results that exceeded the 20 µSv/y criterion described in our guidance (Environment Agency, 2006a).

The discharge limits used in the assessment are those presented in Table 1 and Table 2 of the main text. The overall scope and assessment approach is described in Appendix C, and reflects the principles (Environment Agency et al., 2012) and relevant guidance.

E.2 Site characteristics

As discussed in Appendix C, the generic site used in this independent dose assessment has been based on the Oldbury site in Gloucestershire. The discharge height has been based on the smallest stack at existing ABWRs in Japan, 57 m (Hitachi-GE, 2016). The effective height of discharges has been taken to be 1/3 of this value, 19 m, to account for building wake effects (Jones, 1983). According to Clarke (Clark, 1979), the general long-term average atmospheric conditions at Oldbury lie on the 55% Pasquill Category D contour. (In practice, the choice of frequency of Category D conditions is not crucial in determining the level of dispersion at the range of the critical groups for the discharge height assumed.) Corresponding meteorological parameters have been adopted in the dose assessments. For the main calculations, a uniform distribution of wind directions has been assumed. There is the potential for the plume to be influenced by prevailing winds and this aspect is considered in sensitivity calculations presented at the end of this appendix.

E.3 People most exposed to atmospheric discharges

Exposure pathways to people for atmospheric discharges were derived from the generalised patterns of behaviour considered in the IRA methodology (Environment Agency, 2006b) and other guidance (Smith and Jones, 2003). Those most exposed group will live close to where the ground level air concentration is a maximum and have a range of exposure pathways. This group will therefore be a family living close to the site, in which the adults are home workers or carers for small children and thus spend the majority of their time at home. Children and infants are assumed to be looked after at home. Furthermore, it is cautious but reasonable to assume that the family farms the land and therefore they obtain much of their food from a local source. For the purposes of the independent dose assessment, the group are assumed to live 300 m from the discharge stack, with their food obtained 500 m from the stack. These distances take into account the distance of the site boundary from the stack in Hitachi-GE's generic site layout (Hitachi-GE, 2014).

The exposure pathways include:

- internal exposure to radionuclides from ingestion of local fruit and vegetable products (green vegetable and root vegetable), cow and sheep meat, and cow milk
- external doses from exposure to the plume (with allowance for the shielding offered by a home)
- inhalation of radionuclides in the plume and resuspended from the ground

It would be overly cautious to assume that people eat all food groups at high rates. Guidance suggests that a reasonable assumption is that the two foodstuffs that contribute most to a person's dose should be taken to be at a high rate, with the others at average rates (NDAWG, 2009). Scoping calculations indicate that, when all intake rates are set to the high rates given in Environment Agency's IRA methodology (Environment Agency, 2006b), the dominant foodstuffs are milk and milk products for children and infants. For adults, the dominant foodstuffs are milk products and root vegetables. On this basis, these were assigned high rates in the assessment of the local resident family.

The human exposure characteristics implied by these assumptions are summarised in Table E.1.

Table E.1: Exposure characteristics for the local resident most exposed to atmospheric discharges

Parameter	Adult	Child	Infant
Indoors, home (100m from site) (h/y)	4380	7008	7884
Outdoors, home (100m from site) (h/y)	4380	1752	876
Cow liver consumption (kg/y)	2.75	1.5	0.5
Cow meat consumption (kg/y)	15	15	3
Cow milk consumption (kg/y)	95	240	320
Cow milk products consumption (kg/y)	60	45	45
Fruit consumption (kg/y)	20	15	9
Green veg consumption (kg/y)	35	15	5
Root veg consumption (kg/y)	130	50	15
Sheep liver consumption (kg/y)	2.75	1.5	0.5
Sheep meat consumption (kg/y)	8	4	0.8

Note: Food production is assumed to be at 500 m from the stack. The indoors occupancy at home is taken to be 50% of the year for adults, 80% for children and 90% for infants, based on Environment Agency (Environment Agency, 2006b).

A local farming group is also a candidate for the 'representative person' for exposure to all discharges from the UK ABWR, if they are also assumed to ingest locally sourced seafood (at average rates (Smith and Jones, 2003)) and visit the local beach (for example for recreation). The assessment of doses to representative persons, exposed by atmospheric and liquid discharges, is presented in Appendix G.

The Principles (Environment Agency et al., 2012) also require that the exposure of non-nuclear workers is assessed. A person living permanently next to the site, and eating locally produced foods, would be expected to have a longer duration exposure, and more exposure pathways, than a non-nuclear worker. There are no obvious circumstances in which a non-nuclear worker could be exposed to a greater degree, so the local farmer exposure group will bound the possible exposures

E.4 Modelling approach

The independent dose assessment of atmospheric discharges was undertaken using the PC-CREAM 08 code (Version 1.5.1.85, with database Version 2.0.0). The code includes a Gaussian plume atmospheric dispersion model for the assessment of routine discharges to air, PLUME. The model calculates air concentrations and deposition rates for a range of user-specified stack heights and meteorological conditions. The PLUME model results were then used in the ASSESSOR module to determine individual doses.

The meteorological properties for the generic site, specified in Section E.2 and based on Oldbury, were used. It should be noted that the PLUME model does not represent the vertical discharge velocity of the discharge, or the turbulent effects of buildings. The former is cautiously ignored in the assessment. The latter has been accounted for by specifying an effective release height lower than the actual stack height.

The most recent compilation of element-dependent uptake factors for foodstuffs by the IAEA (IAEA, 2010) was used in place of older default data included in PC-CREAM 08 (see Tables E.2 and E.3). Other parameters were set to default values defined for PC-CREAM 08 (Smith and Simmonds, 2009).

The calculated air concentrations, after 60 years of continuous releases at the rates presented in Table 1, are shown in Table E.4. Soil concentrations, after 60 years of continuous discharges, are shown in Table E.5.

Table E.2: Concentration factors for plants (kg/kg) used in the independent dose assessment

Element	Green Veg.	Grain	Pasture	Root Veg.	Fruit
Ag	1.8E-04	2.0E-01^	2.0E-01^	1.3E-03	2.0E-01^
Am	2.7E-04	2.2E-05	1.5E-03	6.7E-04	1.5E-04
Ar *	-	-	-	-	-
Ba	5.0E-03	1.0E-03	1.0E-02^	5.0E-03	1.0E-02^
Ce	6.0E-03	3.1E-03	3.7E-01	6.0E-03	5.3E-04
Cm	1.4E-03	2.3E-05	1.0E-03	8.5E-04	5.3E-04
Co	1.7E-01	8.5E-03	4.5E-02	1.1E-01	4.8E-03
Cr	1.0E-03	2.0E-04	2.0E-03	1.0E-03	3.0E-04^
Cs	6.0E-02	2.9E-02	2.5E-01	4.2E-02	5.8E-03
Fe	1.0E-03	2.0E-04	2.0E-03	1.0E-03	4.0E-04^
I	6.5E-03	6.3E-04	3.7E-03	7.7E-03	1.5E-02
Kr*	-	-	-	-	-
La	5.7E-03	2.0E-05	2.0E-02	1.6E-03	3.0E-03^
Mn	4.1E-01	2.8E-01	6.4E-01	4.2E-01	3.9E+00
Nb	1.7E-02	1.4E-02	2.0E-02	1.7E-02	1.0E-02^
Np	2.7E-02	2.9E-03	6.1E-02	2.2E-02	1.7E-04
Pr	2.0E-02	2.0E-02	2.0E-03^	2.0E-02	6.4E-04^
Pu	8.3E-05	9.5E-06	5.5E-04	3.9E-04	1.0E-05^
Rb	6.2E-01	9.0E-01	1.0E-01^	9.0E-01	1.0E-01^
Sb	9.4E-05	1.8E-03	1.0E-02^	6.2E-04	1.0E-02^
Sr	7.6E-01	1.1E-01	1.3E+00	7.2E-01	4.4E-02
Te	3.0E-01	1.0E-01	1.0E+00	3.0E-01	3.0E-03^

U	2.0E-02	6.2E-03	4.6E-02	8.4E-03	1.0E-03^
Xe*	-	-	-	-	-
Y	2.0E-03	5.0E-04	5.0E-03	2.0E-03	1.0E-02^
Zn	2.4E+00	1.8E+00	1.0E+00	5.0E-01^	1.0E+00^
Zr	4.0E-03	1.0E-03	1.0E-02	4.0E-03	1.0E-04^

Note: All data are from IAEA (IAEA, 2004) with the exception of cells indicated with "^" for which no values are available in IAEA (IAEA, 2004) and the default value in PC-CREAM 08 is taken. Hydrogen and carbon uptake are calculated by specific activity. *Element is gaseous and so is not relevant for liquid discharges.

Table E.3: Uptake factors for animal products (d/kg) used in the independent dose assessment

Element	Cow milk	Cow meat	Cow liver	Sheep meat	Sheep liver
Ag	3.0E-02	1.0E-03	4.0E-01	4.8E-04^	3.0E+00
Am	1.0E-06	1.0E-04	2.0E-02	4.0E-04	3.0E-02
Ar *	-	-	-	-	-
Ba	1.6E-04^	1.4E-04^	5.0E-04^	5.0E-03^	5.0E-03^
Ce	2.0E-05^	1.0E-03^	2.0E-01	2.5E-04	2.0E+00
Cm	1.0E-06	1.0E-04	2.0E-02	4.0E-04	3.0E-02
Co	1.1E-04^	4.3E-04^	1.0E-02	1.2E-02^	1.0E-01
Cr	4.3E-04^	5.0E-03	5.0E-03	5.0E-02	5.0E-02
Cs	5.0E-03	3.0E-02	3.0E-02	5.0E-01	5.0E-01
Fe	3.5E-05^	1.4E-02^	4.0E+00	1.0E-02	3.0E+01
I	5.0E-03	2.0E-03	2.0E-03	5.0E-02	5.0E-02
Kr*	-	-	-	-	-
La	2.0E-05	1.3E-04^	2.0E-01	5.0E-02	2.0E+00
Mn	4.1E-05^	6.0E-04^	2.0E-02	9.0E-03^	2.0E-01
Nb	4.1E-07^	2.6E-07^	3.0E-07	3.0E-06	3.0E-06
Np	1.0E-06	1.0E-04	2.0E-02	4.0E-04	3.0E-02
Pr	2.0E-05	3.0E-04	3.0E-04	4.0E-03	2.0E-03
Pu	1.0E-06	1.0E-04	2.0E-02	4.0E-04	3.0E-02
Rb	1.0E-02	1.0E-02	1.0E-02	1.0E-01	1.0E-01
Sb	3.8E-05^	1.2E-03^	1.0E-01	1.0E-02	1.0E+00
Sr	2.0E-03	3.0E-04	3.0E-04	3.0E-03	3.0E-03
Te	3.4E-04^	7.0E-03^	5.0E-03	5.0E-02	5.0E-02
U	1.8E-03^	3.9E-04^	2.0E-04	2.0E-03	2.0E-03
Xe*	-	-	-	-	-
Y	2.0E-05	1.0E-03	1.0E-02	1.0E-02	1.0E-01
Zn	2.7E-03^	1.6E-01^	2.0E-03	4.5E-02^	2.0E-02
Zr	3.6E-06^	1.2E-06^	1.0E-07	1.0E-06	1.0E-06

Note: Where possible data are from IAEA (IAEA, 2004) and are indicated with "^". For other cells no values are available in IAEA (IAEA, 2004) and the default value in PC-CREAM 08 is taken.

The values for americium, curium, caesium, iodine, neptunium, plutonium and strontium cannot be changed in PC-CREAM, so the defaults are used.

Hydrogen and carbon uptake are calculated by specific activity.

*Element is gaseous and so is not relevant to liquid discharges.

Table E.4: Air concentrations calculated by PC-CREAM 08, 300 m distance from a 57 m high stack, assuming 55% Pasquill Category D conditions and a uniform distribution of wind directions

Radionuclide (discharge rate)	Conc. in air (Bq/m^3)	Radionuclide (discharge rate)	Conc. in air (Bq/m^3)
H-3 (1.00E+13 Bq/y)	7.1E-01	I-133 (7.30E+7 Bq/y)	5.2E-06
Ar-41 (5.20E+12 Bq/y)	3.7E-01	I-135 (4.30E+7 Bq/y)	3.0E-06
C-14 (1.70E+12 Bq/y)	1.2E-01	Rb-88 (Kr-88)^	2.9E-06
Xe-133 (2.00E+11 Bq/y)	1.4E-02	Xe-133m (1.80E+7 Bq/y)	1.3E-06
Kr-85m (1.00E+10 Bq/y)	7.1E-04	Xe-135m (I-135)*	1.6E-07
Xe-131m (2.90E+9 Bq/y)	2.1E-04	Co-58 (1.50E+5 Bq/y)	1.1E-08
Kr-85 (1.30E+9 Bq/y)	9.3E-05	Co-60 (1.50E+5 Bq/y)	1.1E-08
Kr-88 (9.30E+8 Bq/y)	6.6E-05	Cr-51 (1.30E+5 Bq/y)	9.3E-09
I-131 (3.20E+8 Bq/y)	2.3E-05	Nb-95 (1.10E+5 Bq/y)	7.8E-09
I-132 (1.10E+8 Bq/y)	7.7E-06	Mn-54 (9.00E+4 Bq/y)	6.4E-09

Note: Highest 20 concentrations shown. * Ingrown from Kr-88. ^Ingrown from I-135

Table E.5: Soil concentrations calculated by PC-CREAM, 300 m distance from a 57 m high stack, assuming 55% Pasquill Category D conditions and a uniform distribution of wind directions

Radionuclide (discharge rate)	Conc. in soil (Bq/kg)	Radionuclide (discharge rate)	Conc. in soil (Bq/kg)
C-14 (1.70E+12 Bq/y)	5.7E+00*	Cs-137 (9.40E+2 Bq/y)	1.7E-07
H-3 (4.20E+12 Bq/y)	4.5E+00*	Ce-144 (7.00E+3 Bq/y)	6.3E-08
I-131 (1.10E+8 Bq/y)	1.8E-04	Co-58 (2.60E+4 Bq/y)	5.8E-08
I-133 (1.50E+7 Bq/y)	2.6E-06	Sb-125 (1.60E+3 Bq/y)	4.5E-08
Co-60 (4.90E+4 Bq/y)	2.4E-06	Cs-134 (1.50E+3 Bq/y)	3.2E-08
I-132 (9.20E+7 Bq/y)	1.8E-06	Cr-51 (3.70E+4 Bq/y)	2.9E-08
I-135 (1.70E+7 Bq/y)	9.4E-07	Sb-124 (7.00E+3 Bq/y)	1.3E-08
Zn-65 (3.20E+4 Bq/y)	2.5E-07	Rb-88 (Kr-88)^	1.1E-08
Sr-90 (1.40E+3 Bq/y)	2.3E-07	Nb-95 (9.40E+3 Bq/y)	9.6E-09
Mn-54 (2.30E+4 Bq/y)	2.2E-07	Zr-95 (4.50E+3 Bq/y)	9.0E-09

Note: Highest 20 concentrations shown. * Calculated by specific activity method. ^ Ingrown from Kr-88.

