# Generic design assessment of new nuclear power plants

## Generic site, doses to the public and dose rates to wildlife for the UK HPR1000 design - AR07

## Detailed assessment – final report

10 January 2022

Version 1

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# Executive summary

This report is our detailed assessment for the Generic Design Assessment (GDA) of the UK HPR1000, the UK Hualong Pressurised (water) Reactor design. This report covers the assessment of 2 topics, the generic site and the radiological assessment, based on the requirements in Table 1 of our Process and Information Document (P&ID) (Environment Agency, 2016a).

Our assessment has considered the Requesting Party's (RP's) submission in relation to relevant UK policy, legislation and guidance. These include the Environment Agency's Radioactive Substances Regulation (RSR) Environmental Principles (REPs) (Environment Agency, 2010); Nuclear National Policy Statement (UK Parliament, 2011a, 2011b) and the Dose Principles document (Environment Agency et al., 2012). We also considered relevant guidance provided by the National Dose Assessment Working Group (NDAWG) and other technical documents from Public Health England (PHE).

For the generic site characteristics, we found that the RP's submission had taken into account the sites listed in the Nuclear National Policy Statement (UK Parliament, 2011a, 2011b). The policy statement lists sites potentially suitable for new nuclear power plants; all of which are adjacent to existing nuclear power plants or nuclear sites. The RP's generic site description takes account of the characteristics of the Bradwell site.

We consider that the generic site characteristics are justified and reasonable for the GDA stage for new reactors and represent an appropriate UK site. The parameters chosen for the generic site are quite cautious and will tend to form a bounding case for liquid discharges to the marine environment. The parameters and values that define the generic site for the UK HPR1000 are appropriate to use in assessing the radiological impact of the UK HPR1000 at the GDA stage.

The RP's submission on radiological assessment was of the prospective (future) doses to members of the public arising from the expected disposal of liquids and gaseous radioactive waste to the environment from a single UK HPR1000.

The RP's submission indicates that, potentially, the highest total dose to members of the public, from a single UK HPR100 reactor unit discharging at the proposed discharge limits will be between 10 and 23 micro-Sieverts per year (μSv/y) depending on age group. The highest dose would be to an adult member of a 'fishing family' who are most affected by discharges of liquids. That is a family assumed to be living near the site, eating fish and foods farmed around the site. Half of the dose to the adult is predicted to occur from the intake of local foodstuffs affected by liquid discharges. The rest of the dose is from exposure to discharges to the atmosphere and from direct radiation. Carbon-14 contributed 95% to 99% of the dose from discharges. The RP's submission showed that doses from enhanced short duration releases to atmosphere were between 6 and 10 μSv per release depending on age group.

We appointed a technical support contractor (TSC) to carry out an independent assessment of the radiological impact of the UK HPR1000 at the generic site on our behalf.

Our independent assessment indicates that the highest doses range from 10 to 23 µSv/y. The most exposed group is a local resident farming family. These doses are well below the dose constraint for members of the public of 300 µSv/y. The assessed doses are also well below the public dose limit of 1,000 uSv/y specified in Environmental Permitting Regulations 2016. The biggest contribution to doses is from discharges to the atmosphere. The highest dose is to an infant consuming locally produced foods. Carbon-14 contributed 96% to 99% of the dose from discharges. Direct radiation is a less significant component of the dose because the farming family are assumed to be 300 m from the site where direct radiation is lower. Doses from enhanced short duration releases to atmosphere were between 6 and 8 µSv per release depending on age group.

The small differences in outcomes are due to the independent assessment assuming occupancy at the location where ground level air concentrations are highest (300 m from the release point) and including doses from eating locally produced milk products. In the RP's submission occupancy is assumed to be at 100 m from the release point, which gives slightly lower air concentrations, and doses from milk products are not included. The dose from atmospheric discharges assessed at 300 m are higher than those established assuming a 100 m distance. The independent assessment uses less cautious dispersion information for the marine environment around the generic site than the RP does. Therefore doses from liquid discharges are predicted to be lower in the independent assessment than from the RP's.

Our conclusions are that the discharges to atmosphere and liquid discharges of radioactive wastes at proposed limits from a single UK HPR1000 at the generic site is likely to result in doses to the public that are well below the dose constraint for members of the public of 300 µSv/y. The assessed doses are also well below the public dose limit of 1,000 uSv/y specified in Environmental Permitting Regulations 2016. We consider that the assessment the RP carried out is cautious, reasonable and has used an appropriate approach. Our independent assessment has a similar outcome.

Discharges of radioactive wastes from a single UK HPR1000 reactor at the generic site are unlikely to pose a risk to wildlife. We consider the assessment the RP carried out to be cautious and reasonable, and we consider that the RP has used an appropriate approach to assess the radiological impacts of the UK HPR1000 on wildlife. The dose rates range from 0.00043 µGy/h to 0.15 µGy/h. Our independent assessment outcomes are similar ranging from 0.03 µGy/h to 0.13 µGy/h. The dose rates are well below the dose rate criterion of 10µGy/h.

This assessment is a prediction of the radiological impact for discharges made from a single reactor at a generic site, discharging at the proposed limits. A detailed radiological assessment will be needed to support any application for an environmental permit in future. The radiological assessment would be based on site-specific environmental characteristics.

We have not identified any GDA Issues or Assessment Findings (AFs) related to the radiological assessment. However, the importance of the carbon-14 discharges to the assessed dose indicates that minimisation of carbon-14 and its impact is an important factor for future regulatory focus. Therefore, Assessment Findings have been raised in our BAT assessment report (Environment Agency, 2022c) related to carbon-14 abatement; the assessment of chemical form of carbon-14 discharged to the environment and the optimisation of the balance between gaseous, liquid and solid phases of carbon-14.

# Contents

# 1. Introduction

This report is our detailed assessment for the Generic Design Assessment (GDA) of the UK HPR1000, the UK Hualong Pressurised (water) Reactor design. This report covers the assessment of 2 topics, the generic site and the radiological assessment, based on the requirements in Table 1 of our Process and Information Document (P&ID) (Environment Agency, 2016a).

Our assessment has considered the Requesting Party's (RP's) submission in relation to relevant UK policy, legislation and guidance. These include the Environment Agency's Radioactive Substances Regulation (RSR) Environmental Principles (REPs) (Environment Agency, 2010); Nuclear National Policy Statement (UK Parliament, 2011a, 2011b) and the Dose Principles document (Environment Agency et al., 2012). We also considered relevant guidance provided by the National Dose Assessment Working Group (NDAWG) and other technical documents from Public Health England (PHE).

This report is based on information received in the the RP's final GDA submission and consideration of relevant responses to our consultation or made via the the RP's public comments process.

We use a 2-stage process to carry out GDA: initial assessment, followed by detailed assessment. The findings from our initial assessment are set out in the Initial Assessment: Statement of Findings report published in November 2018. Our initial conclusions were that for a coastal site:

- the annual dose constraints and limits are unlikely to be exceeded by this design
- the action level for non-human species are unlikely to be exceeded by this design

We required further information on:

- the detail of generic site parameters and their justification for use
- the justification for the chosen modelling tools
- the underpinning of the direct dose assessment
- detailed stage 3 dose assessment
- the assessment of a short duration release

In order to assess the potential impact of a particular reactor design on the environment, we need to know the characteristics of the generic site proposed by the RP. We recognise that at the GDA stage the proposed specific location of the nuclear plant may not be known so our assessments for GDA are based on the generic site. However, the generic site description the RP presented has used some characteristics of the Bradwell site. When a proposed location for a plant is confirmed, a site-specific assessment will always be required as part of the application for an environmental permit. At the GDA stage, we need to satisfy ourselves that:

- the reactor design is such that any environmental impacts would be acceptable under relevant UK legislation
- any radiological impacts of new build reactors in the England are as low as reasonable achievable (ALARA), as required by the Environmental Permitting Regulations 2016 (Schedule 23) as amended)

We also sought to identify any particular features of the reactor design that could lead to impacts of a type or scale that could constrain the locations at which such a plant could be located.

In GDA, we require a generic site to be defined in order to assess the environmental impacts of the reactor design. The RP has made a radiological impact assessment (GNSL 2021c) using its generic site description (GNSL, 2021a). Our assessment of the generic site is presented in this report.

We require the RP to demonstrate that the radiological impact of its operations would be consistent with the UK dose constraints and dose limits for the public and meet the dose rate criteria for the radiological impact on wildlife, which are non-human species that require protection.

The basis of the assessment is discharges at the proposed limits from a single reactor. The assessment calculations used the maximum annual discharges. The proposed limits were derived from the maximum annual discharges and therefore the permit limits and the maximum annual discharges are equivalent.

As part of our assessment, we commissioned our own radiological assessment, which is independent of the one that the RP submitted. We have published the full report of this independent assessment separately (Environment Agency, 2020a). We appointed a technical support contractor (TSC), (Cavendish Nuclear Ltd) to make the assessment on our behalf. The generic site used for our independent assessment took into account the relevant characteristics of other UK locations where a new reactor might be constructed in future based on the UK siting report (UK Parliament, 2011a and 2011b). In the assessment, our TSC predicted environmental activity concentrations by modelling and made an assessment of the radiological impact on people and wildlife of the UK HPR1000 discharges (Environment Agency, 2020a).

## 1.1. Generic site

The parameters that are part of the generic site description include:

- the position of the reactor and the environment around it
- environmental parameters such as meteorological conditions, dispersion of liquids and atmospheric dispersion
- the distance to the nearest occupied buildings, farmland and centres of population
- habits of the local population
- potential designated or protected wildlife sites

The RP has derived its generic site characteristics for the UK HPR1000 assuming the UK HPR1000 will be located on the coast. The generic site characteristics have been chosen to represent sites where a new UK HPR1000 might be located and adopt some of the environmental characteristics of the current Bradwell site.

The main assumptions declared for the generic site are as follows:

- The site is in a coastal or estuarine location and the topography of the site is flat.
- There is no water extraction from aquifers and no standing water at the site.
- There are no freshwater bodies on or adjacent to the site.
- The nearest human receptors are assumed to be a fisherman family and local resident family.
- Discharge routes are assumed to be discharges of gases (and some particulates) to atmosphere and liquid (aqueous) discharges to the marine/estuarine environment adjacent to the site.
- There are no other nuclear sites adjacent to the generic site.
- There is no incinerator on the site.

The design assumes once-through seawater cooling and has been reflected in the generic site.