E.5 Radiation doses to individuals

The annual effective dose to the hypothetical local resident family, considered to be most exposed to the radioactive discharges from the UK ABWR, was calculated using the approach described above. A summary of the calculated doses is shown in Table E.6. The highest dose of 24 μSv/y to the infant is well below the source-related dose constraint of 300 μSv/y (Environment Agency et al., 2012).

The infant local resident is most exposed by the atmospheric discharges as a result of their high intake of milk and milk products. The contribution of radionuclides and pathways to their exposure is shown in Table E.7. This illustrates that the dominant pathways are consumption of milk and milk products, with the most important radionuclide being carbon-14.

Table E.6: Doses (μSv/y) to the local resident

Age	Inhalation	External radiation	Meat	Milk	Vegetables	Total
Adult	2.1	0.3	1.0	5.3	4.3	13
Child	2.0	0.2	1.0	8.5	2.6	14
Infant	1.6	0.12	0.46	20	1.9	24

Table E.7: Contribution of radionuclides and pathways to the doses to the infant (μSv/y) in the local resident family from radioactive discharges

Age	Inhalation	External radiation	Meat	Milk	Vegetables	Total	% of Total
Ar-41	0.0E+00	1.2E-01	0.0E+00	0.0E+00	0.0E+00	1.2E-01	0.50%
C-14	1.5E+00	9.5E-06	4.5E-01	1.8E+01	1.8E+00	2.2E+01	91%
H-3	9.7E-02	0.0E+00	8.6E-03	7.8E-01	5.9E-02	9.5E-01	3.9%
I-131	3.1E-03	5.5E-04	2.5E-03	1.1E+00	1.5E-02	1.1E+00	4.7%
Total	1.6E+00	1.2E-01	4.6E-01	2.0E+01	1.9E+00	2.4E+01	

Note: Only radionuclides contributing 0.01% or more to the total dose are shown. Noble gases only contribute by external radiation pathways.

E.6 Exploring sensitivity to model assumptions

Long-term exposure to atmospheric discharges is related to the average calculated air concentrations and deposition of radionuclides over the course of a typical year. These are defined by the atmospheric dispersion characteristics of the stack and the site. The stack height is a key factor, as it determines the ground level concentrations, particularly those close to the site, where there is least dispersion. The site's location determines the strength of the wind and factors like the frequency of different meteorological conditions (for example different boundary layer heights).

These factors can be varied in the PC-CREAM 08 code and so have been examined to illustrate their significance for the independent dose assessment. The variation in air concentration with distance is shown in Figure E.1, illustrating key radionuclides. In these calculations, the site meteorological conditions were the same as for the independent dose assessment.

Figure E.2 shows that the effective discharge height is a key factor, particularly close to the stack. In the independent dose assessment, the release height is assumed to be 19 m (corresponding to an actual stack height of 57 m, to take account of the effects of building wake effects), which can be seen to be a relatively cautious assumption. This figure also shows that concentrations close to the stack are more sensitive to stack height than further away as the 'skip distance' (before the plume reaches ground level) increases. For stacks more than about 25 m high the highest concentrations may occur several hundred metres from the stack.

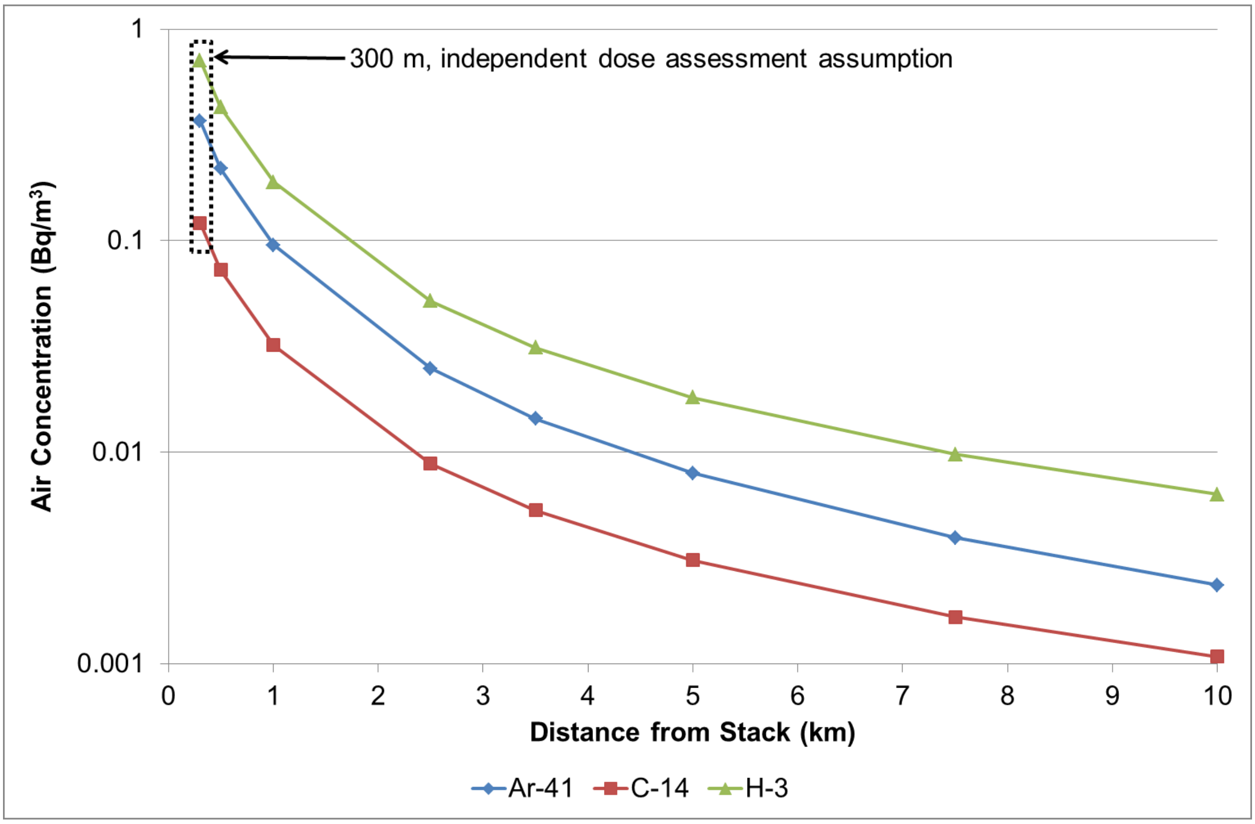

Figure E.1: Variation in ground level air concentration with distance from the stack, for continuous discharges, 19 m effective release height and 55% Category D conditions

Another important factor affecting the local air concentrations and deposition rates is whether there is any preferential wind direction. By default, PC-CREAM 08 includes meteorological profiles that assume dispersion according to a uniform windrose. This means the atmospheric conditions are such that the wind is equally likely to blow from any given direction. In practice, many locations in the UK, particularly those at the coast or in the vicinity of prominent topographical features, display a bias in a particular direction. As a result, it is possible that locations downwind of prevailing winds may experience more frequent exposure and thus there will be a corresponding increase in the annual dose to candidate representative persons.

The independent dose assessment has adopted Oldbury as an example site. Oldbury is in a location that has features that result in a significant bias in wind direction. Although there are no measurements from the site itself, data are available from a number of airfields and airports in the vicinity of the site (Figure E.4).

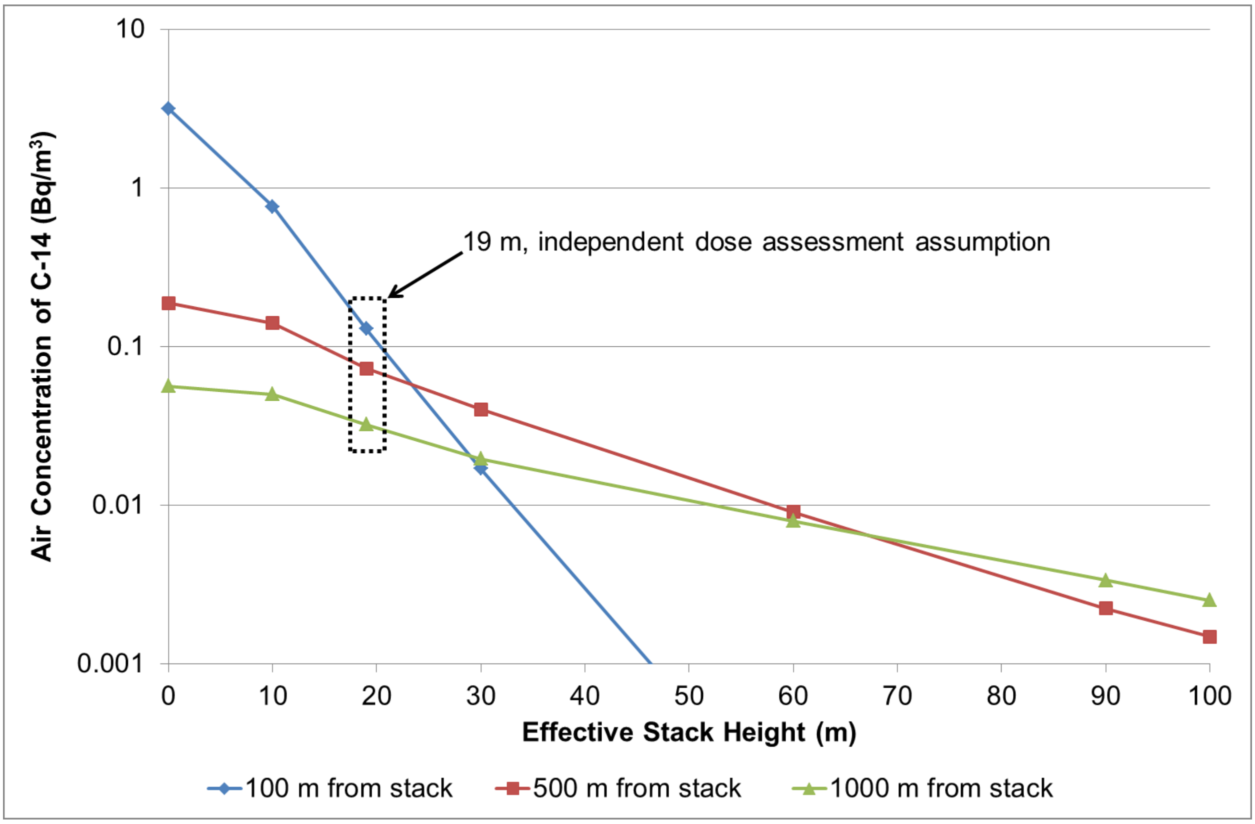

Figure E.2: Variation in ground level air concentration, at various distances from the point of release, with height of the stack, for continuous discharges, and 55% Category D conditions

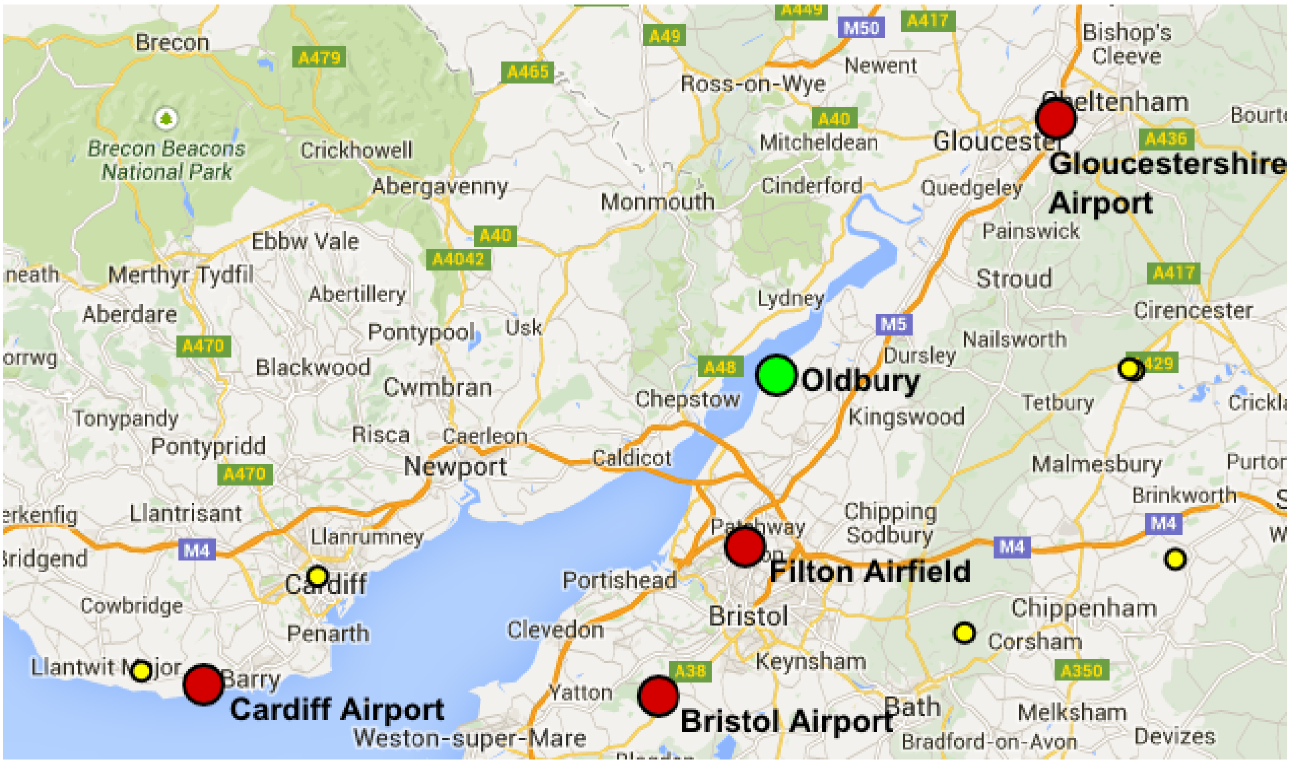

Figure E.4: Location of meteorological stations near to Oldbury

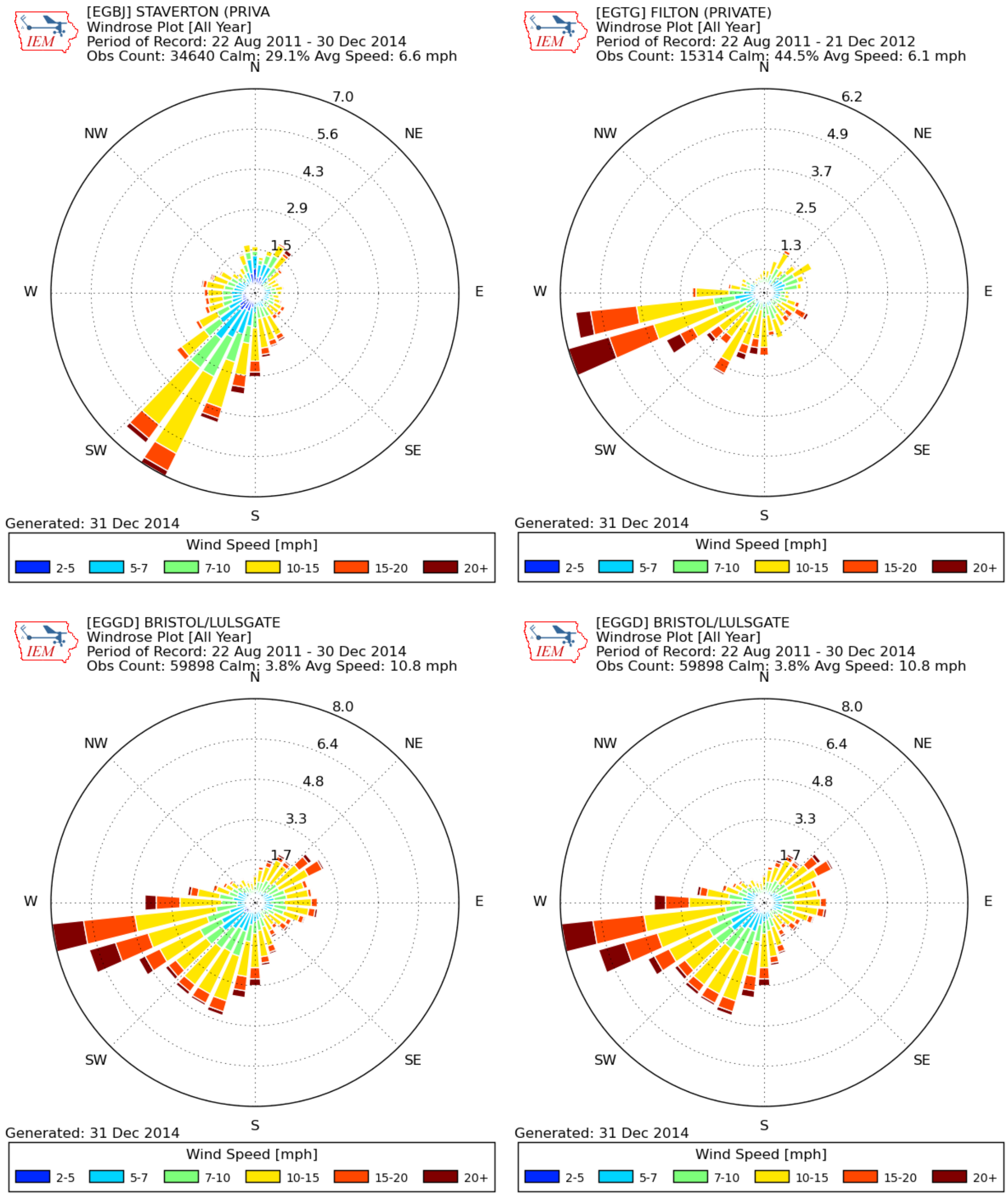

Figure E5: Windroses for 4 locations in the vicinity of Oldbury

Analysis of the frequency data shows that (for all wind speeds) the wind blows in the dominant sector at Filton 1.4 times as frequently as expected, or 2.5 times as frequently if calm conditions are neglected. For Staverton (Cheltenham) wind blows to the dominant sector 2.2 times as frequently, or 3.1 times when calm conditions are not considered.

As a first approximation of the effects of prevailing winds it is therefore reasonable to scale environmental concentrations for a uniform windrose by a factor of 2 to 3. This means that a person resident in to the North East of the site (in this case) could receive a dose approximately 2 to 3 times higher than that calculated on the basis of a uniform windrose.

E.7 References

Reference	Details
Clarke, 1979	Clarke R H (1979). A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere. NRPB-R91
Environment Agency, 2006a	Initial radiological assessment methodology – part 1 user report, Science Report: SC030162/SR1, May 2006.
Environment Agency, 2006b	Initial radiological assessment methodology – part 2 methods and input data, Science Report: SC030162/SR2, May 2006.
Environment Agency et al., 2012	Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment. Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), August 2012.
Hitachi-GE, 2014	UK ABWR Generic Design Assessment: Generic Site Description, Report GA91-9901-0020-00001, Rev D
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F
IAEA, 2004	Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment Technical Reports Series No. 422, April 2004.
Jones, 1983	Models to allow for the effects of Coastal Sites, Plume Rise and Buildings on Dispersion of Radionuclides and Guidance on the value of Deposition Velocity and Washout Coefficients, Fifth report of a working group on Atmospheric Dispersion. National Radiological Protection Board (NRPB) R-157
NDAWG, 2009	Acquisition and Use of Habits Data for Prospective Assessments. National Dose Assessment Working Group - Habits Sub-group. NDAWG/2/2009
Smith and Simmonds, 2009	Smith JG and Simmonds JR (2009). The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08, Health Protection Agency Report HPA-RPB-08, October 2009.
Smith and Jones, 2003	Smith KR and Jones AL (2003). Generalised Habit Data for Radiological Assessments, National Radiological Protection Board Report NRPB-W41, May 2003.

Appendix F: Detailed independent assessment of individual doses from liquid discharges

F.1 Introduction

The Stage 1 and 2 dose assessment for the liquid radioactive discharges from a UK ABWR nuclear power station (Appendix D) gave results that were significantly lower than those from the atmospheric discharges.

Although the calculated doses were below the level normally expected to require further analysis a detailed (Stage 3) assessment has been undertaken. This enables a comparison with the results calculated by Hitachi-GE (Hitachi-GE, 2016) for the most exposed members of the public for liquid discharges.

The site has been assumed to be at a coastal location and discharge to the marine environment. The annual discharge limits proposed by Hitachi-GE (Hitachi-GE, 2016) have been used. The overall scope and assessment approach is described in Appendix C, and reflects our principles (Environment Agency et al., 2012) and relevant guidance.

F.2 Characteristics of the marine environment

As discussed in Appendix C, the Oldbury site has been used as the basis for the independent dose assessment. The point of discharge from this site, into the Severn Estuary, has amongst the lowest rates of dispersion found at nuclear sites in England and Wales. The site-specific properties of the marine environment used in the detailed model were taken from Smith and Simmonds (Smith and Simmonds, 2009) and are presented in Table F.1.

Table F.1: Local compartment characteristics used in the independent dose assessment of liquid discharges from the UK ABWR

Parameter	Value	Parameter	Value
Volume (m^3)	$2\ 10^{8}$	Suspended sediment ($t\ /m^3$)	$2\ 10^{-4}$
Depth (m)	10	Sedimentation rate ($t\ /y\ /m^2$)	$1\ 10^{-4}$
Coastline length (m)	$1\ 10^{4}$	Sediment density ($t\ /m^3$)	2.6
Seawater exchange rate ($m^3\ /y$)	$4\ 10^{9}$	Diffusion rate ($m^2\ /y^1$)	$3.15\ 10^{-2}$

F.3 People most exposed to liquid discharges

Assumptions about the exposure pathways for people were derived from the generalised patterns of behaviour considered in the IRA methodology (Environment Agency, 2006) and supporting guidance (Smith and Jones, 2003). These were used to characterise the hypothetical behaviours for a person most exposed to the liquid discharges. It has been assumed that commercial fishing can take place in the vicinity of the UK ABWR, therefore the most exposed people to liquid discharges are assumed to be a fisherman and his family (including children and infants). The exposure group has been assumed to spend time on beaches and intertidal areas, and consume locally caught fish and shellfish (crustaceans and molluscs) at high intake rates (based on values in Environment Agency's IRA methodology (Environment Agency, 2006).

This group is also a candidate for the 'representative person' for exposure to all discharges from the UK ABWR, if they are also assumed to live close to the site and ingest other locally produced foods (at average rates (Smith and Jones, 2003)). These provide a pathway for exposure from atmospheric discharges, as well as direct radiation from the reactor buildings. The assessment of representative persons is presented in Appendix G.

The principles (Environment Agency et al., 2012) require that the exposure of non-nuclear workers is also assessed. In this case, the adult fisherman can reasonably be assumed to be the person most exposed to the liquid discharges, as there are no obvious circumstances in which a non-nuclear worker could be exposed to the effluent prior to its discharge.

The exposure characteristics used in the dose assessment of the people most exposed to liquid discharges are summarised in Table F.2.

Table F.2: Exposure characteristics for the fisherman and family - most exposed to the liquid discharges

Parameter	Adult	Child	Infant
Crustacean consumption (kg/y)*	20	5	0
Fish consumption (kg/y)*	100	20	5
Mollusc consumption (kg/y)*	20	5	0
Beach occupancy (h/y)	2000	300	30
Handling fishing gear (h/y)	300	0	0

Note: * 50% of fish was assumed to be obtained from the local compartment and 50% from the larger regional compartment. All crustaceans and molluscs were assumed to come from the local compartment.

F.4 Modelling Approach

The PC-CREAM 08 code (version 1.5.1.85, database version 2.0.0) has been used to undertake the independent dose assessment. It includes a representation of the marine model for Europe, developed by the EC (Smith and Simmonds, 2009) and widely used for radioactive discharge modelling. The marine modelling component of PC-CREAM 08, DORIS, can represent different 'local' marine compartment properties into which initial discharges from a nuclear site occur. The properties given in Table F.1 have been used for this assessment, and the annual discharge limits proposed by Hitachi-GE (Hitachi-GE, 2016) have been assumed. The most recent IAEA compilation of marine sorption coefficients and concentration factors (Table F.3, from IAEA TRS 422 (IAEA, 2004)) was used in place of the default values in PC-CREAM 08. All other parameter values used PC-CREAM 08 default data (Smith and Simmonds, 2009).

Activity concentrations in environmental media (seawater and sediment) were calculated assuming discharges lasted for 60 years at the annual rate specified by Hitachi-GE (Hitachi-GE, 2016). The highest concentrations were in the local coastal waters and sediment, and it was conservatively assumed that this area was fished by the candidate representative person. The calculated environmental concentrations for the local compartment at the selected site, Oldbury, are presented in Table F.4.

Table F.3: Sorption coefficients (m^3/kg) and concentration factors (kg/kg) used in the independent dose assessment

Element	Ocean (m^3/kg)	Coast (m^3/kg)	Fish (kg/kg)	Crustacean (kg/kg)	Mollusc (kg/kg)	Seaweed (kg/kg)
Ac	2E+06	2E+06	5E+01	1E+03	1E+03	1E+03
Ag	2E+04	1E+04	1E+04	2E+05	6E+04	5E+03
Am	2E+06	2E+06	1E+02	4E+02	1E+03	8E+03
Ba	9E+03	2E+03	1E+01	7E-01	1E+01	7E+01
Ce	7E+07	3E+06	5E+01	1E+03	2E+03	5E+03
Cm	2E+06	2E+06	1E+02	4E+02	1E+03	5E+03
Co	5E+07	3E+05	7E+02	7E+03	2E+04	6E+03
Cr	4E+05	5E+04	2E+02	1E+02	2E+03	6E+03
Cs	2E+03	4E+03	1E+02	5E+01	6E+01	5E+01
Fe	2E+08	3E+08	3E+04	5E+05	5E+05	2E+04
H	1E+00	1E+00	1E+00	1E+00	1E+00	1E+00
I	2E+02	7E+01	9E+00	3E+00	1E+01	1E+04
La	1E+08	2E+06	1E+02	1E+03	1E+03	5E+03
Mn	2E+08	2E+06	1E+03	5E+03	5E+04	6E+03
Nb	3E+05	8E+05	3E+01	2E+02	1E+03	3E+03
Ni	3E+05	2E+04	1E+03	1E+03	2E+03	2E+03
Np	1E+03	1E+03	1E+00	1E+02	4E+02	5E+01
Pb	1E+07	1E+05	2E+02	9E+04	5E+04	1E+03
Po	2E+07	2E+07	2E+03	2E+04	2E+04	1E+03
Pr	1E+06	1E+06	5E+01	1E+01	5E+02	1E+02
Pu	8E+06	1E+05	1E+02	2E+02	3E+03	4E+03
Ra	4E+03	2E+03	1E+02	1E+02	1E+02	1E+02
Ru	1E+03	4E+04	2E+00	1E+02	5E+02	2E+03
Sb	4E+03	2E+03	6E+02	3E+02	3E+02	2E+01
Sr	2E+02	8E+00	3E+00	5E+00	1E+01	1E+01
Te	1E+03	1E+03	1E+03	1E+03	1E+03	1E+04
Th	5E+06	3E+06	6E+02	1E+03	1E+03	2E+02
U	5E+02	1E+03	1E+00	1E+01	3E+01	1E+02
Zn	2E+05	7E+04	1E+03	3E+05	8E+04	2E+03
Zr	7E+06	2E+06	2E+01	2E+02	5E+03	3E+03

Note: All data are from IAEA TRS 422 (IAEA, 2004).