We note that the generic site has taken into account the characteristics of the Bradwell site. At the Bradwell site and at all other potentially suitable sites there are other nuclear power stations or nuclear sites nearby. If proposals are brought forward a UK HPR1000 would be adjacent to a nuclear site or power station operating or decommissioning. Therefore, a UK HPR1000 is likely to be adjacent to at least one another power station.

## 1.2. Radiological impact

In England, the Environment Agency regulates the discharges of radioactive waste into the environment during normal operation, making sure that any radiation exposure of the public is below the statutory dose limit and dose constraints. The Office for Nuclear Regulation (ONR) is responsible for regulating nuclear safety, including making sure that doses to the public resulting from direct radiation during normal operation are acceptable and below the statutory dose limits. Direct radiation is radiation from radioactive sources within a nuclear power plant boundary, instead of indirectly as a result of radioactive discharges.

This assessment aims to establish whether the design could be operated in England in line with UK statute, policy and guidance on radioactive waste as currently written. It is recognised however, that the assessment will be kept under review to reflect changes in the statute, policy and guidance that may occur between now and plant commissioning and operation.

The radiological assessment does not cover radioactive discharges arising from decommissioning at the end of the reactor life cycle. These are out of the scope of GDA. Discharges during operation of the reactor will dominate the overall radiological discharges from the UK HPR1000 plant. The decommissioning phase at the end of operation normally leads to a substantial reduction in discharges to the environment.

The radiological assessment outcome is dependent on the generic site definition and description (GNSL 2021a). Consequently, the radiological assessment for humans and wildlife and the generic site have been assessed together in a single assessment report.

### Dose to public

To assess the potential radiological impact of a reactor design, the potential future (prospective) doses of radiation to members of the public need to be determined. These can result from discharges of radionuclides to the environment from a reactor (within a nuclear power plant) and its associated facilities. Doses may also arise from any exposure offsite from direct radiation from radioactive sources within the reactor structures. Prospective dose assessments are required to determine the potential radiological impact of a reactor design and to inform optimisation decisions at the design stage.

The assessment the RP provided was of discharges from a single UK HPR1000 reactor (GNSL 2021c). It includes the predicted levels of radionuclides from discharges into the environment at the proposed discharge limits from the UK HPR1000 and the radiological impact from direct radiation (GNSL 2021b). We have assessed the RP's submission to make sure that it is comprehensive, is based on a valid approach and is technically correct. We have compared the prospective doses with the dose constraints and the legal dose limit set by government in EPR 2016.

### Doses to wildlife

To assess the potential radiological impact of a reactor design, the prospective impact of radiological discharges on wildlife also needs to be determined.

Our assessment considers the information the RP provided for its UK HPR1000 design. The RP's submission presents an assessment of the impact of radiological discharges, assumed to be discharged at proposed discharge limits on wildlife from a single UK HPR1000 reactor (GNSL 2021c). Our assessment of the RP's submission will ensure that it is comprehensive, based on a valid approach and technically correct.

# 2. Assessment

We assessed the generic site and the radiological impact during our initial assessment (Environment Agency, 2018). This assessment is a review and continuation of the earlier work and considers the generic site the RP described and the radiological impact on public and wildlife.

## 2.1. Assessment method

Our assessment method is summarised as follows:

- We considered the Pre-Construction Environmental Report (PCER) and its supporting documents that the RP submitted (see section 2.3 below).
- We used technical meetings with the RP to clarify our understanding of the information presented and explain any concerns that we had with that information.
- We raised Regulatory Queries (RQs) to clarify information the RP supplied.
- We assessed the generic site characteristics that the RP proposed to decide if they were reasonable and applicable to the UK.
- We assessed the methods used against UK guidance input parameters to ensure they were applicable to England, and outcomes of the radiological assessment that the RP carried out for the public and wildlife.

We carried out an independent assessment of the radiological impact.

During the assessments we identified that, in some cases, we needed existing information to be clarified or further information provided. We managed this using the system of RQs and through technical discussion. We did not raise any Regulatory Observations (ROs) or Regulatory Issues (RIs) during our assessment of the generic site or radiological impact of the UK HPR1000. Our overall assessment process is set out in our P&ID (Environment Agency, 2016).

The radiological assessment outcomes are dependent on discharges of radionuclides from a single UK HPR1000 reactor (GNSL, 2021c). Discharges of radionuclides are presented in a separate submission (GNSL, 2021b) and we have assessed these elsewhere (Environment Agency, 2022b). The radiological assessment outcomes are also affected by direct radiation. Information on direct radiation was summarised in the RP radiological assessment. The radiation protection submission contains more detailed information on direct radiation from the UK HPR1000 (GNSL, 2018; GNSL, 2021d).

## 2.2. Assessment objectives

We set objectives for our assessment of the generic site, radiological impact on the public and radiological impact on wildlife.

For our assessment of the generic site, our objectives were to assess the following:

- Are the generic site characteristics reasonable, justified and well described?
- Are the conditions and parameters described appropriate for possible locations for nuclear power stations in the UK?
- Are there any aspects of the generic site that could rule out any location at site-specific permitting?
- How does the RP's defined generic site compare with our independent assessment?

For our assessment of radiological impact on the public, our objectives were to assess the following:

- Is the radiological impact assessment carried out by the RP reasonable and justified?
- Does the RP radiological assessment follow established UK methods and guidance?
- Are the predicted doses to members of the public below the relevant dose constraints and limits?
- Is the radiological impact assessment valid and are the outcomes consistent with our independent assessment?

For our assessment of radiological impact on wildlife, our objectives were to assess the following:

- Is the radiological impact assessment the RP carried out reasonable and justified?
- Does the RP's radiological assessment follow established UK methods and guidance?
- Can the radiological impact assessment the RP carried out be reproduced so that we can understand how the RP has carried out its assessment?
- Are the predicted dose rates to wildlife below the relevant dose rate criteria?

## 2.3. Submissions assessed

For this assessment, we considered the documents the RP submitted shown below.

- Preliminary Safety Report Chapter 26 – Environment, HPR/GDA/PSR/0026, Revision 001 (GNSL, 2017)
- Pre-Construction Environmental Report Chapter 2 - Generic Site Description, HPR/GDA/PCER/0002, Revision 002 (GNSL, 2021a)
- Pre-Construction Environmental Report Chapter 6 - Quantification of Discharges and Limits, HPR/GDA/PCER/0006, Revision 002 (GNSL, 2021b)
- Pre-Construction Environmental Report Chapter 7 - Radiological Assessment, HPR/GDA/PCER/0007, Revision 002 (GNSL, 2021c)
- Pre-Construction Safety Report Chapter 22 - Radiological Protection, HPR/GDA/PCSR/0022, Revision 002 (GNSL, 2021d)

## 2.4. Guidance and standards

There are no specific UK standards for assessing the generic site and radiological impact. However, there are technical reports, good practice guides and principles. We used guidance, principles and published methods in our assessment, including:

- the Radioactive Substances Regulation Environmental Principles (REPs) (Environment Agency, 2010)
- the requirements specified in the P&ID (Environment Agency 2016)

- the Principles document for Prospective Dose (Environment Agency et al., 2012)
- good practice guides and technical methods issued by the National Dose Assessment Working Group (NDAWG)
- specific technical guidance and methods issued by Public Health England (PHE) (which provides radiation protection advice for England)

Data and methods have been derived from the recommendations of the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP).

## Radioactive Substances Regulation Environmental Principles (REPs)

The REPs (Environment Agency, 2010) that are relevant to assessing the RP's submissions on generic site (GNSL 2021a) and radiological impact (GNSL, 2021c) are as follows:

- Fundamental Principle E - Protecting human health and the environment.
- Developed Principle SEDP1 General RSR Principle for siting new facilities - When evaluating sites for a new facility, account shall be taken of the factors that might affect the protection of people and the environment from radiological hazards and the generation of radioactive waste.
- Developed Principle SEDP2 Movement of radioactive material in the environment - Data shall be provided to allow the assessment of rates and patterns of movement of radioactive materials in the air and the aquatic and terrestrial environments around sites.
- Developed Principle RPDP1 Optimisation of protection - All exposures to ionising radiation of any member of the public and of the population as a whole shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- Developed Principle RPDP2 Dose limits and constraints - Radiation doses to individual people shall be below the relevant dose limits and constraints.
- Developed Principle RPDP3 Protection of non-human species - Non-human species (wildlife) should be adequately protected from exposure to ionising radiation.
- Developed Principle RPDP4 Prospective dose assessments for radioactive discharges to the environment - Assessments of potential doses to people and to non-human species (wildlife) shall be made before granting any new or revised authorisation for the discharge of radioactive wastes into the environment.

## Process and Information Document (P&ID) requirements

Our P&ID (Environment Agency, 2016) sets out our requirements to the RP, the Requesting Party (RP), at the start of this GDA process. The information that an RP is required to provide in its submission to address the generic site and radiological assessment is summarised below.

Information requirements for the generic site are as follows.

- Identification of discharge points to the environment for discharges to atmosphere and liquid radioactive wastes.
- Description and characteristics of the generic site (or sites) that the RP will use to provide its dose assessment. Any statement of acceptability we issue after our assessment will be on the basis of these characteristics. A range of generic sites might be chosen with coastal, estuarine and inland characteristics.

Information requirements for the radiological assessment are as follows.

- Prospective radiological assessment at the proposed limits for discharges and for any onsite incineration.
- Annual dose to the most exposed members of the public from liquid (aqueous) discharges.*
- Annual dose to the most exposed members of the public for discharges to atmosphere, identifying separately the dose associated with onsite incineration, where applicable.*
- Annual dose to the most exposed members of the public for all discharges from the facility.*
- Annual dose from direct radiation to the most exposed members of the public.
- 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, might have the potential to prejudice legitimate users or uses of the land or sea.
- Dose-rate to non-human species.
- Identify the models used to calculate these doses and why they are appropriate, and set out all the data and assumptions, with reasoning, that was used as input to the models.

For those items above marked with an asterisk (*), we recommended using our initial radiological assessment tool (IRAT) (which is available on request), refining the default data to reflect the characteristics of the facility and generic site.

## Principles for assessing prospective dose

Dose principles were published in 2012. There are 13 principles which should be applied when assessing prospective doses (Environment Agency et al., 2012). Their main purpose is for assessing the future discharges of radionuclides from nuclear and non-nuclear sites. Some of the 13 principles apply directly in the radiological assessment at GDA and these are identified below.

The NDAWG has also published discussion papers, methods and guidance notes in the area of dose assessment. Some are relevant to the principles that apply to GDA and are also summarised below.