Table F.4: Environmental concentrations of key radionuclides in the marine environment calculated in the independent dose assessment

Highest concentrations in water		Highest concentrations in sediment	
Radionuclide (aqueous discharge)	Concentration (Bq/l	Radionuclide (aqueous discharge)	Concentration (Bq/l
H-3 (7.60E+11 Bq/y)	1.9E-01	H-3 (7.60E+11 Bq/y)	3.3E-01
Fe-55 (9.40E+6 Bq/y)	2.2E-06	Fe-55 (9.40E+6 Bq/y)	1.8E-03
Ni-63 (8.60E+5 Bq/y)	2.1E-07	Ni-63 (8.60E+5 Bq/y)	7.2E-04
Co-60 (8.20E+5 Bq/y)	1.9E-07	Co-60 (8.20E+5 Bq/y)	2.7E-04
Mn-54 (4.00E+5 Bq/y)	8.9E-08	Mn-54 (4.00E+5 Bq/y)	2.7E-05
Ce-144 (2.40E+5 Bq/y)	5.4E-08	Ce-144 (2.40E+5 Bq/y)	1.5E-05
Nb-95 (1.80E+5 Bq/y)	3.1E-08	Zn-65 (1.10E+5 Bq/y)	5.4E-06
Zn-65 (1.10E+5 Bq/y)	2.4E-08	Sb-125 (8.20E+4 Bq/y)	5.1E-06
Sb-125 (8.20E+4 Bq/y)	2.0E-08	Te-125m (Sb-125)*	5.0E-06
Co-58 (8.20E+4 Bq/y)	1.6E-08	Cs-137 (6.60E+3 Bq/y)	2.5E-06

Note: Only the ten most significant radionuclides for each medium are shown. *Ingrown from antimony-125.

F.5 Radiation doses to individuals

Effective doses to infants, children and adults have been calculated with the ASSESSOR module in PC-CREAM 08. This combines the assumed behaviour of people (Table F.2) and the calculated environmental concentrations (Table F.4). A summary of the calculated doses is shown in Table F.5. Calculated doses at this level (far below 20 μSv/y) are of no concern in relation to regulation (Environment Agency et al., 2012).

A breakdown of the doses to the adult in the fishing family is shown in Table F.6. This illustrates that the dominant exposure pathway for the aqueous discharges is the consumption of seafood, with the most important radionuclide being tritium followed by cobalt-60.

Table F.5: Doses (μSv/y) to the fishing family from liquid discharges

Age	Seafood	Beach	Fishing Gear	Total
Adult	3.7E-04	1.3E-04	1.3E-06	4.9E-04
Child	1.1E-04	1.9E-05	0.0E+00	1.3E-04
Infant	2.4E-05	1.9E-06	0.0E+00	2.5E-05

Table F.6: Contribution of radionuclides and pathways to the doses to the adult fisherman (in µSv/y) from liquid radioactive discharges

Radio-nuclide	Crusta-ceans	Fish	Mollu-scs	Ext. beach	Ext. gear	Sea Spray	Total	%
Ce-144	9.2E-09	1.2E-09	1.9E-08	2.4E-07	1.2E-08	2.1E-11	2.8E-07	0.06%
Co-58	2.8E-08	7.0E-09	7.9E-08	2.0E-07	2.1E-09	2.9E-13	3.1E-07	0.06%
Co-60	1.5E-06	3.8E-07	4.3E-06	1.2E-04	1.2E-06	2.1E-11	1.3E-04	25.65%
Cs-134	1.4E-08	7.2E-08	1.7E-08	1.1E-07	1.3E-09	9.9E-14	2.2E-07	0.04%
Cs-137	1.2E-08	5.9E-08	1.4E-08	2.7E-07	3.7E-09	8.3E-14	3.6E-07	0.07%
Fe-55	1.2E-07	1.8E-08	1.2E-07	5.5E-07	5.5E-09	9.1E-12	8.1E-07	0.16%
H-3	6.8E-05	1.7E-04	6.8E-05	0.0E+00	0.0E+00	5.7E-08	3.1E-04	62.43%
I-131	7.6E-09	5.7E-08	2.5E-08	1.2E-10	1.8E-12	4.8E-13	9.0E-08	0.02%
Mn-54	3.2E-09	8.0E-10	3.2E-09	4.0E-06	4.0E-08	1.5E-12	4.0E-06	0.82%
Nb-95	4.5E-10	1.7E-10	2.3E-09	1.5E-07	1.6E-09	5.2E-13	1.6E-07	0.03%
Ni-63	1.3E-07	3.2E-07	2.6E-07	0.0E+00	0.0E+00	1.1E-12	7.1E-07	0.14%
Ru-106	6.7E-09	3.4E-10	3.4E-08	5.8E-08	1.6E-09	1.9E-11	1.0E-07	0.02%
Sb-124	1.2E-07	5.8E-07	1.2E-07	6.4E-08	6.8E-10	7.6E-13	8.7E-07	0.18%
Sb-125	9.4E-08	4.7E-07	9.4E-08	3.9E-07	4.8E-09	1.1E-12	1.1E-06	0.21%
Te-125m^	5.2E-08	1.3E-07	5.2E-08	3.2E-08	1.3E-09	1.4E-13	2.7E-07	0.05%
Zn-65	3.8E-05	3.2E-07	1.0E-05	5.7E-07	5.7E-09	4.3E-13	4.9E-05	9.96%
Zr-95	1.5E-10	3.8E-11	3.8E-09	1.4E-07	1.6E-09	8.5E-13	1.4E-07	0.03%
Nb-95*	5.8E-11	2.2E-11	2.9E-10	1.6E-07	1.7E-09	6.7E-14	1.6E-07	0.03%

Note: Only radionuclides contributing 0.01% or more to the total dose are shown. ^Tellurium-125m ingrown from anitmony-125. *Niobium-95 ingrown from zirconium-95.

F.6 Exploring sensitivity to model assumptions

The radiation doses calculated for marine discharges are dependent on a number of factors in the model. The most important site-specific aspects are the assumed volume of seawater into which the effluents are discharged and the rate at which this water disperses into the wider marine environment due to currents and tides. It is for this reason that the recommended adjustment in Stage 2 of the independent dose assessment is to scale the doses according to the latter parameter (the local marine dispersion rate in m^3/y). The marine dispersion rate can also be expressed as the 'residence time', which is the volume divided by the dispersion rate. This gives a measure of the average time that a given contaminant remains in the compartment before being dispersed.

The sensitivity to these factors has been examined in order to gauge their significance and illustrate the conservatism in the independent dose assessment. Calculations were undertaken with PC-CREAM 08 using the assumptions for the generic site, but:

- with modifications to the volume of the local compartment, from a value slightly lower than that assumed for the independent dose assessment, to the largest volume assigned to a nuclear site in England and Wales and a fixed residence time of 18.3 days (that of the Oldbury local compartment)

- with modifications to the residence time the local compartment, from the lowest for a nuclear site in England and Wales to the highest, for a fixed volume of 2 10^8 m^3 (that of the Oldbury local compartment)

The variation of seawater concentrations of key radionuclides with compartment volume is shown in Figure F.1 for nominal discharge rates (which scale with the proposed discharge limits). The concentration of radionuclides in seawater is directly proportional to the dose from foodstuffs, which is the dominant exposure pathway for the fisherman. Figure F.1 shows that the concentration is highly sensitive to the volume assumed, and that the assumptions for the independent dose assessment are suitably conservative. Similar results are found when the residence time is varied, as shown in Figure F.2, which also demonstrates that the conditions assumed in the independent assessment are conservative.

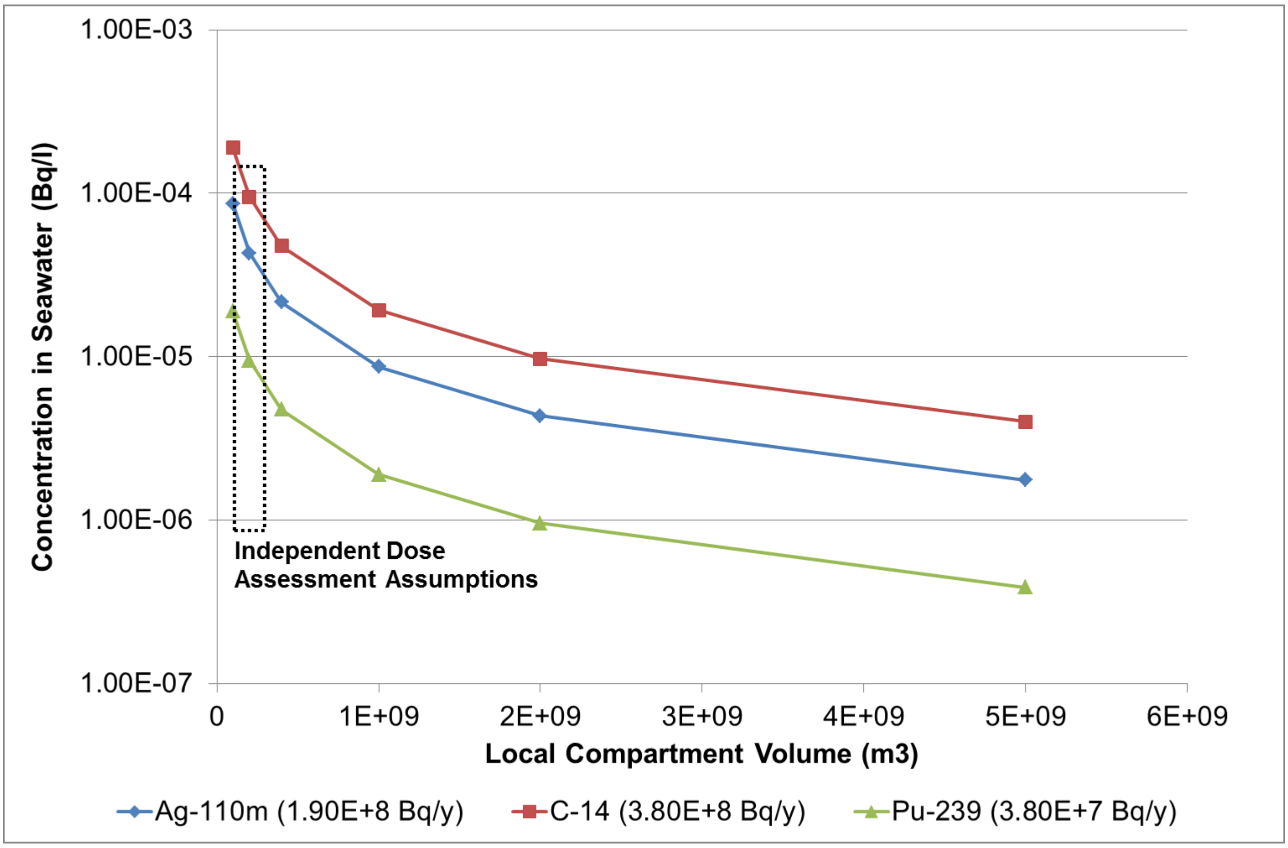

Figure F.1: Variation in seawater concentration with local compartment volume for a fixed residence time of 18.3 days (that of the Oldbury local compartment)

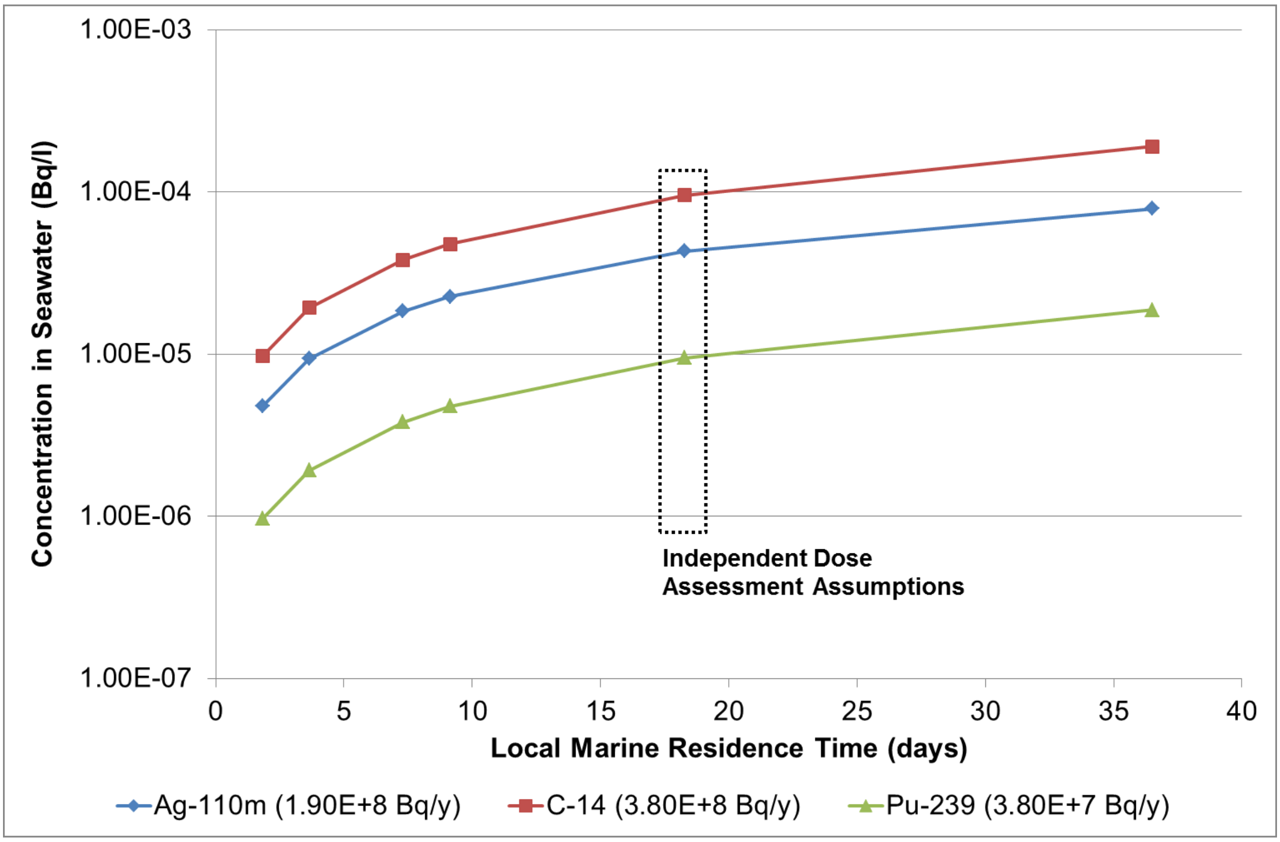

Figure F.2: Variation in seawater concentration with residence time (compartment volume divided by its volumetric exchange rate) of contaminants for a local compartment of volume 2×10^8 m^3 (that of the Oldbury local compartment)

F.7 References

Reference	Details
Environment Agency, 2006	Initial radiological assessment methodology – part 2 methods and input data, Science Report: SC030162/SR2, May 2006.
Environment Agency et al., 2012	Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment. Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), August 2012
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F
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Smith and Jones, 2003	Smith KR and Jones AL (2003). Generalised Habit Data for Radiological Assessments, National Radiological Protection Board Report NRPB-W41, May 2003.