- Dose Principle 1: Prospective dose assessment methods, data and results should be transparent and made publicly available. See NDAWG GN 1: Overview of guidance on the assessment of radiation doses from routine discharges of radionuclides to the environment. (NDAWG, 2008a)
- Dose Principle 2: When determining discharge permits or authorisations, the dose to the representative person should be assessed. See NDAWG GN 7: Use of habits data in prospective dose assessments. (NDAWG 2013) and NDAWG GN 3: Guidance on exposure pathways. (NDAWG, 2009)
- Dose Principle 3: Doses to the most affected age group should be assessed to determine discharge permits or authorisations. Assessment of doses to 1 year olds, 10 year olds and adults (and foetus, when appropriate) is adequate age group coverage. See NDAWG GN 7: Use of habits data in prospective dose assessments (NDAWG, 2013).
- Dose Principle 4: 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. See NDAWG GN 7: Use of habits data in prospective dose assessments (NDAWG, 2013).
- Dose Principle 5: 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. See NDAWG GN 2: Guidance on initial/simple assessment tools (NDAWG, 2008b).
- Dose Principle 6: The assessment of dose to the representative person should take account of accumulation of radionuclides in the environment from future discharges (no NDAWG guidance available).
- Dose Principle 7: 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. See NDAWG GN 6A: Guidance on short-term release assessments (NDAWG, 2019).
- Dose Principle 8: For permitting or authorisation purposes, collective doses to the populations of the UK, Europe and the world at 500 years should be estimated (no NDAWG guidance available).
- Dose Principle 9: Where the assessed mean dose to the representative person exceeds 0.02 mSv/y (20 µSv/y), the uncertainty and variability in the main assumptions used for the dose assessment should be reviewed. See NDAWG GN 4: Guidance on considering uncertainty and variability in radiological assessments (NDAWG, 2011).

## 2.5. Independent assessment

An independent radiological assessment was carried out for us by a technical services contractor. The assessment supports our detailed assessment of the RP's submission and provides a reference point for comparison with the RP's submission. It enables an

independent validation of the assumptions and methods the RP used in its generic site definition and in its assessment of the radiological impact. The independent assessment is provided in a separate report (Environment Agency, 2020a).

# 3. Technical assessment

## 3.1. Generic site

The submissions related to the generic site description assessed during the GDA process are shown in section 2.3.

The generic site assumptions provide a representation of a potential site in England. Some of the assumptions made led to no assessment of specific aspects of the environment and exposure pathways, such as no groundwater pathways; no freshwater exposure pathways and no assessment of the impact on freshwater wildlife. The assessments made based on the generic site are the first stage of the regulatory process and provide an indication of the expected radiological impact on people and the environment based on one reactor. If an application for an environmental permit is made in future at a particular site, it will include a more detailed site-specific assessment. This would take into account all the main environmental features around the specific site, including exposed groups and protected environmental sites and species.

### Our initial assessment

During our initial assessment (Environment Agency, 2018), we compared the RP's submission with the relevant REPs (Environment Agency, 2010), the P&ID (Environment Agency, 2016) and the dose principles document (Environment Agency et al., 2012) (see section 2.4). The RP submitted a 3-tier radiological assessment, with stages 1 and 2 being screening assessments. Each stage of the tiered assessment used information from the generic site description. Stage 1 and stage 2 assessments were completed, however the third assessment stage was described, but only partially completed. The generic site description used general information, which has been augmented by some information from the Bradwell nuclear site. We reviewed and verified the stage 1 and stage 2 outcomes.

### Our detailed assessment

During our detailed assessment of the updated and final submissions from the RP (GNSL, 2021a), we reviewed the submission against our REPs, the P&ID, and the dose principles document, as we did for the initial assessment. In the updated and final RP submissions, all 3 stages of the assessments were complete. We reviewed and verified the stage 1 and stage 2 outcomes. We observed that the generic site description used some information on environmental dispersion (meteorological data and marine dispersion data) that is consistent with the Bradwell site. Information on habits, land use and exposed groups was

taken from UK wide data sources, with additional information from the area around the Bradwell site. These are considered in more detail below.

## Atmospheric dispersion

For the assessment of continuous releases to atmosphere, the RP has used meteorological data based on Pasquill stability categories, as used in the R-91 aerial dispersion model (NRPB, 1979). For the stage 1 and stage 2 assessments, the RP has used our IRAT. The atmospheric conditions assumed in IRAT are 50% category D, which is cautious (Environment Agency, 2006a and 2006b). The release point is from the top of the stack, which is assumed to be at a physical height of 70m. For assessment purposes, an effective stack height of 20m can be used, which takes into account the wake effects of nearby buildings. The effective stack height is approximately 1/3 of the physical stack height. Generally, a lower stack height leads to higher ground level air concentrations close to the site.

For the stage 1 assessment using IRAT the outcomes are likely to be cautious, mainly because of the baseline assumption of a ground level release.

For the stage 3 detailed assessment, the RP selected conditions of 65% category D, which is representative of some coastal conditions around the UK and encompasses conditions around the Bradwell site (NRPB, 1979). In our independent assessment, we have established that the range of meteorological data available for the UK (50% to 80% category D) and used in the modelling can influence ground level air concentrations by a factor of about 30%. The 65% category D leads to air concentrations that are in the middle of the range and are appropriate for assessing the generic site for the UK HPR1000.

Meteorological data specific to modelling short-term releases are discussed in the prospective dose modelling submission (GNSL, 2021c). Parameters were derived for the ADMS model that were approximately equivalent atmospheric conditions to the Pasquill stability classes used for continuous discharge assessment, which is considered appropriate for GDA. For any future dose assessment in support of permitting, it is expected that site-specific meteorological data would be used.

## Marine environment modelling data

For the stage 1 assessment, default marine dispersion data (volumetric exchange) were taken from IRAT (Environment Agency, 2006a; 2006b). The volumetric exchange rate is a parameter that defines the mixing rate between local and regional waters. This default is very cautious for most coastal sites and reasonably cautious for most estuarine locations. It is, therefore, an appropriate upper bound assessment for GDA. For the stage 2 assessment using IRAT (Environment Agency, 2006a and 2006b), the RP adopted a volumetric exchange rate based on the Bradwell site. These volumetric data were also used in the stage 3 assessment.

We raised RQ-UKHPR1000-0202 noting that the stage 2 and 3 dose impact assessments had used data for the Bradwell site without clear justification. The RP confirmed that it was aware that under GDA a specific site is not being selected. However, a generic site using Bradwell characteristics is likely to be cautious and the radiological assessment will represent an upper estimate.

Our independent assessment indicates that the generic site the RP defined is conservative and would lead to a cautious assessment of doses to the public.

## Exposed groups

Based on the above assumptions for the site, the RP has determined that the most exposed members of the public for radioactive discharges to air will be a local resident family and for discharges to sea will be a fisherman family. These are consistent with the exposure groups we use in the IRAT (Environment Agency, 2006a and 2006b). These assumptions are appropriate for GDA. Site-specific exposure routes will be assessed during any future environmental permitting process.

The exposed group representing the local resident family at the generic site was assumed to be consistent with the underlying assumptions in the IRAT system and the stage 1 and stage 2 assessment. IRAT assumes that the local resident lives 100 m from the release point and that a range of food is produced 500 m from the release point. These basic assumptions were retained for the stage 3 assessment. We raised RQ-UKHPR1000-0202 related to the expected size of the reactor and other buildings on the site to support the assumptions around the location of the local residents and to provide a justification for this assumption. We were content with the response.

In our independent assessment, we have explored the effect of increasing the receptor distance from 100 m to 1 km from the release point on ground level air concentration. For a 20 m stack height, ground level air concentrations at 300 m can be higher than at 100 m. The range in the factors depends on the meteorological conditions assumed and data used. At 65% Pasquill stability category D, the ground level air concentrations 300 m from the release for a release height of 20 m are up to 3 times higher than at 100 m. However, the exposure pathways directly related to the plume at 100m and 300m are of relatively low significance and so the effect on total dose is small. This was considered further in our independent assessment (Environment Agency, 2021a).

## Habits data

The IRAT system (Environment Agency, 2006a; 2006b) has generic habits data (for example, food intake rates) taken from UK generic habits data published by the National Radiological Protection Board (NRPB) (NRPB, 2003). Therefore, we are confident that parameters appropriate for the generic site have been applied for the stage 1 and stage 2 assessments.

The RP has also reviewed site-specific habits data for the population local to the Bradwell site and selected additional habits (for example, Clyne et al., 2016). The RP identified in the local habits surveys that there are people who live on houseboats for a large part of the year and have high occupancy above intertidal sediments. The local habits surveys also identified higher rate intakes of some foods (fish, seaweed, vegetables and fruit). These substituted for some of the UK generic habits data in the the RP's assessment. We are content that the method and data are appropriate to use for a generic site. However, substituting Bradwell site habits data where the data is higher than in UK generic habits data may lead to a more conservative generic site and a cautious estimate of doses to the public.

## Wildlife

The RP's submission concerned with generic site (GNSL, 2021a) states that it will use the Environmental Risk from Ionising Contaminants: Assessment and management (ERICA) tool (Beresford et al., 2007; Brown et al., 2007; Brown et al., 2016) and the Ar-Kr-Xe dose calculator (Vives i Batlle et al., 2015) to assess the radiological impact of discharges from the HPR1000 on wildlife. We are content that these are suitable methods that can be used in the assessment. The ecological receptors considered for GDA are the reference organisms defined in the ERICA tool. The RP uses these reference organisms to represent sensitive habitats and protected species which may be located at the generic site. We are content that using the ERICA reference organisms is appropriate for the GDA stage. Specific designated wildlife sites would be defined and assessed at any future site-specific environmental permitting stage.

The RP's submission (GNSL, 2021a) states that radiological discharges from the UK HPR1000 are aerial discharges to the atmosphere and liquid (aqueous) discharges to the estuary. The RP has, therefore, considered both terrestrial and marine reference organisms in its assessment. As the generic site is assumed to be a coastal site – the assumption is that there are no freshwater bodies on or adjacent to the generic site. Therefore, the RP has not considered the freshwater ERICA reference organisms. We are content that this approach is appropriate for GDA. If at any future site-specific stage, relevant freshwater bodies are identified, an assessment of the radiological impact on freshwater ecological receptors would be required.

Dose rates to wildlife depend on the concentrations of radionuclides in the environment. For this assessment, the RP calculated the accumulation of radionuclides in air, soil and seabed sediment from the HPR1000 over the proposed 60-year period of operation. These environmental activity concentrations were used as input data into the wildlife dose assessments. The environmental activity concentrations from discharges to air were derived based on a ground level release and Pasquill stability category D for 50% of the time. The wildlife receptors are assumed to be 100 m from the release point. This is a conservatively defined generic site that will give a cautious assessment of dose rates to wildlife.