Appendix G: Radiation exposure of representative persons and assessment of total doses

G.1 Introduction

The Stage 1 and 2 dose assessment for the radioactive discharges from a UK ABWR nuclear power station (Appendix D) gave results that exceeded the 20 µSv/y dose criterion for atmospheric discharges. This means that our dose assessment approach requires a detailed (Stage 3) assessment to be undertaken. The detailed assessment considers not just the most exposed members of the public for atmospheric and liquid discharges (Appendix E and F) but also doses to 'representative persons', in order to satisfy the principles (Environment Agency et al., 2012) and the requirements for GDA (Environment Agency, 2013).

The representative person is an individual receiving a dose that is representative of the more highly exposed individuals in the population (Environment Agency et al., 2012). It differs from the 'most exposed persons' assessed in Appendix E and F in that the representative person is exposed to all sources of radioactivity emanating from the nuclear facility (atmospheric discharges, liquid discharges and direct radiation).

The doses to representative persons have been calculated using the models and data for atmospheric and liquid discharges (Appendix C, E and F) but with different assumptions about the behaviours of the exposed groups, consistent with the definition of representative persons. This appendix presents the assumptions and the resulting doses.

G.2 Definition of representative persons

For prospective dose assessments, it is not possible to assess doses to existing individual members of the public. For this reason, doses are assessed to a ‘representative person‘ who has behaviours that lead them to be amongst the most highly exposed individuals in the population from a nuclear facility. The dose to the representative person can be compared with the key criteria (the source-related dose constraints, site constraints and dose limits) in the process of determining discharge permits or authorisations (Environment Agency et al., 2012).

For the purposes of assessing doses to representative persons, the site assumptions described in Appendix C have been used. The dose assessment models, and the resulting environmental concentrations, are as described in Appendix E and F. Only the human exposure characteristics are changed for the atmospheric and liquid exposure pathways. In addition, an estimate of the annual dose from direct radiation also needs to be taken into account. However, the assessment of direct radiation exposures is not within our remit, so we have used values calculated by Hitachi-GE (Hitachi-GE, 2016) for this component of the assessment. Direct radiation dose rates are discussed in Appendix K.

In order to determine the representative person, two candidate groups have been considered - one with greater exposure to atmospheric discharges and one with greater exposure to liquid discharges:

- The local farming family
- The local fishing family

G.2.1 Local farming family

The local farming family is assumed to live at the boundary of the site, assumed to be 300 m from the discharge stack, farm the surrounding land and eat local produce (which is assumed to be grown at 500 m distance from the stack). They are also assumed to visit the beach and ingest locally sourced seafood. This representative person is therefore a variant of the local resident used in the assessment of the most exposed person for atmospheric discharges, with additional pathways to account for liquid discharges and direct irradiation. The exposure characteristics for the local farming family are presented in Table G.1. For direct radiation, we have used values from Hitachi-GE (Hitachi-GE, 2016). External dose rates are presented in Appendix K.

Table G.1: Exposure characteristics for a candidate representative person based on the local farming family

Parameter	Source^	Adult	Child	Infant
Terrestrial pathways				
Indoors, home (300m from site) (h/y)	Atmospheric	4380	7008	7884
Outdoors, home (300m from site) (h/y)	Atmospheric	4080	1452	846
Cow liver consumption (kg/y)	Atmospheric	2.75	1.5	0.5
Cow meat consumption (kg/y)	Atmospheric	15	15	3
Cow milk consumption (kg/y)	Atmospheric	95	240	320
Cow milk products consumption (kg/y)	Atmospheric	60	45	45
Fruit consumption (kg/y)	Atmospheric	20	15	9
Green veg consumption (kg/y)	Atmospheric	35	15	5
Root veg consumption (kg/y)	Atmospheric	130	50	15
Sheep liver consumption (kg/y)	Atmospheric	2.75	1.5	0.5
Sheep meat consumption (kg/y)	Atmospheric	8	4	0.8
Marine pathways				
Crustacean consumption (kg/y)*	Liquid	1.75	1.25	0
Fish consumption (kg/y)*	Liquid	15	6	3.5
Mollusc consumption (kg/y)*	Liquid	1.75	1.25	0
Beach occupancy (h/y)*	Liquid	300	300	30

Note: Food production is assumed to be at 500 m from the stack. The indoors occupancy at home is taken to be 50% of the year for adults, 80% for children and 90% for infants, based on Environment Agency's IRA methodology (Environment Agency, 2006). The time spent outdoors is the remainder minus the time spent at the beach. ^Liquid discharges, atmospheric discharges or direct radiation. * 50% of fish was assumed to be obtained from the local compartment and 50% from the larger regional compartment. All crustaceans and molluscs were assumed to come from the local compartment.

G.2.2 Local fishing family

The local fishing family is a variant of the group used in the assessment of the most exposed person for liquid discharges. Additional pathways have been included to account for potential exposures to atmospheric discharges and direct irradiation. The family is assumed to live at the site boundary and obtain food from surrounding farmland, in addition to spending time on the beach and fishing. The exposure characteristics for the local farming family are presented in Table G.2.

Table G.2: Exposure characteristics for the fisherman and family - candidate representative person

Parameter	Source^	Adult	Child	Infant
Marine pathways				
Crustacean consumption (kg/y)*	Liquid	20	5	0
Fish consumption (kg/y)*	Liquid	100	20	5
Mollusc consumption (kg/y)*	Liquid	20	5	0
Beach occupancy (h/y)	Liquid	2000	300	30
Handling fishing gear (h/y)	Liquid	2000	300	30
Terrestrial pathways				
Indoors, home (300m from site) (h/y)	Atmospheric	4380	7008	7884
Outdoors, home (300m from site) (h/y)	Atmospheric	2380	1452	846
Cow liver consumption (kg/y)	Atmospheric	2.75	1.5	0.5
Cow meat consumption (kg/y)	Atmospheric	15	15	3
Cow milk consumption (kg/y)	Atmospheric	95	110	130
Cow milk products consumption (kg/y)	Atmospheric	20	15	15
Fruit consumption (kg/y)	Atmospheric	20	15	9
Green veg consumption (kg/y)	Atmospheric	35	15	5
Root veg consumption (kg/y)	Atmospheric	60	50	15
Sheep liver consumption (kg/y)	Atmospheric	2.75	1.5	0.5
Sheep meat consumption (kg/y)	Atmospheric	8	4	0.8

Note: The indoors occupancy at home is taken to be 50% of the year for adults, 80% for children and 90% for infants, based on the Environment Agency's IRAT methodology (Environment Agency, 2006). The time spent outdoors is the remainder minus the time spent at the beach. ^Liquid discharges, atmospheric discharges or direct radiation. * 50% of fish was assumed to be obtained from the local compartment and 50% from the larger regional compartment. All crustaceans and molluscs were assumed to come from the local compartment.

G.3 Radiation doses to representative person

Effective doses to infants, children and adults from the two groups of candidate representative persons have been calculated with the ASSESSOR module in PC-CREAM 08. A summary of the doses is shown in Table G.3 (the farming family) and Table G.4 (the fishing family). In both cases, the dominant exposure pathway is from atmospheric discharges. The infant is the most exposed, owing to the intake of cow's milk and milk products (46% and 37% of the dose, respectively). The dominant radionuclide is C-14 (91% of the dose). The calculated dose to the infant is shown in more detail in Table G.5.

Table G.3: Doses (μSv/y) to the local farming family candidate representative persons

	Atmos. discharges	Liquid discharges	Direct radiation*	Total
Adult	13	6.3E-05	0.98	14
Child	14	5.0E-05	0.54	15
Infant	24	1.9E-06	0.32	24

Note: * Direct radiation doses are based on Hitachi-GE (Hitachi-GE, 2016) results. This is considered further in Appendix K.

Table G.4: Doses (μSv/y) to the local fishing family candidate representative persons

	Atmos. discharges	Liquid discharges	Direct radiation*	Total
Adult	7.5	4.9E-04	0.9	8.4
Child	8.8	1.3E-04	0.5	9.3
Infant	12	2.5E-05	0.3	12

Note: * Direct radiation doses are based on Hitachi-GE (Hitachi-GE, 2016) results. This is considered further in Appendix K.

Table G.5: Doses (μSv/y) from atmospheric and liquid discharges to the representative person (infant in the farming family)

Note: *Only radionuclides contributing more than 0.001% shown

Radio-nuclide	Inh. home	Ext. home	Inh. beach	Ext. beach	Meat	Milk	Veg.	Sea-food	Total	Total %
Ar-41	0E+00	1E-01	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	1E-01	0.49
C-14	1E+00	9E-06	0E+00	0E+00	4E-01	2E+01	2E+00	0E+00	2E+01	91
H-3	9E-02	0E+00	4E-10	0E+00	9E-03	8E-01	6E-02	2E-05	9E-01	3.9
I-131	3E-03	5E-04	1E-14	2E-12	2E-03	1E+00	1E-02	2E-08	1E+00	4.7
I-133	2E-04	3E-05	0E+00	0E+00	2E-06	3E-03	5E-05	0E+00	3E-03	0.013
Total	2E+00	1E-01	4E-10	2E-06	5E-01	2E+01	2E+00	2E-05	2E+01	

G.3 Comparison with dose criteria

During the planning for the development of a new nuclear facility such as the UK ABWR, the Environment Agency compares assessed doses with radiation protection criteria to determine what controls may be required over the discharges (Environment Agency et al., 2012). The criteria that apply to existing nuclear sites are:

- the source-related dose constraint of 300 μSv/y (which applies to a single source such as a single UK ABWR unit)
- the site-related dose constraint of 500 μSv/y (i.e. the total dose from multiple sources on the site)

Application of these constraints ensures that no individual person should receive a radiation dose from man-made sources of radioactivity that exceeds the public dose limit of 1 mSv/y (1,000 μSv/y).

The total dose to the representative person (Table G.3 for the farming family and Table G.4 for the fishing family) can be compared with these criteria. The highest dose (25 μSv/y) is well below the source-related criterion. This level of dose means a site could operate more than one UK ABWR and remain within the site-related constraint (to a first approximation, the total dose to an individual can be assumed to scale directly with the number of reactors.) Furthermore, doses from existing nuclear sites, including historic discharges, do not exceed about 300 μSv/y to the most exposed person (the most exposed person being exposed to discharges from Sellafield and LLWR in 2012 (Environment Agency et al., 2014)). This indicates that there are no circumstances in which the public dose limit would be exceeded.

G.4 References

Reference	Details
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Environment Agency, 2013	Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs, Version 2, March 2013.
Environment Agency et al., 2012	Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment. Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), August 2012.
Environment Agency et al., 2014	Radioactivity in Food and the Environment, 2013, RIFE – 19, December 2014.
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F.

Appendix H: Individual doses from short-term discharges

H.1 Introduction

The assessment of the impact of expected ongoing continuous discharges of gases and liquids from a UK ABWR are considered in Appendix E and F. The outcomes show that the releases of liquids containing radioactivity are low because of the abatement and liquid recycling systems. Calculated doses from the liquid releases are small, well below 1 µSv/y. Gaseous discharges have greater doses of up to about 20 µSv/y.

This appendix considers the effect of short duration increases in discharges of radioactivity from the reactor. It considers discharges of radioactivity to air only because the impact of routine releases to air is much greater than for releases of liquids.

Some variation in the total radioactive discharges from an operating ABWR may be expected over the 18 month fuel cycle. Variation in the discharges can be triggered due to sporadic, but expected, events during the plant operation. One such event is fuel cladding failure allowing release of radioactive fission products into the cooling water and steam. This could result in an enhanced release of fission products to air over a period of a few hours to days. Given that short duration increases could occur at a time where atmospheric conditions lead to enhanced ground level air concentrations or other conditions – such as peaks in the growing season, it is therefore important to evaluate the potential doses that might result from such a short-term discharge. The need to assess such situations is recognised by NDAWG, who provide guidance on the treatment of such situations (NDAWG, 2011).

This appendix presents an independent assessment of the dose from a short-term discharge to air from a UK ABWR.

H.2 Meteorological conditions

Calculations of mean air concentrations from a short duration release are not straightforward to undertake within the GDA. This is because meteorological conditions are both site and time dependent, whereas the GDA by its nature is not site-specific. Atmospheric stability can also vary between day and night, particularly in clear sky conditions due to the effect of the energy input by the sun.

This assessment was made by considering a reasonable range of weather patterns for the UK. This means assuming:

- low pressure weather systems - cloudy overcast and breezy conditions
- high pressure systems - less cloud, more sun and lighter winds

The time of day / year is also an important consideration, especially in the high pressure case, because it affects the rate of ground heating (and thus, thermal mixing of the atmosphere).

Also, a given weather pattern may not remain constant throughout the period of a short-term release. In particular, wind speed and wind direction can vary. Local effects such as land and sea breezes could be an important additional effect for some sites

H.3 Atmospheric dispersion models

Gaussian plume models have been widely used to predict the atmospheric concentrations that result from the dispersion of emissions. Hitachi-GE used the Gaussian plume R91 model described by the National Radiological Protection Board (Clarke, 1979) and also the more recent ADMS system (CERC, 2012) when calculating the impact of releases to atmosphere. Both are well proven and well-tested models. For reasons of consistency with the dose assessment undertaken by Hitachi-GE (Hitachi-GE, 2016), ADMS has been used. Calculations based on the older R91 model have also been included below, for comparison purposes.

H.4 Dispersion model parameters

The averaging times used in Gaussian plume models are important in calculating air concentrations. This is because fluctuations in wind direction lead to plume meandering and, consequently, an overall broadening of the plume (with enhanced dispersion and thus lower ground-level air concentrations) as the averaging time increases. ADMS calculates hourly mean concentrations and there are input parameters that can be included to allow for plume meander. R91 provides 30-minute average concentrations and utilises a modifying factor to take into consideration plume meander and allow the calculation of average concentrations over longer periods.

Atmospheric stability is represented in the description of the boundary layer. ADMS uses specific input parameters, including cloud cover, wind speed and the time of day and year to calculate aspects such as the ground heating and thermal effects that determine the atmospheric conditions. R91 uses the Pasquill stability category (which ranges from A, highly unstable, through D to G, highly stable). The corresponding meteorological conditions for various stability categories in R91 are given in Table H.1.