## Independent assessment

The independent assessment we commissioned (Environment Agency, 2021a) included a review of the generic site. The review considered 8 locations identified for possible new nuclear power plants (UK Parliament, 2011a and 2011b). In our independent assessment, our contractor considered the effect of varying the main environmental factors that influence dispersion of discharges at the 8 sites. For liquid discharges, the main factor is exchange rates of marine water near the discharge point (volumetric exchange rate). Values for each of the 8 locations identified as possible locations for new nuclear power plants. This showed considerable variation in the predicted local water concentration of a factor of up to 25. The generic site data for the Bradwell site generated the highest predicted water concentrations.

The independent assessment considered the atmospheric dispersion conditions and the resulting ground level air concentrations at each of the 8 locations identified as possible locations for new nuclear power plants. This analysis showed that ground level air concentrations varied by only a factor of 1.25 between the various possible locations. The Bradwell site atmospheric conditions resulted in predicted air concentrations that were in the middle of the range.

The independent assessment adopted the staged dose assessment process, with an initial cautious assessment (stage 1) followed by a more refined assessment (stage 2). For these first 2 stages, the assessments also used the IRAT system. For the discharges to atmosphere, the IRAT model assumption is that the receptor points are a family living 100 m from the release point and eating all their food which is produced 500 m from the release point. For the releases to the marine environment, the IRAT model assumption is that the most exposed group is a fishing family spending time on intertidal areas and consuming high rates of fish and shellfish caught locally.

For the detailed stage of the assessment (stage 3) for releases to atmosphere, the independent assessment, the resident farming family is placed at 300 m from the release point, coinciding with the highest ground level air concentrations. Food production is assumed to occur at 500 m from the atmospheric release point. Therefore, it may be expected that doses associated with non-food pathways such as doses from inhalation and external doses might be higher than those for the RP’s assessment, while dose from direct radiation would be lower. Our independent assessment showed that most of the dose was from carbon-14 in food, which is the same as the RP’s submission.

Our assessment included a review of the available habits data. We have concluded that UK generic data are appropriate for the assessment.

The independent assessment used fish consumption data and information on houseboat occupancy from local habits surveys. This is similar to the RP’s approach to use of habits data. The generic site used in the independent assessment is therefore similar to that defined by the RP, except for the position of the local resident receptor and assumptions about consumption of locally produced milk products.

## 3.2. Radiological impact - public

The submissions related to the radiological impact assessed during the GDA process are shown in section 2.3.

### Assumptions about discharges

The assessment was made on the assumption that discharges will be made from a single UK HPR1000 reactor (GNSL, 2021c) for 60 years at the proposed limits. Accumulation in the soil, air and marine sediment has been included in the modelling.

For the staged assessment process, it was assumed that discharges to atmosphere are released at ground level. This assumption results in the highest activity concentrations in air at ground level. Discharges from the UK HPR1000 would be made from a stack that is well above ground level, leading to greater dispersion and dilution than a release at ground level. The later stages of the assessment take this into account.

We are content that the assumptions concerned with discharges are appropriate and acceptable.

### Assumptions about models and methods

The radiological assessment requires models that can calculate the transfer of radionuclides from the point of discharge through the environment to a receptor (for example, local resident). The dispersion of radionuclides in the environment and predictions of radionuclide concentrations in air, soil, food, water and sediment at future times can be made. The predicted radionuclide concentrations are then combined with information on human habits such as occupancy times and food consumption data to provide estimates of dose to the public.

The RP has used several models for predicting environmental dispersion (GNSL, 2021c and 2021d). The RP used the PC-CREAM 08 computer program (Smith et al., 2009) in assessing the dispersion of radionuclides expected to be discharged over the generating lifetime of the reactor (60 years). PC-CREAM 08 is a suite of environmental models and data developed by Public Health England to predict environmental concentrations from continuous discharges of radioactive wastes. The environmental concentrations predicted take into account build-up of discharged radionuclides over the period of discharges. Concentrations in soil, vegetation and farm animals, sea water, suspended sediment, sea bed sediment, fish and shellfish are predicted and used to calculate the annual radiation doses to members of the public.

In addition to the continuous discharges made at a steady rate, there is a need to consider the potential impact of elevated discharges over short periods of time as a result of foreseeable events during normal operations. Short periods of elevated discharges may occur during shutdown at the end of the fuel cycle or during start-up.

The PC-CREAM 08 system is designed for assessing the dispersion and effects of continuous releases, but is not suitable for assessing short duration releases. Environmental models are available to assess the dispersion of short duration releases to the atmosphere. Appropriate short duration release models include ADMS (CERC, 2012) and AERMOD (US EPA, 2004). The RP has used ADMS version 5 (CERC, 2012). This model can provide estimates of transient concentrations of pollutants in air at ground level from a defined release over short time frames such as 30 minutes. Deposition onto the ground and through the environment, including in soil and plants, is derived from the short duration air concentrations.

Collective doses to the UK, Europe and the world from continuous discharges also need to be assessed. This takes into account the distribution of radioactivity over these population groups. The PC-CREAM 08 system is suitable for calculating collective doses from discharges of gases and particulates to atmosphere and liquid discharges. The RP has used PC-CREAM 08 (Smith et al., 2009) to estimate collective doses over 500 years to these populations per year of discharge.

## Initial assessment

We made an initial assessment of the radiological impact the RP provided in its submission (GNSL, 2017). We reviewed the assumptions and repeated the stage 1 and stage 2 assessment. We reviewed the assumptions for the stage 3 assessment and sought clarification of parts of the technical approach to the assessment via Regulatory Queries (RQs) - see section 3.4.

## Detailed assessment

We carried out a detailed assessment of the PCER-002 and PCER-007 (section 2.3). The assessment considered the resolution of the RQs raised during the initial assessment (section 3.4), a review of the completed method and results for the detailed assessment; the verification of the dose assessment outcomes and our independent dose assessment.

We reviewed the assumptions and repeated the stage 1 and stage 2 assessment. We reviewed the assumptions for the stage 3 assessment and sought more information and clarification of the updated assessment via further RQs. The RQs raised during our detailed assessment are summarised in section 3.4.

The direct radiation dose to members of the public was assessed based on modelling and calculations and justified by operational experience. However, there will be additional sources of direct radiation (spent fuel store and radioactive waste store) that will arise during future operations. These buildings are currently at concept design stage and, therefore, the doses to the public have been assessed based on the conservative assumption that the stores are full of spent fuel and radioactive waste (GNSL, 2019; GNSL, 2021d).

## Results

The results of the dose assessment were compared with the dose constraints and limits for the public set by EPR 2016. The dose impact results may also be included in decisions around BAT and abatement options.

There are no regulatory limits and constraints for collective dose. Collective dose is mainly an input when comparing options. In addition, collective doses can be converted to per capita doses, which give an indication of average annual doses and can be assessed against criteria set by PHE (Environment Agency et al 2012).

## Stage 1 and stage 2

The initial assessments provide an early indication of doses to the public and adopt a cautious and generic approach. The dose criterion for initial assessment is 20 μSv/y. Initial assessment of the impact and decisions can be made using a stage 1 assessment. There is a need for a refined assessment at the second stage if doses are above 20 μSv/y. The second stage, therefore, is to refine the initial assessment using any more specific data related to expected dispersion of the source term. If doses from the second stage remain above 20 μSv/y, a third stage using a more detailed assessment is carried out using a more detailed model if appropriate.

For discharges from a single UK HPR1000 reactor (GNSL, 2021c), the RP reported the following doses for stage 1 and 2 (Table 1):

**Table 1. The Requesting Party stage 1 and stage 2 doses**

| Route | Stage 1 doses (μSv/y) | Stage 2 doses (μSv/y) |
|---|---|---|
| Liquid discharges | 27.8 | 21.4 |
| Discharges to atmosphere | 140 | 22.3 |
| Direct radiation | 6.3 | 6.3 |
| Total | 174 | 50.0 |

The main change in predicted doses between stage 1 and stage 2 is due to changes in the modelling assumptions for environmental dispersion. For discharges to atmosphere, stage 1 assumes a release at ground level. Stage 2 assumes an effective stack height of 20 m. Increasing the effective stack height leads to more dilution of the release and lower air concentration at ground level at the distances of interest.

Stage 1 for discharges of liquids assumes a cautious initial volumetric exchange of sea water between the local compartment and the compartment representing the open sea. This is the default cautious value for an initial assessment. Volumetric exchange is crucial to dispersion of sea water and radionuclides at the release point. The stage 2 assessment adopts published values for the Bradwell area for volumetric exchange, which are greater than the default used for initial assessment. The volumetric exchange for the Bradwell area is a greater initial dispersion, leading to lower predicted radionuclide concentrations in the water.

## Stage 3 - Individual doses

The RP carried out a detailed assessment (stage 3). The assessment included doses from discharges to atmosphere, liquid discharges and offsite direct radiation. The results are summarised below.

The radiological assessment results in the RP's submission version 002 (GNSL, 2021c) are summarised in the tables below.

Table 2 shows the individual doses to several groups. Adults most exposed to discharges of liquids received the highest doses. The adult was a member of a fishing family living close to the site and consuming local food (Table 2a). Their doses were predicted to be 16.5 μSv/y from liquid discharges and discharges to atmosphere. In addition, a dose of 6.3 μSv/y from direct radiation has been assessed, giving a total dose of 22.8 μSv/y. The largest dose pathway is from eating fish and shellfish (11 μSv/y). In the same group, the total doses to other ages are lower (9.6 μSv/y to infants and 12.4 μSv/y to children).

The RP's submission also presents doses to a local resident farming family most exposed to discharges to atmosphere (Table 2b). Doses to adults in this group are slightly lower than those in the fishing family, but doses to infants and children are higher. Doses from discharges are in the range 12 to 15.7 μSv/y, of which discharges of liquids contribute 0.6 to 3.0 μSv/y. This group, who also live close to the reactor, are also projected to receive a dose from direct radiation of 2.2 and 6.3 μSv/y. Their total doses are 17.9 μSv/y to an infant, 15.8 μSv/y to a child and 18.3 μSv/y to an adult.

Therefore, the RP's assessment shows that the representative person is an adult member of a possible fishing family who live close to the reactor and are most exposed to discharges of liquids, with some exposure to discharges to atmosphere and direct radiation. The total dose to the adult is expected to be 22.8 μSv/y (rounded up to 23 μSv/y) from one reactor.