Table H.1: Assumption of Pasquill stability categories for use in R91

Notes: * Category D is recommended for overcast conditions irrespective of wind speed.

Surface wind speed (m/s)	Daytime insolation^			Night~	
	Strong	Intermediate	Weak	Thinly Over-cast or ≤ 4/8 Cloud	≤ 3/8 Cloud
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	D	D	D	D	D

^Strong insolation would be representative of clear skies in mid-summer and weak insolation would be representative of clear skies in mid-winter.

~Night relates the period from one hour before sunset to one hour after dawn.

Hitachi-GE (Hitachi-GE, 2016) assumed a short-term release occurred from a 57 m stack (with a 19 m effective release height to take account of the turbulent effect of nearby buildings - the turbine building) over a period of twenty four hours (to give a daily mean concentration). These same assumptions have been made in this assessment for reasons of consistency. As noted above, the averaging time in ADMS is 1 hour, so the derivation of a daily mean concentration is not straightforward. The approach used has been to adopt meteorological parameters representative of synoptic weather patterns (high and low pressure systems) for summer and winter, and to assume these persist throughout the day (with the exception of solar radiation). There is a wind meandering coefficient embedded into ADMS. However for averaging over 24 hours increased meandering can be expected which will result in lower air concentrations at a given point. In the ADMS modelling no account has been made of increased meandering for a longer averaging time of 24 hours. The approach of not allowing for additional meandering tends to over-predict ground level concentrations and is, thus, conservative. Hitachi-GE (Hitachi-GE, 2016) sought to consider meandering but its method of doing so was unclear, as discussed in Appendix A.

H.5 Short-term dispersion calculation cases

In order to ascertain the dispersion of the plume under a range of conditions calculations have been undertaken for the winter and summer solstices and for the autumn equinox. For each, conditions were taken to be either overcast (sky obscured by cloud and windy, a wind speed of 5 m/s) or clear (no cloud and slightly windy, a wind speed of 1 m/s). These scenarios are intended to represent low and high pressure conditions at different times of the year. In addition, a case including higher wind speeds (10 m/s) has been considered for overcast conditions for the autumn equinox and winter solstice. The daily mean air concentrations for a release lasting 24 hours have been calculated by averaging the hourly output data from ADMS and using the default hourly meandering coefficient embedded in the ADMS model. Atmospheric concentrations without a consideration of enhanced plume meander are summarised in Table H.2.

Table H.2: Daily mean air concentrations based on hourly calculations from ADMS

Distance	ADMS air concentration at ground level (Bq/m^3) for unit release rate of 1 Bq/s							
(m)	Winter solstice		Summer solstice		Autumn equinox		Windy (10 m/s)	
							Summer solstice	Autumn equinox
	Clear	Over-cast	Clear	Over-cast	Clear	Over-cast	Over-cast	Over-cast
100	4.87E-05	6.95E-05	6.84E-05	7.12E-05	6.68E-05	7.05E-05	3.74E-05	3.73E-05
300	1.41E-05	3.21E-05	8.27E-06	3.09E-05	8.52E-06	3.15E-05	1.53E-05	1.54E-05
500	1.12E-05	1.55E-05	5.99E-06	1.46E-05	7.50E-06	1.51E-05	7.09E-06	7.17E-06

Note: * The air concentrations will be conservative because no account has been taken of longer-term wind meandering.

The daily mean air concentrations shown in Table H.2 cover a range of about a factor of 2 at 100 m and 500 m from the release point to a factor of 4 at 300 m from the release point. At all 3 distances, overcast conditions lead to higher predicted air concentrations than clear conditions. Clear conditions in summer lead to the lowest air concentrations (due to thermal effects from warming caused by the sun). Windy conditions lead to lower air concentrations, due to the greater volume of air passing over the stack release point.

Atmospheric concentrations are not uniform in time and the peak occurs during a relatively short interval around midday. An example of this is illustrated for winter solstice in Figure H.1. The reason for the variation is that the stratified atmosphere during the night means the plume does not reach ground level at the receptor points; conversely, thermal effects enhance vertical mixing during the day, when the sun is at its highest. This variation in concentration with time of day has implications when assessing dose (in terms of occupancy factors). It also illustrates the sensitivity of the calculations to assumed modelling parameters, including both those used in predicting dispersion and dose.

Given the differences in occupancy factors and the variability of meteorological conditions throughout a period of 24 hours, the adoption of hourly mean concentrations, rather than daily ones, might lead to higher doses for certain exposure pathways (i.e. direct or inhalation). Exposure pathways related to deposited radionuclides are adequately represented by a daily mean concentration, assuming that there is a constant deposition velocity and constant rate of release of radionuclides. In either case, for the purposes of a generic assessment of short-term releases it is appropriate to assess a range of ground level concentrations (hourly and daily mean) to calculate dose. Estimates of the range of upper limits to the calculated air concentrations, derived from the range of meteorological conditions considered, have been derived using ADMS and given in Table H.3. The lower air concentrations extend down to zero or close to zero, and it would not be conservative to use these in the dose calculations.

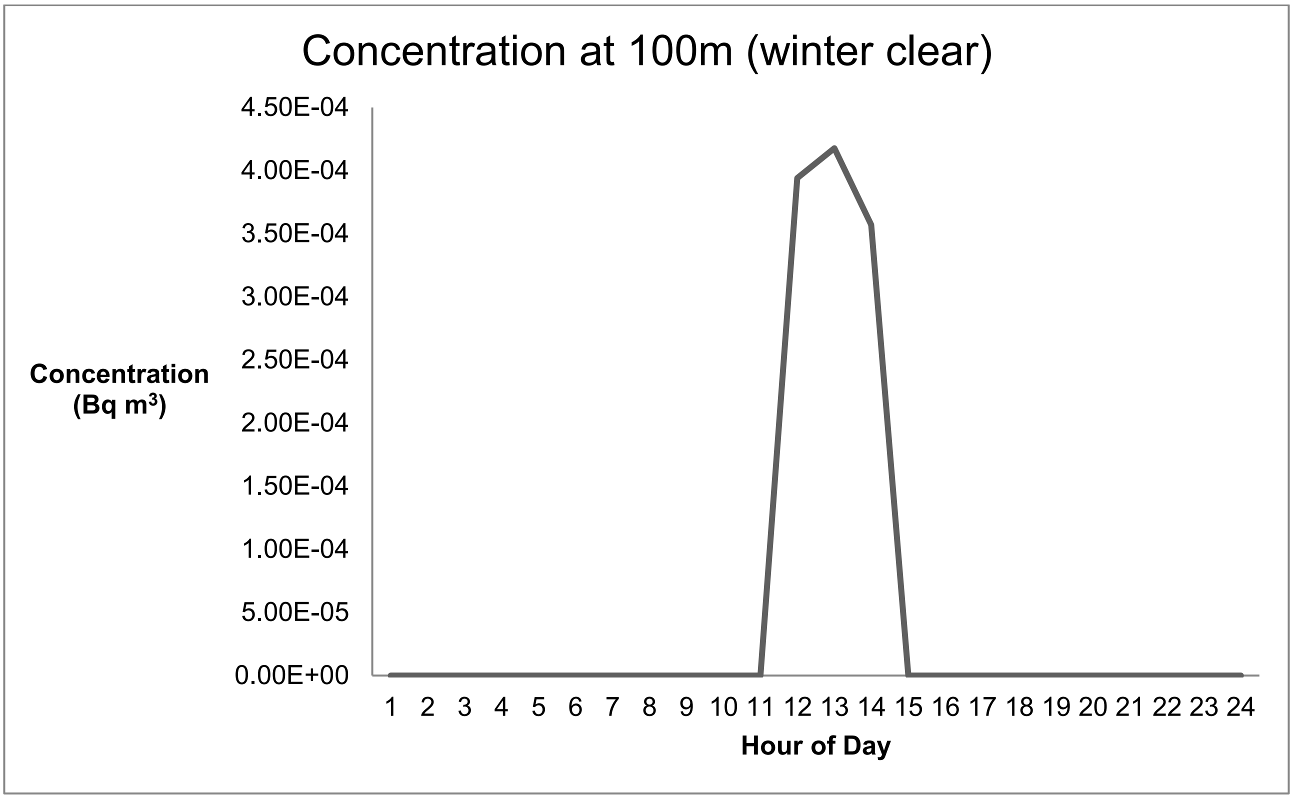

Figure H.1: Concentration at 100 m (unit release of 1 Bq /s) on a clear winter solstice

Table H.3: Hourly and daily mean concentrations from ADMS assuming a stack with an effective discharge height of 19 m

* Note: values are conservative because no account has been taken of plume meandering

Distance (m)	Air Concentration (Bq/m^3) for a unit release rate of 1 Bq/s*	
	1 hour Mean	24-hour Mean
300	1E-05 – 7E-05	5E-06 - 2E-05

H.6 Dose calculations

The representative short-term release rate stated by Hitachi-GE (Hitachi-GE, 2016) has been used in the calculation of radiation doses. The release comprises a range of noble gases only (see Table H.4, reproduced from Hitachi-GE (Hitachi-GE, 2016)) and occurs over a 24-hour period.

Table H.4: Amount of radioactivity assumed to be in the short-term release by Hitachi-GE

Radionuclide	Activity discharged in 24 hours (Bq)	Fraction of annual release
Kr-85	1.10E+09	0.85
Kr-85m	5.50E+09	0.55
Kr-87	5.00E+03	0.51
Kr-88	5.50E+08	0.59
Xe-131m	2.60E+09	0.9
Xe-133	1.80E+11	0.9
Xe-133m	1.40E+07	0.78

Air concentrations were calculated using the upper end of the range of atmospheric dispersion factors in Table H.3. In order to explore the significance of assuming either a daily mean or hourly mean concentration, 2 calculations have been undertaken:

- all age groups, exposed over the course of the day to the daily mean air concentration
- an adult, exposed for a short period (2 hours) to the peak hourly mean concentration

In assessing the dose, a key consideration is the assumed location of the potentially exposed members of the public and their habits. Tables H.2 and H.3 suggest the highest daily mean concentrations occur within around 100 m, for the scenarios addressed, although the nearest location that could be inhabited, due to the site boundary, is around 300 m (Hitachi-GE, 2016). There are an almost infinite number of other scenarios that can be considered, including different levels of plume buoyancy, suffice to note that there are also conditions where the maximum ground level concentration can occur far beyond 300 m.

Three main exposure pathways were considered for the continuous releases of radionuclides.

- Internal exposure from inhalation of radionuclides from the plume. Secondary inhalation of radionuclides resuspended after deposition on the ground was not considered to represent a significant contribution to dose on the basis of Smith et al. (Smith et al., 2004).
- External exposure to radionuclides in the plume and deposited onto the ground.
- Internal exposure from ingestion of local fruit and vegetable products, cow and sheep meat, offal, and cow's milk.

Of these, only exposure to radionuclides in the plume is relevant to the short-term release, as noble gases do not deposit. Consequently, food pathways and those associated with deposited radionuclides have not been assessed.

The most exposed members of the public were assumed to remain at 300 m from the discharge throughout the short-term release. This is reasonable given the likely site perimeter. The time spent outdoors is based on Smith and Jones (Smith and Jones, 2003) and assumed occupancy factors are presented in Table H.5.

Table H.5: Exposure group occupancies assumed in the assessment of short-term releases

Age group	Basis of air concentration	Fraction indoors	Fraction outdoors	Exposure duration
Adult (daily mean)	Daily mean	0.5	0.5	1 day
Child (daily mean)	Daily mean	0.8	0.2	1 day
Infant (daily mean)	Daily mean	0.9	0.1	1 day
Adult (2 hour peak)	Peak hourly mean	0	1	2 hours

Note: Data are based on Smith and Jones (Smith and Jones, 2003), with the child assumed to be 10 years old.

The effective dose (Sv) from external irradiation by each radionuclide in the plume of a short-term release has been calculated as follows:

$$E_{ExtP} = C_{Air}\, t_{Exp} \left(\left(O_{Out} + O_{In}\, f_{\gamma} \right) D_{Ext\,P\,\gamma} + D_{Ext\,P\,\beta} w_T \right)$$

Where

C_{Air} is the concentration of the radionuclide in the air (Bq /m^3), calculated by multiplying the discharge rate by the air concentration factor (see Table H.3)

t_{Exp} is the exposure duration (in hours), noting that there is no reduction for exposures indoors (NDAWG, 2011)

O_{Out} is the fraction of time spent outdoors (-), from Smith and Jones (Smith and Jones, 2003)

O_{In} is the fraction of time spent indoors (-), from Smith and Jones (Smith and Jones, 2003)

f_{γ} is the reduction factor for exposure indoors to take account of building shielding

$D_{Ext\,P\,\gamma}$ is the external dose factor for exposure to gamma emissions from the radionuclide in a cloud in Sv m^3 / Bq h (Eckerman and Ryman, 1993). Values for children and infants have been extrapolated by applying a scaling factor for gamma irradiation of 1.14 and 1.32, derived from UNSCEAR (UNSCEAR, 2000)

$D_{Ext\,P\,\beta}$ is the equivalent dose factor for skin exposure to beta emissions from the radionuclide in a cloud in Sv m^3 / Bq h (Smith and Simmonds, 2009; USDOE, 1988)

w_T is the tissue weighting factor for skin of 0.01 (ICRP, 2012)

Smith et al. (Smith et al., 2004) note that noble gas concentrations indoors will be similar to those outdoors, unlike the case for particulate where particulate can be filtered out from the air entering a building. The reduction factor f_{γ} therefore only represents the reduction in the dose rate from the cloud due to building shielding, not any reduction in the concentration in indoors air. Smith and Simmonds (Smith and Simmonds, 2009) recommend a general value of 0.2 for assessment purposes, and this is applied to the dose rate from gamma radiation. A reduction factor is not applied to beta emissions as these are shorter range in air, so the dose rate will be dominated by the indoors air concentration, from which there is no shielding.

H.7 Estimated doses

Potential radiation doses to a hypothetical exposure group, living 300 m from the point of an atmospheric release have been calculated using the equations and data presented in the preceding sections. The radiation dose from the plume is incurred during the one-day period in which the short-term release occurs. The dose from the short-term release should be summed to the annual dose from continuous releases (see Appendix E and G) to obtain a total dose incurred over the course of a year.

Table H.7 shows that the highest dose is for an adult. xenon-133 is the most dominant radionuclide contributing to dose, in this case accounting for 72%. The estimated doses from short-term releases have been calculated with a range of conservative assumptions, yet are well below the level at which further refinement in the assessment may be needed (20 μSv), assuming one event occurs per year.

Table H.7: Estimated doses in μSv from a short-term release

Radionuclide	Adult (daily mean)	Child (daily mean)	Infant (daily mean)	Adult (2 hour peak)
Kr-85	6.1E-06	5.1E-06	4.9E-06	2.4E-06
Kr-85m	4.7E-04	3.3E-04	2.9E-04	2.2E-04
Kr-87	2.5E-09	1.7E-09	1.6E-09	1.2E-09
Kr-88	6.4E-04	4.4E-04	4.0E-04	3.1E-04
Xe-131m	1.3E-05	9.6E-06	8.8E-06	5.9E-06
Xe-133	3.0E-03	2.1E-03	1.9E-03	1.4E-03
Xe-133m	2.4E-07	1.7E-07	1.6E-07	1.1E-07
Total	4.1E-03	2.8E-03	2.6E-03	2.0E-03

H.8 Uncertainties in dispersion modelling

As discussed in Sections H.3 and H.4, there are significant uncertainties in the calculated air concentrations. Hence significant variation in air concentrations (and doses) could be expected, depending on the atmospheric conditions and assumptions made for the atmospheric dispersion model. Furthermore, it has been assumed that the exposed groups lie directly within the plume at the time of the short-term release. Even at locations where there are substantially prevailing winds, the direction varies frequently. The nearest residents may not be exposed at all if they lie downwind during the release.

The air concentrations predicted by ADMS have been compared with those predicted by the R91 model (Clarke, 1979). The 30 minute average concentrations provided by R91 are given in Table H.9, according to various stability categories. The values illustrate that zero or low ground level concentrations can exist at night under clear skies (i.e. Stability Category F or G) at distances close to the point of release and that the highest concentrations would occur around the middle of the day if the conditions persist (i.e. Category A or B).

Table H.9: 30 minute mean air concentrations from R91 for a unit release rate

Distance (m)	Air concentration (Bq/m3) for a unit release rate of 1 Bq/s (Pasquill stability Category)						
	(A)	(B)	C	(D)	(E)	(F)	(G)
100	4.00E-04	2.30E-04	8.00E-05	3.00E-05	0.00E+00	0.00E+00	0.00E+00
300	7.00E-05	7.30E-05	4.50E-05	7.00E-05	8.00E-05	1.20E-05	0.00E+00
500	2.60E-05	3.40E-05	2.20E-05	4.00E-05	8.00E-05	5.00E-05	2.00E-06

R91 recommends the use of modifying factors to take into account plume meandering over times of more than 30 minutes. With the exception of Category D, modifying factors up to 12 hours are reported (on the basis that other stability categories would not persist for longer than 12 hours). The modifying factors for one hour are given in Table H.10, with the consequentially modified air concentrations from R91 summarised in Table H.11.

Table H.10: R91 modifying factors

Distance	1-hour modifying factors (12-hour modifying factors in brackets) Pasquill Stability Category						
(m)	A	B	C	D	E	F	G
100	0.90 (0.40)	0.78 (0.42)	0.93 (0.39)	0.86 (0.32)	0.78 (0.26)	0.74 (0.22)	0.72 (0.21)
200	0.89 (0.39)	0.77 (0.40)	0.92 (0.38)	0.86 (0.32)	0.78 (0.26)	0.74 (0.22)	0.72 (0.21)
500	0.89 (0.39)	0.76 (0.39)	0.92 (0.38)	0.87 (0.32)	0.78 (0.25)	0.74 (0.22)	0.72 (0.21)

Table H.11: One-hour mean R91 concentrations

Distance	R91 1-hour mean air concentration (Bq/m3) for a unit release rate of 1 Bq/s Pasquill Stability Category						
(m)	A	B	C	D	E	F	G
100	3.60E-04	1.82E-04	7.44E-05	2.58E-05	0	0	0
200	6.23E-05	5.62E-05	4.14E-05	6.02E-05	6.24E-05	8.88E-06	0
500	2.31E-05	2.58E-05	2.02E-06	3.48E-05	6.24E-05	3.70E-05	1.42E-06

The R91 modifying factors give some estimate of how hourly ADMS data could be adjusted for plume meander when calculating daily mean concentrations. The 24 hour R91 modifying factors for Category D conditions are about 25% at receptors between 100 m to 500 m. This would suggest daily mean concentrations would be around 30 % of the ADMS predicted hourly values.

A direct comparison of model output from R91 and ADMS is not straightforward because of the different input data required. ADMS does not use Pasquill stability categories to describe the boundary layer. Generally, the R91 model gives slightly higher air concentrations than calculated by ADMS (see Table H.12). However, ADMS predicts higher concentrations than R91 in overcast conditions for stability Category D. The R91 model shows a greater range in concentrations than ADMS. Furthermore, the difference between air concentrations assumed in the independent dose assessment (the maximum of the range of the ADMS scenarios) and those that would be adopted using Pasquill Category D (the most frequent weather conditions) relatively limited (a factor of 2-3). The ADMS values are conservative for the 100 m distance assumed in the independent dose assessment.

The dose to a person is directly related to the calculated air concentrations, so these results indicate an uncertainty of around a factor of 2 depending on the modelling approach, with the indication that the ADMS model is conservative for exposures at 300 m or less.

Table H.12: Comparison of the range of daily mean concentrations calculated with ADMS for various atmospheric conditions, with the 12 hour average values from R91 (Bq/m3 per Bq/s)

Distance (m)	ADMS (24 hour mean)	R91 (12 hour mean) – range of Pasquill Categories, A – G	R91 (12 hour mean) Category D
100	1E-05 - 2E-05	0 - 1E-4	8E-6
300	2E-06 - 1E-05	0 – 2E-5	2E-5
500	5E-06 - 2E-05	3E-7 – 2E-5	1E-5

Note: * The air concentrations will be conservative because no account has been taken of longer-term wind meandering.

H.9 References

Reference	Details
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Appendix I: Collective doses

I.1 Introduction

The total exposure from radioactive discharges by a population is referred to as the 'collective dose' and is assigned the unit of manSv per year of discharge. It is the sum of the doses to all individuals that are exposed over a specified time period. The time period can be more than a person's lifetime as many radionuclides are persistent in the environment.

This section presents the assessment of the collective dose from a UK ABWR resulting from both atmospheric and liquid discharges. The annual discharge limits proposed by Hitachi-GE (Hitachi-GE, 2016) have been used in the calculation.

I.2 Scope and approach

Although collective doses involve large populations, they are nevertheless dependent on the point of release. For the purposes of the assessment the generic site characteristics are the same as used in the assessment of individual doses from atmospheric and marine discharges (see Appendix C). The same atmospheric and marine dispersion parameters used for individual dose calculations (as described in Appendix E and F) were used.

PC-CREAM 08 includes models for the calculation of collective dose which have been used in the independent dose assessment. The collective dose for each pathway was calculated in the following way.

- For liquid discharges, the DORIS model calculates the dispersion of radionuclides in the marine environment globally. Each region of the world's oceans is represented in the model, as are the transfers between them, and the models and data are presented in Smith and Simmonds (Smith and Simmonds, 2009). The resulting marine water and sediment concentrations can be used to estimate the collective radiation dose resulting from the ingestion of seafood, and due to exposure on beaches, from each region.
- For atmospheric discharges, radiation exposures from the “first pass” of the dispersed plume are calculated with the same suite of models as used in the assessment of individual doses, albeit for much larger distances. In addition, the long-term global circulation of gaseous radionuclides that remain in the atmosphere needs to be accounted for. PC-CREAM 08 includes atmospheric global circulation models for tritium, carbon-14 and kryptonr-85 and iodine-131 (Smith and Simmonds, 2009) which have been used in the calculation.

Over time, radioactive discharges to air and water can spread far, indeed throughout the entire world. Collective doses therefore require the calculation of exposures to large populations. For the purposes of regulatory authorisation the populations of the UK, Europe and the World are required to be considered (Environment Agency et al., 2012). This guidance also recommends that the total dose be estimated, truncated for a period of 500 y (to account for the persistence of radionuclides in the environment even after discharges have ceased). These assumptions have been used in our assessment.

PC-CREAM 08 includes default datasets of population distribution and habits (Smith and Simmonds, 2009) which have been used in the calculations. It is noted that there are various definitions of European nations in the results provided by PC-CREAM 08, reflecting the gradual expansion of the union over the period in which PC-CREAM has been developed. In the results presented here the largest measure of the Europe population (EU-25) has been used.

I.3 Collective radiation doses

The calculated collective doses, for a 500 y period of time, are presented in Table I.1 for a range of populations. On all measures the dominant contributor to collective dose is the atmospheric discharges, with the key radionuclide being carbon-14 and the main exposure pathway being ingestion of grain (Table I.2). For the much less significant liquid discharges, the dominant radionuclide is zinc-65 (Table I.3).

Table I.1: Collective dose (manSv), truncated at 500 years, for one years of radioactive discharges from a UK ABWR

Discharges	Dose type	UK population	EU population+	World population
Atmospheric discharges	First pass	0.65	3.1	
	Global circulation	0.18	1.4	30
	Total (atmospheric)	0.83	4.5	30
Liquid discharges	First pass	8.1E-08	1.7E-07	2.0E-07
	Global circulation	1.5E-07	9.2E-07	2.6E-05
	Total (marine)	2.3E-07	1.1E-06	2.6E-05
Total		0.83	4.5	30

+EU-25

Table I.2: Collective dose (manSv), truncated at 500 years, for key radionuclides following one years of radioactive atmospheric discharges from a UK ABWR

Radionuclide	UK	EU-25	World*
Ar-41	4.8E-04	5.4E-04	-
C-14	8.1E-01	4.4E+00	3.0E+01
Co-60	3.5E-07	4.7E-07	-
H-3	1.8E-02	3.5E-02	3.3E-03
I-131	6.4E-04	3.5E-04	-
I-133	5.2E-07	5.4E-07	-
Kr-85	1.2E-08	3.7E-08	3.3E-07
Kr-85m	2.5E-07	2.7E-07	-
Kr-88	3.1E-07	3.2E-07	-
Sr-90	7.4E-08	4.1E-07	-
Xe-133	3.5E-06	6.1E-06	-
Zn-65	7.5E-08	2.6E-07	-

Note: Only the top 10 contributors to the collective dose for each population are included. *Global circulation models only consider tritium, carbon-14 and krypton-85.

Table I.3: Collective dose (manSv), truncated at 500 years, for key radionuclides following one year's radioactive liquid discharges from a UK ABWR

Radionuclide	UK	EU-25	World
Co-58	7.0E-11	1.2E-10	1.2E-10
Co-60	5.1E-09	8.4E-09	8.7E-09
Cs-134	2.1E-11	4.9E-11	5.7E-11
Cs-137	2.1E-11	5.3E-11	6.8E-11
Fe-55	1.5E-10	2.8E-10	3.3E-10
H-3	2.2E-07	1.1E-06	2.6E-05
Mn-54	2.1E-11	2.4E-11	2.5E-11
Ni-63	3.5E-10	8.6E-10	1.0E-09
Sb-124	9.4E-11	1.9E-10	2.1E-10
Sb-125	2.1E-10	5.3E-10	6.4E-10
Zn-65	1.2E-08	2.5E-08	2.8E-08

Note: Only the top 10 contributors to the collective dose for each population are included.

Using estimated population data from Smith and Simmonds (Smith and Simmonds, 2009), the average dose to each person in the exposed population can be calculated, for illustrative purposes. This is presented in Table I.4 and shows that it is around 0.014 μSv/y (14 nSv/y), for the UK, 0.01 μSv/y (10 nSv/y) for Europe and 0.003 μSv/y (3 nSv/y) for the world. Calculated average annual individual doses for a population group in the 10 nSv range or less can be ignored in the decision making process (Environment Agency et al., 2012).

Table I.4: Average doses per person (per caput) (μSv/y), truncated at 500 years, following 1 year of radioactive discharges from a UK ABWR

Population group	Population*	Per caput dose (μSv/y)		
		Atmospheric discharges	Liquid discharges	Total
UK	59,600,000	1.4E-02	3.9E-09	1.4E-02
EU+25	456,000,000	9.8E-03	2.4E-09	9.8E-03
World	10,000,000,000	3.0E-03	2.6E-09	3.0E-03

Note: *Population data are based on Smith and Simmonds (Smith and Simmonds, 2009).

I.4 References

Reference	Details
Environment Agency et al., 2012	Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment. Radioactive Substances Regulation under the Radioactive Substances

	Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), August 2012.
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F
Smith and Simmonds, 2009	Smith JG and Simmonds JR (2009). The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08, Health Protection Agency Report HPA-RPB-08, October 2009.

Appendix J: Radiation exposure of non-human species

J.1 Introduction

As well as people, wildlife (non-human species) are exposed to radioactive substances that have accumulated in the environment as a result of discharges from a nuclear power plant. The principles for prospective dose assessment (Environment Agency et al., 2012) require that the most exposed non-human species are assessed. For the independent dose assessment of the UK ABWR, it has been assumed that:

- marine biota are exposed to seawater and sediment contaminated by up to 60 years of continuous liquid discharges
- terrestrial biota are exposed to radioactive noble gases and to soil contaminated by up to 60 years of continuous atmospheric discharges

This appendix presents the dose calculations. The dose assessment uses the internationally accepted ERICA methodology (Version 1.2.1 (Beresford et al., 2007)) for most pathways and species. This was supplemented by the Environment Agency's approach (Copplestone et al., 2001) for the exposure of non-human species to noble gases, using the latest version of the tool (Vives i Batlle et al., 2015). As is discussed in Section J.2, and the sections referenced therein, the discharge data from Hitachi-GE (Hitachi-GE, 2016) has been used for this independent assessment

J.2 Model assumptions

J.2.1 Atmospheric discharges

The same characteristics have been assumed as used for the assessment of doses from atmospheric discharges to people. Continuous atmospheric discharges were assumed to occur for 60 years from a stack at an effective height of 19 m, at the proposed annual discharge limit (Table 1 in the main text). The generic site local meteorological characteristics were cautiously based on the Oldbury site as discussed in Appendix C, and are given in Appendix E. The PLUME model was used to calculate concentrations in soil and air, which are given in Appendix E. Doses to non-human biota have been assessed at a distance of 300 m from the stack. All species were assumed to be potentially present at this location.

Default assumptions were used in the ERICA models with the exception of the uncertainty factor for which a value of 5 was used.