Table 2c shows the contribution of radionuclides to the doses from discharge. Carbon-14 is the main radionuclide, accounting for more than 95% of the dose from discharges.

The highest dose to infants and children are as members of a different group - resident farming family who lives close to the site and is most exposed to discharges to atmosphere. Their doses are 15.8 to 18.3 μSv/y respectively.

Doses from short duration releases to the atmosphere are shown in Table 2d and range from 5.8 μSv/y for adults and children to 9.7 μSv/y for infants. The RP has assumed that radionuclides may be discharged as part of the short duration release under normal operation. The assessment assumed a release of radionuclides equivalent to a month's worth over 24 hours, in summer, later in the growing season and before harvesting. The majority of the dose (87-89%) is from carbon-14. The consumption of foods and the time of year assumed for the release (summer and before harvest) tends to maximise the doses from food. These doses can be included with the dose to the representative person dose. Adults most exposed to liquid discharges plus the dose from short duration releases gives a dose of 28.6 μSv/y to adults.

In its submission, the RP has included doses from short duration releases to the assessed doses from ongoing discharges. The RP presents a cautious bounding outcome of dose from the summation of doses from continuous discharges, from short term discharges and direct radiation. The doses 33.1 μSv/y to an adult; 22.9 μSv/y to a child and 27.9 μSv/y to an infant members of a local resident family.

Doses estimated during GDA can be compared with several dose criteria. The main criterion is the EPR 2106 source dose constraint of 300 μSv/y. Doses for comparison are total doses to the public offsite from a single source - comprising doses from future discharges and doses from future direct radiation. Another criterion is the EPR 2016 site dose constraint of 500 μSv/y. Doses for comparison with the site constraint are doses to the public from future discharges. The doses from discharges should include doses from any other source-making discharges, for example, where the source is on an adjacent site. The potential doses from the UK HPR1000 are well below the source dose constraint for the public of 300μ Sv/y.

All of the sites listed in the Nuclear National Policy Statement (UK Parliament 2011a, 2011b) as potentially suitable for a new nuclear power plant are adjacent to existing nuclear power plants. During GDA, the specific site at which a UK HPR1000 will be located is not yet confirmed. However, it is very unlikely that doses from future discharges at any of the potential sites will exceed the site dose constraint of 500 μSv/y or the overall dose limit for members of the public of 1,000 μSv/y (1 mSv/y). However, if we receive an application for a permit for a site where UK HPR1000s will operate, another dose assessment will be required using site-specific factors and the outcomes compared with the site dose constraint and dose limit for the public.

**Table 2. Summary of individual doses from discharges from a single UK HPR1000 in the Requesting Party submission (Stage 3 assessment) (GNSL 2021c)**

| Table 2a Overall prospective dose µSv/y to the local fishing family (most exposed to liquid discharges) | | | | |
|---|---|---|---|---|
| Age group | Liquid discharges | Discharges to atmosphere | Direct radiation | Total |
| Adult | 11.2 | 5.3 | 6.3 | 22.8 |
| Child | 4.3 | 4.9 | 3.2 | 12.4 |
| Infant | 0.9 | 6.5 | 2.2 | 9.6 |

| Table 2b Overall prospective dose µSv/y to the local resident family (most exposed to discharges to atmosphere) | | | | |
|---|---|---|---|---|
| Age group | Liquid discharges | Discharge to atmosphere | Direct radiation | Total |
| Adult | 2.2 | 9.8 | 6.3 | 18.3 |
| Child | 3.0 | 9.6 | 3.2 | 15.8 |
| Infant | 0.6 | 15.1 | 2.2 | 17.9 |

| Table 2c Contribution of radionuclides in discharges to the dose to adult members of the local fishing family. | | | | |
|---|---|---|---|---|
| Radionuclide | Dose from liquid discharges | Dose from terrestrial foods[#] | Total | % contribution |
| C-14 | 11.1 | 5.22 | 16.3 | 98.5 |
| Co-60 | 0.08 | 0.00 | 0.08 | 0.5 |
| H-3 | 0.04 | 0.11 | 0.15 | 0.9 |
| All others[@] | 0.0 | 0.01 | 0.01 | 0.05 |
| Total | 11.2 | 5.3 | 16.6 | 100 |

[#]From discharges to atmosphere

[@] 114 radionuclides including I-131

| Table 2d Dose µSv to the local resident family most exposed to a short term discharge to atmosphere. | |
|---|---|
| Age group | Total |
| Adult | 5.8 |
| Child | 5.8 |
| Infant | 9.7 |

## Stage 3 - Accumulation of radionuclides in the environment

In its submission, the RP has included modelling of the accumulation of radionuclides in the environment (sea bed sediment, sea water and soil) from 60 years of discharges to the marine environment and to the air. Modelling accumulation gives an estimate of the maximum predicted concentrations in the environment from 60 years of ongoing discharges and takes them into account appropriately in the assessment. The modelling shows that initially radionuclides increase in concentration in the environment with time. The modelling the RP presented shows that radionuclides reach equilibrium in 20 years or less in the marine environment. For soil, concentrations of some radionuclides increased for a longer time after releases to air, taking up to 60 years to approach equilibrium. The RP's assessment is for 60 years of operation and release period and uses concentrations

predicted to have accumulated after 60 years. Therefore, the RP's radiological impact assessment takes into account accumulation in the environment.

## Stage 3 - Collective dose

Collective dose is the sum of all individual effective doses over a defined population over a set period of time. Collective doses are assessed for future discharges and can be used for optimisation decisions, including decisions on abatement options.

The RP has estimated collective doses per year of discharge for the UK, Europe and the world populations from discharges from a single UK HPR1000 reactor (GNSL, 2021c). The calculations are made, using appropriate models, taking into account the levels of radioactivity in the environment, including food and global circulation. Results have been calculated for the UK, Europe and the world from one year of discharge. The collective doses are calculated over a period of (or truncated at) 500 years (Table 3). Collective doses range from 0.7 man-Sievert (man-Sv) per year of discharge for discharges to atmosphere for the UK population to 29.7 man-Sv per year of discharge for the world population. Carbon-14 in discharges to atmosphere is the main contributor to the collective doses due to its long half-life and its mobility which allows global circulation. Collective doses from liquid discharges were lower, less than 1 man-Sv per year of discharge for all populations.

**Table 3. Summary of collective doses (up to 500 years) man-Sv per year of discharge from a single UK HPR1000 in the Requesting Party submission**

| Population | Dose from liquid discharges (manSv/y) | Dose from discharges to atmosphere (manSv/y) | Total |
|---|---|---|---|
| UK | 0.013 | 0.68 | 0.69 |
| EU-12 | 0.078 | 3.59 | 3.67 |
| EU-25 | -- | 3.88 | 3.88 |
| World | 0.743 | 29.7 | 30.4 |

Collective doses can be used to estimate average annual individual doses in a population by calculating per caput doses (Health Protection Agency, 2009). Average annual individual doses for a population group in the nano-Sievert per year (nSv/y) range or below can be ignored in the decision-making process as the contribution to total doses to individuals is very small. Higher annual average doses, up to a few micro-Sievert per year (μSv/y), are still low but may require some consideration, particularly if they are approaching a few micro-Sieverts. Calculated annual average individual doses in excess of a few micro-Sievert should prompt careful consideration of the potential discharge options (Environment Agency et al., 2012).

In the RP's assessment, the collective doses were used to derive average individual doses. The average doses from a single UK HPR1000 unit from liquid discharges are 0.22 nSv/y, 0.22 nSv/y and 0.007 nSv/y for the populations of the UK, Europe and the world, respectively. The average individual doses from discharges to atmosphere are 11.4 nSv/y; 10.0 nSv/y; and 2.97 nSv/y for populations of the UK, Europe and the world, respectively.

## Independent assessment

Our independent assessment included an initial assessment at stage 1, stage 2 and, in detail, at stage 3. For the initial assessment, the stage 1 outcome from discharges was 148 μSv/y and the doses were mostly from releases to atmosphere. For the initial assessment at stage 2, our assessment outcome from discharges was 44 μSv/y. In the stage 2 initial assessment, the outcome was balanced between doses from discharges to atmosphere and discharges to the marine environment. This is similar to, but slightly lower than, the RP's radiological assessment.

For the detailed assessment at stage 3, our independent assessment results are summarised in Table 4 (individual doses). More details of the independent dose assessment will be published separately (Environment Agency, 2021a).

**Table 4. Summary of individual doses from discharges from a single UK HPR1000 from our independent dose assessment**

| Table 4a Overall prospective dose μSv/y to the local fishing family (most exposed to liquid discharges) | | | | |
|---|---|---|---|---|
| Age group | Liquid discharges | Discharges to atmosphere | Direct exposure | Total |
| Adult | 8.0 | 7.0 | 0.44 | 15.4 |
| Child | 2.4 | 7.7 | 0.22 | 10.3 |
| Infant | 0.61 | 9.8 | 0.15 | 10.6 |

| Table 4b Overall prospective dose µSv/y to the local resident family (most exposed to discharges to atmosphere) | | | | |
|---|---|---|---|---|
| Age group | Liquid discharges | Discharges to atmosphere | Direct exposure | Total |
| Adult | 0.98 | 11 | 0.44 | 12.4 |
| Child | 0.68 | 12 | 0.22 | 12.9 |
| Infant | 0.43 | 21 | 0.15 | 21.6 |

| Table 4c Dose µSv to the local resident family (most exposed to discharges to atmosphere) for a short-term discharge | |
|---|---|
| Age group | Total |
| Adult | 6.9 |
| Child | 6.0 |
| Infant | 7.8 |

Doses to the group most exposed to discharges of liquids (fisherman family) ranged from 0.6 µSv/y (infant) to 8.0 µSv/y (adult). The majority of the dose is from carbon-14 (up to 99%). The doses are lower than those the RP assessed from liquid discharges, which ranged from 0.8 µSv/y (infant) to 11.0 µSv/y (adult). The main reason is due to differences in the definition of the marine environment at the release point. The RP used a lower volumetric exchange rate and larger volume of marine water at the release point than the independent assessment - this leads to higher water concentrations and higher doses.

Total doses to the fisherman family that include all sources of discharge (liquids and gases and some particulates to atmosphere) and direct radiation range between 10.3 µSv/y (infant) and 15.4 µSv/y (adult). There is a significant contribution to doses from discharges to atmosphere. The doses are similar to but lower than those the RP assessed (Table 2), which ranged from 9.6 µSv/y (infant) to 22.8 µSv/y (adult). The doses the RP predicted are higher due to 2 main factors. Firstly, the contribution from liquid discharges is higher for the reasons described above. Secondly, the contribution from direct radiation is higher for the reasons described below.