For the assessment of noble gases, the atmospheric concentrations were calculated in the same manner as other discharges (see Appendix E). The environmental concentrations of selected radionuclides is shown in Table E.4. The concentrations can be seen to be very low, so a cut-off of $1x10^{-10}$ Bq/kg was applied in the calculations. The subsequent dose assessment was made with the updated version of the Environment Agency's R&D128 tool (Vives i Batlle et al., 2015). This does not include data for all of the noble gases specified in the UK ABWR discharge estimate. Whilst some gases can be modelled directly (argon-41, krypton-85, krypton-88, xenon-131m and xenon-133), for others krypton-88 was used as a proxy (thus in addition to krypton-88 it was also used for krypton-85m, krypton-87, xenon-133m, xenon-135 and xenon-135m). This is the most conservative approach for estimating the potential radiological effects with the available models and data. The default values specified in the tool (Vives i Batlle et al., 2015) were used for all other aspects of the assessment.

J.2.2 Liquid discharges

The characteristics of the marine environment were the same as used in the independent assessment of doses to humans (Appendix F). The DORIS model used for that assessment provides site-specific concentrations of radionuclides in unfiltered seawater and seabed sediment following 60 years continuous discharge. The local marine characteristics that were assumed (conservatively based on the Oldbury site) and associated results are given in Appendix F. These values were used directly for the assessment of the exposure of non-human species. The peak concentrations of selected radionuclides is shown in Table F.4. The concentrations can be seen to be very low, so a cut-off of a marine concentration of $1x10^{-10}$ Bq/l was applied in the calculations. All species were assumed to be present in the local marine compartment where the concentrations are highest.

Default assumptions were used in the ERICA models with the exception of the marine sediment distribution coefficients for iron and the uncertainty factor applied. The distribution coefficient has been taken from an IAEA compilation (IAEA, 2004), an approach consistent with that adopted in the ERICA tool for the other distribution coefficient values. An uncertainty factor of 5 was used in the tool.

J.3 Non-human species considered in the assessment

J.3.1 Species in the terrestrial environment

In this assessment, all terrestrial biota included in the ERICA tool (Beresford et al., 2007) have been considered to be present in the vicinity of the UK ABWR. The biota have been assumed to spend 100% of their time in the contaminated terrestrial environment, with their time apportioned between 3 regions: on soil, in soil or in air (see Table J.1).

With respect to radionuclide uptake factors for these biota, the default ERICA data were used where possible. However, iron and rubidium are not included in the parameter database included in the ERICA tool. For these elements the maximum concentration ratio for all other elements was used, cautiously. Typically this was the concentration ratio for carbon.

Table J.1: Location of terrestrial biota used in the ERICA assessment

	Resident on soil	Resident in soil
Biota	Bird	Reptile
	Flying insects	Amphibian
	Grasses & herbs	Annelid
	Lichen & bryophytes	Arthropod - detritivore
	Mammal - large	Mammal - small-burrowing
	Mollusc - gastropod	
	Shrub	
	Tree	

For the assessment of exposure to radioactive noble gases, the biota were assumed to be permanently present in the vicinity of the UK ABWR. Their time was apportioned between three regions: on soil, in soil or in air using the default values in the updated version of the Environment Agency's assessment tool (Vives i Batlle et al., 2015) (Table J.2). Default values of the dose per unit concentration factors were used in the assessment.

Table J.2: Terrestrial biota occupancy factors in used in the assessment of exposure to radioactive noble gases

	In the soil	On soil surface	In air
Amphibian	0	1	0
Annelid	1	0	0
Arthropod - detritivore	0	1	0
Bird	0	1	0
Flying insects	0	1	0
Grasses & herbs	1	0	0.5
Lichen & bryophytes	0	1	0
Mammal - large	0	1	0
Mammal - small-burrowing	1	0	0
Mollusc - gastropod	0	1	0
Reptile	0	1	0
Shrub	1	0	0.5
Tree	1	0	0.5

J.3.2 Species in the marine environment

In our independent assessment, all the marine species specified in the ERICA tool have been assumed to be present in the vicinity of the UK ABWR at a generic site. These species may be in the seawater, at the seabed or in the seabed sediment (Table J3).

The majority of the uptake factors used in the independent assessment were the default concentration ratios included in the ERICA Version 1.2.1 database (Beresford et al., 2007). However, iron is not included in the parameter database. Where possible concentration ratio values for iron were taken from (IAEA, 2004), and where no value was available the maximum for all elements was used.

Table J.3: Location of marine biota in ERICA version 1.2

	Water	On seabed	In seabed sediment
Biota	Bird Mammal Pelagic fish Phytoplankton Reptile Zooplankton	Benthic fish Crustacean Macroalgae Mollusc - bivalve Sea anemones & coral Vascular plant	Polychaete worm

J.4 Radiation doses to non-human species

J.4.1 Atmospheric discharges

The calculated dose rates to terrestrial biota following exposure to non-noble gas discharges, and the corresponding risk quotients, are given in Table J.4. All of the total dose rates calculated lie below the screening value of 10 µGy/h. Carbon-14 is the dominant radionuclide for the terrestrial biota.

Table J.4: Calculated dose rates to terrestrial biota and corresponding risk quotients from atmospheric discharges

Terrestrial biota	Total dose rate (µGy/h)	Risk coefficient (expected)*	Risk coefficient (conservative)^
Amphibian	2.2E-01	2.2E-02	1.1E-01
Annelid	7.5E-02	7.5E-03	3.8E-02
Arthropod - detritivore	7.6E-02	7.6E-03	3.8E-02
Bird	2.3E-01	2.3E-02	1.2E-01
Flying insects	7.5E-02	7.5E-03	3.8E-02
Grasses & herbs	1.5E-01	1.5E-02	7.5E-02
Lichen & bryophytes	1.5E-01	1.5E-02	7.6E-02
Mammal - large	2.3E-01	2.3E-02	1.2E-01
Mammal - small-burrowing	2.3E-01	2.3E-02	1.2E-01
Mollusc - gastropod	7.6E-02	7.6E-03	3.8E-02
Reptile	2.3E-01	2.3E-02	1.2E-01
Shrub	1.5E-01	1.5E-02	7.5E-02
Tree	2.2E-01	2.2E-02	1.1E-01

Note: * Calculated using a screening value of 10 µGy/h. ^Calculated by applying an uncertainty factor of 5 to the expected risk coefficient.

The calculated dose rates for the exposure of terrestrial biota to noble gases discharged from a UK ABWR are given in Table J.5. These calculated doses are all extremely low and well below the screening value of 10 µGy/h.

J.4.2 Liquid discharges

The calculated total dose rates to marine biota from estimated liquid discharges from the UK ABWR are given in Table J.6. The corresponding risk quotients were calculated using the screening criterion of 10 µGy/h. All of the total dose rates calculated lie well below the screening value.

Table J5: Calculated dose rates to terrestrial biota resulting from the atmospheric discharge of noble gases (µGy/h)

Biota	Ar-41	Kr-85	Xe-131m	Xe-133	Other noble gases*	Total
Amphibian	1.1E-04	1.5E-10	8.8E-10	1.4E-07	5.2E-08	1.1E-04
Annelid	2.8E-08	9.2E-14	2.7E-13	3.8E-11	1.5E-11	2.8E-08

Biota	Ar-41	Kr-85	Xe-131m	Xe-133	Other noble gases*	Total
Arthropod - detritivore	1.3E-04	9.1E-10	1.5E-09	1.7E-07	6.9E-08	1.3E-04
Bird	1.0E-04	8.0E-11	6.2E-10	1.2E-07	4.0E-08	1.0E-04
Flying insects	3.0E-08	2.2E-13	3.6E-13	4.1E-11	1.7E-11	3.0E-08
Grasses & herbs	1.2E-04	5.4E-10	1.2E-09	1.6E-07	6.5E-08	1.2E-04
Lichen & bryophytes	2.4E-04	7.8E-10	2.2E-09	3.1E-07	1.2E-07	2.4E-04
Mammal - large	1.3E-04	1.6E-09	2.0E-09	1.9E-07	7.3E-08	1.3E-04
Mammal - small-burrowing	5.9E-05	2.7E-11	2.0E-10	3.7E-08	2.3E-08	5.9E-05
Mollusc - gastropod	2.6E-08	2.3E-14	1.7E-13	3.1E-11	1.1E-11	2.6E-08
Reptile	1.2E-04	3.3E-10	1.1E-09	1.6E-07	6.1E-08	1.2E-04
Shrub	1.1E-04	1.3E-10	8.3E-10	1.4E-07	4.8E-08	1.1E-04
Tree	1.5E-04	8.1E-11	6.5E-10	1.3E-07	5.8E-08	1.5E-04

Note: *Other radioactive noble gases were assessed using dose factors for Kr-88 as no radionuclide specific factors were available.

Table J.6: Calculated dose rates to marine biota and corresponding risk quotients from liquid discharges

Biota	Total dose rate (µGy/h)	Risk coefficient (expected)	Risk coefficient (conservative)
Benthic fish	2.5E-06	2.5E-07	1.3E-06
Bird	2.3E-06	2.3E-07	1.1E-06
Crustacean	1.2E-05	1.2E-06	5.9E-06
Macroalgae	2.2E-06	2.2E-07	1.1E-06
Mammal	3.9E-04	3.9E-05	2.0E-04
Mollusc - bivalve	1.1E-05	1.1E-06	5.6E-06
Pelagic fish	2.4E-06	2.4E-07	1.2E-06
Phytoplankton	8.5E-06	8.5E-07	4.3E-06
Polychaete worm	4.0E-06	4.0E-07	2.0E-06
Reptile	2.6E-06	2.6E-07	1.3E-06
Sea anemones & true coral	2.3E-06	2.3E-07	1.1E-06
Vascular plant	2.4E-06	2.4E-07	1.2E-06
Zooplankton	1.4E-05	1.4E-06	7.0E-06

Note: * Calculated using a screening value of 10 µGy/h. ^Calculated by applying an uncertainty factor of 5 to the expected risk coefficient.

J.5 References

Reference	Details
Beresford et al., 2007	Beresford N, Brown J, Copplestone D, Garnier-Laplace J, Howard B, Larsson C-M, Oughton D, Pröhl G and Zinger I (2007). D-ERICA: An INTEGRATED APPROACH to the assessment and management of environmental risks from ionising radiation. Euratom 6th Framework Programmes, Contract Number FI6R-CT-2004-508847.
Environment Agency et al., 2012	Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment. Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10), August 2012.
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F, July 2016.
IAEA, 2004	Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment Technical Reports Series No. 422, April 2004.
Vives i Batlle et al., 2015	Vives i Batlle J., Jones S.R. and Copplestone D. (2015). A methodology for Ar-41, Kr-85, 88 and Xe-131m,133 wildlife dose assessment. Journal of Environmental Radioactivity. Volume 144 (152-161).

Appendix K: Assessment of direct radiation

An assessment of the direct radiation emanating from the UK ABWR is not within the scope of this independent dose assessment. Nevertheless, it is necessary to include a contribution from direct radiation in the evaluation of the total exposure of candidate representative persons, along with contributions from radioactive discharges. This enables the total exposure from the UK ABWR to be compared with relevant dose criteria.

Hitachi-GE (Hitachi-GE, 2016) has presented calculated off-site direct radiation doses in its dose assessment. Off-site direct radiation doses are expected to arise from a number of facilities associated with the UK ABWR, primarily the turbine hall. In its submission Hitachi-GE has estimated the dose rates to adults at various distances from the UK ABWR and these are reproduced in the first column of Table K.1.

Hitachi-GE has used these dose rates to make an assessment of the annual dose from direct radiation. Hitachi-GE (Hitachi-GE, 2016) has defined its representative persons to be at the site boundary, with the adult spending 50% of their time outdoors, 20% for children and 10% for infants. On this basis Hitachi-GE calculated direct radiation doses of 0.94, 0.47 and 0.32 µSv/y for adults, children and infants respectively, which round to 0.9, 0.5 and 0.3 µSv/y respectively. These derived direct radiation values are assumed to apply to exposed groups close to the generic site

Table K.1: Direct radiation dose rates (µSv/h) at various distances from a single UK ABWR unit

Distance	Adult*	Child	Infant
100 m	2.14E-03	2.44E-03	2.82E-03
300 m	2.18E-04	2.49E-04	2.88E-04
500 m	3.63E-05	4.14E-05	4.79E-05

Note: *Values for the adult calculated by Hitachi-GE (Hitachi-GE, 2016). Values for children and infants have been calculated by scaling the adult values by 1.14 and 1.32 respectively, based on data presented by UNSCEAR (UNSCEAR, 2000).

The direct radiation dose rates presented in Table K.1 have been applied to the habit data used in the independent dose assessment. The dose rates have been multiplied by the time assumed to be spent at the location by the person to whom the dose assessment relates. A shielding factor of 0.1 has been applied for indoors situation. The direct radiation dose is calculated with:

$$E_{DI}^{x} = e_x(T_o^x + f_s T_i^x)$$

Where

E_{DI}^{x} is the annual direct radiation dose at a distance of x for a given age group (µSv/y)

e_x is the dose rate at distance x for a given age group (µSv/h)

T_o^x is the duration spent outdoors at a location at a distance of x (h/y), from Appendix G (not including time spent at the beach)

f_S is the indoors shielding factor (unit less)

T_i^x is the duration spent indoors at a location a distance of x (h/y), from Appendix G

The estimated annual doses allowing for variation in distance and occupancy time for the age groups are shown in Table K.2. The estimated doses are similar to those derived by Hitachi-GE.

Throughout this report the Hitachi-GE derived annual doses from direct radiation have been adopted (as highlighted)

Table K.2: Scaled estimates of annual direct radiation dose for adults, children and infants in the farming and fishing families

	Exposure distance (m)	Adult	Child	Infant
Hitachi-GE (2016)#	Site boundary#	0.94 (rounded 0.9#)	0.47 (rounded 0.5#)	0.32 (rounded 0.3#)
Scaled dose rate (farming family)	300 m	0.98	0.54	0.47
Scaled dose rate (fishing family)	300 m	0.61	0.54	0.47

These direct radiation data have been used in the total doses presented.

K.1 References

Reference	Details
Hitachi-GE, 2016	UK ABWR Generic Design Assessment: Prospective Dose Modelling, Report GA91-9901-0026-00001, Rev F
UNSCEAR, 2000	Sources and effects of ionizing radiation. Report to the General Assembly, Volume 1, Annex A. United Nations Scientific Committee on the Effects of Atomic Radiation.

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