The RP predicted doses from direct radiation of between 2.2 and 6.3 µSv/y. The dose from direct radiation in the independent assessment is low (less than 1 µSv/y). This is because

in the RP's assessment the receptor is at 100 m. In the independent assessment the exposed group is assessed further from the site (300 m from the release point). A distance of 300 m is used in the independent dose assessment because the ground level air concentrations and therefore doses from atmospheric releases are higher at 300 m compared with 100 m.

For the group most exposed to discharges to atmosphere, the independent assessment shows doses ranging from 11 to 21 µSv/y across the age groups. The majority of the dose is from carbon-14 (up to 96%). The doses are similar to, but higher than, the RP's assessment in which the estimated doses from discharges are between 12.0 and 15.7 µSv/y. The main reasons are that in the independent assessment the radiological impact assumes the group is at 300 m from the release point. The air concentrations are higher at 300 m than at 100 m, which is used in the RP's assessment. In addition, the independent assessment uses generic habits data which include consuming (drinking and eating) milk products. Consuming milk products is not included in the RP's assessment.

Total doses to the local resident family including all sources of discharge (gases and some particulates to atmosphere and liquids) and direct radiation range between 12.4 µSv/y (adult) and 21.6 µSv/y (infant). There is a small contribution to doses from discharges as liquids of 0.4 µSv/y to 1.0 µSv/y. The doses are similar to those the RP (Table 2), which ranged from 15.8 µSv/y (child) to 18.3 µSv/y (adult).

Doses from short duration releases to atmosphere are between 6.0 and 7.8 µSv for each event. Doses from short duration releases in our independent assessment are close to those in the RP's submission which ranged from 6.0 to 9.7µSv. Both assessment outcomes are dominated by ingesting carbon-14 in food.

Total doses that include all sources of discharge (gases and particulates to atmosphere and liquids), direct radiation and doses from short duration releases to atmosphere range between 16 and 29 µSv/y.

The comparison between our independent dose assessment and that the RP submitted allow us to confirm the following conclusions:

- This broad agreement strongly indicates that the potential dose from discharges from the reactor will be well below the source dose constraint for the public of 300 µSv/y.
- Discharges to atmosphere and liquid discharges both contribute to the doses in the independent dose assessment. Doses from discharges to atmosphere are higher than doses from liquid discharges. Milk production consumption and higher ground level air concentrations at the receptor contribute to higher doses from discharges to atmosphere and higher marine dispersion parameters result in lower doses from discharges of liquids.
- Carbon-14 is the dominant nuclide in terms of the doses from discharges (up to 99% of the dose).

Collective doses from our independent assessment are summarised in Table 5.

**Table 5. Summary of collective doses (up to 500 years) man-Sv per year of discharge from a single UK HPR1000 from our independent dose assessment (Environment Agency 2021a)**

| Population | Dose from liquid discharges | Dose from discharges to atmosphere | Total |
|---|---|---|---|
| UK | 0.013 | 0.71 | 0.72 |
| EU | 0.078 | 4.1 | 4.18 |
| World | 0.74 | 30 | 30.7 |

## Interfaces with ONR assessment

We interface with ONR on radiological protection for direct radiation offsite (to the public). ONR regulates direct radiation received by the public offsite. We have consulted with ONR to confirm the offsite dose rates to the public in the PCER are consistent with those in safety related publications (GNSL, 2021d).

There are several potential sources of direct radiation from a site, including the reactor, radioactive waste stores and spent fuel stores. Dose rate data from on-site waste stores and spent fuel store are at concept design only and are based on calculations rather than measurements. ONR raised a Regulatory Observation (RO-UKHPR1000-0028) on Adequate Justification of the Estimated Public Doses for UK HPR1000. This sought to ensure that the RP demonstrated that public doses close to a power plant similar to and representative of the UK HPR1000 are in the measurable range of background, and to provide information to allow ONR to judge whether the direct radiation doses from the UK HPR1000 will be reduced as low as reasonably practical (ALARP).

Environment Agency questions were included in a number of Regulatory Queries to resolve RO-UKHPR1000-0028, which has now been closed. The conclusions and findings of RO-UKHPR1000-0028 are consistent with those the RP reported in its submission (GNSL, 2021c). The RP has provided additional information about the measurements of doses rates in the environment near power stations in China and information on the assessment of doses by modelling and calculation. This information has been used to refine the direct radiation doses to the public presented in the RP’s submission (GNSL, 2021c).

## 3.3. Radiological impact - wildlife

### Main assumptions

The RP based its wildlife radiological assessment on the following assumptions:

- Radioactive waste from a UK HPR1000 was discharged at proposed permitted limits.
- Radiological discharges accumulated in the environment for 60 years of operation.
- Discharges to atmosphere were assumed to occur at ground level.
- PC-CREAM 08 was the tool used for environmental dispersion or radionuclides in terrestrial and marine environments.
- ERICA was the tool used for wildlife dose assessment (plus the Ar-Kr-Xe dose calculator for assessing noble gases).
- Wildlife was located 100 m from the release point for assessing dose rate from discharges to atmosphere.
- Wildlife was located in the local marine environment for assessing dose rates from liquid discharges.
- The dose rate criterion for wildlife dose assessments, used to compare outcomes with, was 10 μGy/h.

### Assumptions about discharges

It is suitably cautious to base this radiological assessment on the assumption that discharges from a single UK HPR1000 reactor (GNSL 2021c) were made for 60 years at proposed limits and that they accumulate in the soil, air and seabed sediment. It is also cautious to assume that discharges to atmosphere are made at ground level. This assumption results in the highest activity concentrations in air. In reality, discharges to atmosphere will be from a stack, enabling more dispersion and dilution than a release at ground level, and discharges will be below the proposed discharge limits. We are content that these assumptions concerned with discharges are appropriate and acceptable.

### Assumptions on modelling systems

Radiological assessment to wildlife involves dispersion modelling to predict the radionuclide activity concentrations in the environment resulting from gaseous and liquid discharges, followed by an assessment of the impact of these radionuclides in the environment on wildlife.

PC-CREAM 08 is a widely accepted system used for dispersion modelling to derive radionuclide activity concentrations in the environment from routine discharges (Smith and Simmonds 2009). PC-CREAM 08 can be used to predict radionuclides concentrations in soil, sediment, air and water from the expected atmospheric and liquid discharges made over a set time period. The concentrations can be used to assess dose rates and risks to wildlife.

A number of systems have been developed to assess the dose rate and risk to wildlife from ionising radiation in the environment. The accepted system for use in European ecosystems is the 'Environmental Risk from Ionising Contaminants: Assessment and Management' (ERICA) integrated approach (Beresford et al., 2007; Brown et al., 2007; Brown et al., 2016).

The ERICA tool calculates the radiation dose rate that wildlife is likely to receive from a defined environmental activity concentration of a radionuclide. Due to the lack of species-specific transfer data available, a reference organism approach is used to represent species of interest. The reference organisms included in the ERICA tool have been selected to be typical or representative of European ecosystems and include terrestrial, freshwater and marine environments.

The ERICA integrated approach is organised into 3 separate tiers:

- Tier 1 is simple and conservative – it requires a minimal amount of input data, the user can select radionuclides from a default list and the results are for the combination of reference organisms that are exposed to the highest dose rates.
- Tier 2 is more specific and less conservative – the user can enter input data such as radionuclides that are not on the default list and edit transfer parameters. The results are calculated for each reference organism individually.
- Tier 3 is a probabilistic risk assessment in which uncertainties within the results may be determined using sensitivity analysis, and biological effects data needs to be considered - the situations requiring a tier 3 assessment are likely to be complex and unique.

The results produced from the ERICA tool includes a risk quotient, which provides a probability that the selected dose rate criteria may be exceeded.

The ERICA tool does not allow the assessor to consider the impact of radioactive noble gases. One tool that does allow this is the Argon-Krypton-Xenon (Ar-Kr-Xe) dose calculator (Vives i Batlle et al., 2015). This tool is based on the R&D 128 methodology (Copplestone et al., 2001) and consists of a basic tool with limited radionuclides which carries out a conservative assessment for reference organisms. This is the appropriate tool to use for assessing dose rates to wildlife from noble gases. The ERICA tool and the Ar-Kr-Xe dose calculator contain the same terrestrial reference organisms so dose rates can be summed to give a total dose rates to terrestrial wildlife.

We are content that the RP has used the appropriate tools for environmental dispersion modelling and dose assessment for wildlife.

## Assumptions about the location of wildlife receptors

We issued RQ-UKHPR1000-0828 in May 2020, requesting clarification of receptor locations used for the wildlife radiological assessment. The RP responded in June 2020 providing these details. The RP assumed that terrestrial wildlife was located 100 m from the point of atmospheric discharge for the terrestrial assessment. This is consistent with the location of human receptors for the public radiological assessment. The RP assumed

that marine wildlife was located in the local environment for the marine assessment. We are content that the assumptions the RP made regarding wildlife receptor locations are appropriate for GDA.

## Assumptions about dose rate criteria

The doses to wildlife are absorbed dose rate in units of µGy/h. The default dose rate screening value in the ERICA tool is a dose rate of 10 µGy/h to be used for all ecosystems and all organisms. The criterion of 10 µGy/h is a screening value that is appropriate to use for a generic site when we cannot determine what impacts there may be from other sources of radioactive waste. For site-specific assessment, the Environment Agency, Natural England and Natural Resources Wales have agreed a dose rate criterion of 40 µGy/h, below which it is concluded that there are no adverse effects on the integrity of Natura 2000 sites. The RP used a dose rate criterion of 10 µGy/h. As GDA is based on a generic site, we agree that the appropriate dose rate criterion for wildlife is 10 µGy/h.

## Assessment

In its submission, the RP detailed the wildlife radiological assessment (GNSL 2021c).

The RP used PC-CREAM 08 to derive radionuclide activity concentrations in soil and seabed sediment. The RP then used the ERICA tool (version 1.3) and the Ar-Kr-Xe dose calculator to calculate dose rates to wildlife. Assessments of the impact of discharges to atmosphere were made to the default terrestrial reference organisms in the ERICA tool. Assessments of the impact of liquid discharges were made to the default marine reference organisms in the ERICA tool. The RP states that the UK HPR1000 will not make any discharges to the freshwater environment and, therefore, it did not consider impact on reference organisms inhabiting the freshwater environment. ERICA assessments were carried out at tier 2 as tier 1 did not include all of the radionuclides that the RP predicts will be discharged from the UK HPR1000.

The RP has used the following parameters in its ERICA tier 2 assessment:

- default ERICA reference organisms were used for the terrestrial and marine environments
- default ERICA values for transfer parameters were used where available
- where default values for transfer parameters were not available in the ERICA tool, values were manually assigned, including those for iron (Fe), bromine (Br), sodium (Na), molybdenum (Mo) rubidium (Rb) and yttrium (Y)

We issued RQ-UKHPR1000-0518 in October 2019 to clarify the reference organisms the RP used and the justification for using them. The RP responded in December 2019 confirming details of the ERICA default reference organisms used in its assessment and also justifying their use as being suitable to represent UK wildlife. We accepted this response. The ERICA tool and its reference organisms are designed to represent species in European ecosystems. Therefore, we are content that it is appropriate to use these reference organisms to represent UK wildlife. In addition, it is appropriate to use the

default transfer parameters in the ERICA tool for this assessment. We agree that the approach the RP used to fill data gaps is appropriate and conservative.

The RP has not considered the impact that discharges of radionuclides might have on freshwater organisms as the UK HPR1000 generic site assumes no discharges are made to freshwater bodies. As part of any site-specific assessment, any future operator will need to consider if an assessment to freshwater organisms is needed.

## Results

Initially, the RP did not provide details of dose rates for each reference organism/radionuclide combination, instead only providing total dose rates for each reference organism from all radionuclides. We issued RQ-UKHPR1000-0205 (section 3.4) in February 2019 requesting more details on the wildlife radiological assessment, including a breakdown of dose rates for each reference organism/radionuclide combination, details of any non-default ERICA parameters used and details of the carbon-14 and tritium air concentrations used in the assessment. The RP responded in March 2019 providing these details to us and including them in a later revision of the submission (GNSL 2021c).

The RP's terrestrial wildlife dose assessment identified that the reference organism exposed to the highest dose rates was the reptile, which received a dose rate of 0.15 µGy/h.

The RP's marine wildlife dose assessment identified that the reference organism exposed to the highest dose rate was the polychaete worm, which received a dose rate of 0.0063 µGy/h.

As the ERICA tier 2 assessment criteria were met, the RP did not carry out an ERICA tier 3 assessment.

The RP has shown that the dose rates to reference organisms in the terrestrial and marine environments are well below the dose rate criterion of 10 µGy/h.

During our assessment, we reviewed the RP's submission and repeated its wildlife dose assessments, using its input parameters to check its assessment. We initially assessed PCER chapter 7 version 001, dated January 2020. When we repeated the RP's assessment using its input parameters, we obtained results that were consistent with the RP's for the marine assessment. However, for the terrestrial assessment, there were apparent discrepancies in some of the data. The concentration ratio data presented in revision 001 of the submission reported to be ERICA default data, but did not match the default data in the ERICA tool. Also, there appeared to be some errors in the reporting of dose rates from the noble gas assessment. We queried these discrepancies in RQ-UKHPR1000-0830.

A full response to RQ-UKHPR10000-0830 was received in June 2020, which gave clarification and corrections, which were included in the submission PCER chapter 7 revision 001-1 (GNSL 2020a). We repeated the terrestrial and marine wildlife dose

assessments using the ERICA tool, and obtained results that were consistent with the RP's. When we repeated the noble gas assessment, most of the results we obtained were consistent with the RP's results except for dose rates from argon-41 and also the dose rates to the reference organism shrub. It appeared that the RP had inaccurately transcribed some results from the Ar-Kr-Xe dose calculator tool, reporting results from incorrect reference organisms for argon-41, and also reporting dose rates of zero for shrub resulting from exposure to radionuclides of krypton and xenon. However, the Ar-Kr-Xe dose calculator tool actually reports very low dose rates to the shrub reference organism from krypton and xenon. We are content that these inaccuracies are limited to reporting errors and are not as a result of incorrectly using the tool or inappropriately inputting the data. The dose rates to wildlife from discharges of noble gases are very low and the reporting errors make no difference to the overall conclusions of the assessment. However, it does change the worst affected terrestrial reference organism to a bird, receiving a dose rate of 0.14 µGy/h.

In summary, we are content that the wildlife radiological assessment the RP carried out is suitably conservative and repeatable, noting the minor reporting errors for Ar-41 in the noble gas assessment. The RP has corrected these errors (GNSL, 2021c).

## Independent assessment

We employed a technical support contractor (TSC) (see section 2.5) to carry out an independent wildlife dose assessment, using our independently derived environmental activity concentrations of radionuclides (Environment Agency 2020a).

The results of the RP's assessment and our independent assessment differed slightly due to differences in the input parameters used. However, our independent assessment also shows that dose rates to wildlife are well below the dose rate criterion of 10 µGy/h, see Tables 6a and 6b.

**Table 6a: Results of the Requesting Party assessment and our assessment of dose rates to wildlife - Terrestrial assessment from discharges to atmosphere**

| Data source | Highest dose rate to worst affected reference organism (µGy/h) | |
|---|---|---|
| | RP results | Our results |
| RP | 0.15 (reptile) | 0.14 (bird) |
| Independent assessment | Not applicable* | 0.13 (mammal - large and small burrowing) |

*our independent assessment did not repeat these parts of the RP assessment

**Table 6b: Results of the Requesting Party assessment and our assessment of dose rates to wildlife - Marine assessment from liquid discharges**

| Data source | Highest dose rate to worst affected reference organism (µGy/h) | |
|---|---|---|
| | RP results | Our results |
| RP | 0.0063 (polychaete worm) | Same as the RP |
| Independent assessment | Not applicable* | 0.023 (mammal) |

*our independent assessment did not repeat these parts of the RP assessment

The dose rates the RP derived are slightly lower than those from our independent assessment. These differences are due to variations in the assumptions and parameters used including:

- location of wildlife receptors: the RP assumed that terrestrial wildlife was located 100m from the release point, while our independent assessment assumed a location of 300m from the release point, where modelled activity in air concentrations were higher
- concentration ratios (CR): the RP and our independent assessment used ERICA default data where available. Where concentrations ratios were not available in the ERICA tool, the RP assigned the highest CR for any radionuclides for reference organisms. Our TSC assigned CR data published by IAEA where available (IAEA 2004)

## 3.4. Regulatory Queries raised

A series of Regulatory Queries were raised during the initial assessment and the detailed assessment. These are shown below.

- RQ-UKHPR1000-0061 - Clarification if a stage 3 public dose assessment of the effect of discharges on the environment will be made and provided.
- RQ-UKHPR1000-0062 - Further information request - the method used to make the assessment of a short duration releases.
- RQ-UKHPR1000-0063 - Further information request – model selection for assessing impact of discharges on the environment.
- RQ-UKHPR1000-0201 - Comparison of doses with criteria.
- RQ-UKHPR1000-0202 - RQ-UKHPR1000-0063. Further information request - model selection and use for the effect of discharges on the environment.
- RQ-UKHPR1000-0203 - Legitimate uses of the environment.
- RQ-UKHPR1000-0204 - Summary of doses.
- RQ-UKHPR1000-0205 - Non-human biota (Wildlife) radiological assessment: ERICA inputs and outputs.
- RQ-UKHPR1000-0249 - Incomplete response to RQ-UKHPR1000-0205.
- RQ-UKHPR1000-0517 - Assessment of foetal exposure.
- RQ-UKHPR1000-0518 - Justification of data PCER-02 generic site.
- RQ-UKHPR1000-0519 - Habits data used – clarity of information.
- RQ-UKHPR1000-0520 - Presentation of doses in the submission – clarity of information.
- RQ-UKHPR1000-0521 - Short-term release assessment.
- RQ-UKHPR1000-0522 - Stage 2 assessment of discharges – possible error.
- RQ-UKHPR1000-0523 - Build-up of radionuclides in the environment over time.
- RQ-UKHPR1000-0828 - Receptor positions not presented in PCER-002.
- RQ-UKHPR1000-0829 – Which of the dose principles apply; clarification of the calculation of doses from short duration releases and collective doses.
- RQ-UKHPR1000-0830 – Check the assessment of dose rates to non-human biota (wildlife) from gases and noble gases

For each of these queries we received a satisfactory response.

## 3.5. Assessment Findings

We are content that the generic site defined is appropriate to use in this GDA and there are no Assessment Findings.

The radiological assessment shows that the radiological impact will be low, and that the dose to the public meets the dose constraint. Similarly, dose rates for wildlife meet the

dose rate criteria. Our independent assessment and our verification confirm the low impact.

Discharges of carbon-14 to the atmosphere and the marine environment will give more than 90% of the total dose from discharges.

Assessment Findings are given in the BAT assessment report requiring a future operator to review the practicability of techniques for abating carbon-14; for a future operator to assess the chemical form of carbon-14 discharged to the environment and use this to inform future dose assessments and optimise the balance between gaseous, liquid and solid phase of carbon-14 (Environment Agency 2020c).

## 3.6. Compliance with Environment Agency requirements for GDA

Compliance with Environment Agency requirements are summarised below.

Generic site

- P&ID Table 1 (generic site) - Appropriate data provided, for coastal site.
- REP SEDP1 - General principle for siting of new facilities - Appropriate government policy documents relating to siting of new reactors are identified and referenced and relevant factors are taken into account in generic site description.
- REP SEDP2 - Migration of radioactive material in the environment - The generic site description allows for an assessment of migration of radioactivity in the environment by providing information that can be used for modelling the process.

Radiological assessment - Public

- REP Fundamental principle E – Protecting Human Health and the Environment.
- REP RPDP1: Optimisation of protection - The radiological assessment outcomes are an input to optimisation of protection.
- REP RPDP2: Dose limits and constraints - The radiological assessment outcomes have been compared with the dose constraint.
- REP RPDP4: Prospective dose assessments for radioactive discharges to the environment - Prospective dose assessment is part of the RP’s submission PCER 007.

Radiological assessment - Wildlife

- REP RPDP3 Protection of non-human species - An assessment of dose rates to wildlife is part of the RP’s submission PCER 007.

# 4. Public comments

## 4.1. The Requesting Party GDA comments process

There have been no comments from the public to the RP's GDA comments process up to 17 September 2021 relating to selecting the generic site for GDA.

There have also been no comments from the public to the RP's GDA comments process up to 17 September 2021 directly relating to the radiological assessment from the UK HPR1000 reactor for GDA.

There have been comments about health effects and radiation which are not directly related to the UK HPR1000. The comments include inferred high levels of mortality around the Bradwell site, the overall risk from radiation and suggested increases in discharges from another nuclear power plant at another location. However, the radiological assessments made for the UK HPR1000 show that the UK HPR1000 can meet the current UK radiation protection arrangements, the requirements for optimisation and the dose constraints for the public.

## 4.2. Public consultation

A number of comments relevant to generic site and radiological assessment were received during the Environment Agency public consultation between 11 January and 4 April 2021. We have considered all responses and some responses relevant to this report are discussed below.

**UKHPR1000-007** - The respondent noted that PHE was reported to have stated "not all organisations use one in a million health detriments as a regulatory criterion for assessing acceptable risk", and that "work is going on about tolerability". We were asked what criteria will be applied to the UK HPR1000 and how any discrepancies in health detriment estimates will be resolved.

The assessment of the doses from discharges from the UK HPR1000 were compared with the dose criteria for the public used in the UK (dose limit and dose constraints). The doses were well below the dose limit and dose constraint. The dose limit and dose constraints are given in Schedule 23 of the EPR 2016 (UK Parliament 2016). It is PHE's role to provide advice on radiation protection to the UK and they endorsed the dose limit and dose constraints for protection of the public. PHE have not advised us of any discrepancies in health detriment estimates.

**UKHPR1000-013** and **UKHPR1000-014** - Both respondents raised a point relating to dose weighting factors. It was noted that relative biological effectiveness factors for wildlife were quoted, but there were none quoted for human dose assessment. The respondent was particularly interested to know what weighting factor was used for alpha activity.

We note that the radiation weighting factors identified in the question are for non-human species and are presented in ERICA report – Beresford et al., (2007) and the FASSET project - Prohl et al., (2003).

The radiation weighting factors for people are taken account of in dose coefficients. Dose coefficients used to calculate effective dose to the public were taken from ICRP-119 (ICRP, 2012). ICRP-119 is a compendium of dose coefficients which serve as a comprehensive reference for dose coefficients based on the primary radiation protection guidance given in the ICRP Publication 60 recommendations (ICRP, 1991). ICRP 60 presented radiation weighting factors ($W_R$) for use in radiation protection. Radiation weighting factors are a dimensionless factor to derive the equivalent dose from the absorbed dose averaged over a tissue or organ, and are based on the quality of the radiation. Radiation weighting factors vary depending on the type of radiation and were published in ICRP-60 (ICRP, 1991). They were used in the derivation of dose coefficients presented in ICRP-119 (ICRP, 2012) and for clarity are reproduced in Table 7. PHE provide advice in the UK on radiation protection including on the recommendations of the ICRP.

**Table 7 Radiation weighting factors ($W_R$) used in dose coefficients for the public**

| Radiation type and energy range | $W_R$ |
|---|---|
| Photons, all energies | 1 |
| Electrons and muons, all energies | 1 |
| Neutrons, energy <10 keV | 5 |
| Neutrons, energy 10 – 100 keV | 10 |
| Neutrons, energy >100 keV to 2.0 MeV | 20 |
| Neutrons, energy >2.0 MeV to 20 MeV | 10 |
| Neutrons, energy >20 MeV | 5 |
| Protons, other than recoil, energy >2 MeV | 5 |
| Alpha particles, fission fragments, heavy nuclei | 20 |

**UKHPR1000-014** – The respondent noted that the assessment was only based on a single unit, that the cooling systems were different to those proposed for Bradwell and that, although the generic site has parameters in common with Bradwell, it cannot be assumed to represent Bradwell. Also, they noted that the assessment does not take into account designated wildlife sites. The respondent thinks we need to be explicit on these points.

GDA is defined as being for one reactor only (section 3.2). If the reactor design is to be built and operated at a specific site, we cannot predict how many units a potential operator may choose to build. As part of an application for an environmental permit, an assessment of the impact of a planned power station would be made, which would allow for the number of reactors in the power station. Site-specific information would be used.

The inclusion of Bradwell specific parameters in the generic site does not suggest the generic site represents Bradwell, but these are included to ensure that the generic site is sufficiently cautious that it will result in a bounding radiological impact assessment for GDA.

The impact of discharges on protected habitats and species would be required as part of a site specific impact assessment if a permit is applied for. An assessment of impact on reference organisms at the generic site was made during GDA. Reference organisms in the assessment are consistent with species that will need to be protected in the UK. This is explained in more detail in section 3.3 (assumptions about dose rate criteria).

**UKHPR1000-018** – The respondent raised a concern that radioactivity would accumulate in the marine conservation zone around Bradwell, adding to that already discharged from Bradwell A.

While site-specific concerns are out of scope of GDA, the accumulation of discharges from other nuclear plants such as Bradwell A would be assessed during an application for a permit. In the case of Bradwell A, the radiological impact of past discharges is captured through monitoring of the environment and an assessment made by the operator and separately by the Environment Agency. The environmental levels and the radiological impact are reported in the RIFE report series (Environment Agency and others, 2020). The impact of future discharges from Bradwell A was assessed when the permit was varied and the power station went into decommissioning. The assessment assumed that all future discharges occurred at the permitted limits - a cautious assumption. The modelling carried out assumes that discharges last for 50 or 60 years and include accumulation of radionuclides in the environment.

The accumulation of discharges from a new nuclear power station would be included in the assessment during an application for a permit. Discharges would be assumed to occur at the discharge limits set in the permit. The assessment will take into account the impact of past and future discharges from other nuclear power stations that are adjacent to the site.

The same consultation response (UKHPR1000-018) also raised a concern that our assessment does not consider ‘spikes’ in discharges.

The RP has made an assessment of the impact from short duration enhanced releases to atmosphere. These are summarised in Table 2c of this report. An independent assessment of doses from short-term releases to atmosphere was also made and the results are presented in Table 4c of this report. Doses to the public are in the range 6 to 10μSv, and vary slightly with age group (adult, child and infant groups). The doses are dominated by the inhalation of the plume and ingestion of foods. Most of the dose was from carbon-14.

**UKHPR1000-019** – The respondent raised a concern that the preliminary assessment report listed so much outstanding information required to define the generic site.

We note that the information listed as missing was related to the findings from our Initial Assessment (Environment Agency, 2018) and not information that was missing as part of our detailed assessment to reach our preliminary conclusions for consultation. This information has been provided during our detailed assessment and no information required for GDA remains outstanding.

**UKHPR1000-021** – This respondent raised concerns that impact assessment studies are always over optimistic to ensure projects proceed.

We are clear throughout this report that discharge estimates and impact assessments made in GDA are cautious. There is overestimation in several areas. The first caution is the assumption that the discharges are made at the proposed permit limits. The proposed permit limits allow for expected events that may result in higher releases which could occur at some point in the lifetime of the reactor. Therefore, basing the assessed discharges on expected permitted limits will be a broad overestimate as actual discharges during normal operation will be less than the proposed permit limits.

Other factors are the assumptions in the assessment about how much local food is eaten, the types of foods eaten and how long people are present either indoors or outdoors. For GDA, the habits data used is based on high intake data taken from UK generalised habits data. This data is generally conservative – resulting in a cautious assessment.

**UKHPR1000-026** – This respondent raised several concerns relating to the consequences of accidents at nuclear sites.

We only assess impacts from discharges from normal operations which include an allowance for expected events/reasonably foreseeable events. ONR assesses the impact from releases from accidents (accident consequence).

**UKHPR1000-043** – This respondent raised multiple points as follows:

a) There are too many unknowns and our language was too vague.
b) Information for the generic site was missing.
c) The RP's model results were 'better' than the Environment Agency's independent assessment.
d) The generic site and habit data does not represent Bradwell.
e) No indication is given how the figures of 20 to 23uSv/y were derived.
f) The assessment considers only a single unit without consideration of any adjacent reactor.

We will address each point in a separate paragraph below:

a) Our assessment is carried out against the standards and guidance referred to in section 2.4 of this report. The use of terms such as 'adequate' and 'acceptable' indicate that the required standards have been met.

b) As noted in our response to UKHPR1000-019, we note that the information listed as missing was related to the findings from our Initial Assessment (Environment Agency, 2018). As part of the normal GDA process, additional information was requested through several RQs. Subsequently, the RP submitted a revised Generic Site document for detailed assessment which contained the information requested in the RQs. All required information has now been received.

c) The assessment the RP made and our independent assessment were carried out by predicting concentrations in the environment using models informed by input data. The concentrations were used with information on habits to make an assessment of the doses to the public. Some differences in outcomes are expected where dose assessments are made independently. The outcomes from the assessments are similar but not identical. The differences in outcomes are because of slightly different input data and assumptions about which habits data to use.

d) The generic site description is not fully representative of Bradwell, but takes account of the Bradwell site parameters. The Requesting Party has set up the model based on some of the input data that are characteristic of the Bradwell

environment. However, the habits data used were a combination of generic UK data and habits observed around the Bradwell site. Generalised habits data include consumption of locallly produced milk. However, consumption of local milk is not observed currently around the Bradwell site. In some cases, habits data from the Bradwell site were included if there was no equivalent generic data. Therefore, the assessment could be considered to be similar to Bradwell with additional conservative (cautious) aspects. If a new power station were to be built and operated in England using the UK HPR1000 reactor, the operator must apply for a site-specific environmental permit. In that case, a site-specific assessment of doses to the public will be required to support the permit.

e) The dose method the RP used is described in its submission in PCER07 (GNSL, 2021c). We also carried out our own assessment (Environment Agency, 2021a). The results were similar. The dose methodology the Requesting Party adopted has been assessed in this report against the published guidance. The guidance is laid out in section 2.4 and includes Regulatory Environmental Principles, principles for the assessment of prospective dose and other technical guidance. These documents contain the methodologies used to derive the reported dose.

f) The assessment in GDA is for a single reactor. This is because we cannot predict how many units a potential operator may choose to include at a particular site. However, we have assessed the known worst case site, which would be adjacent to Sellafield. The total dose for a UK HPR1000 reactor adjacent to Sellafield would be below the dose limit for the public.

**UKHPR1000-044** - The Food Standards Agency (FSA) has reviewed the RP's Pre-Construction Environmental Report (PCER) and proposed radioactive discharge limits. FSA has carried out its own preliminary dose assessments against the proposed radioactive discharge limits and considered the impact on the food chain to inform its response to this consultation. FSA agreed with our preliminary conclusion that the radiation dose to people will be below the UK constraint for any single new source of 300 uSv/y. As such, there will not be an unacceptable impact on the food chain for sites that meet the generic site characteristics. However, the FSA will consider this in more detail on a site-specific basis in its role of advising the Environment Agency in permitting decisions under the Environmental Permitting Regulations.

We note that the Food Standards Agency has assessed that the radiation dose to people will be below the UK dose constraint. The Food Standards Agency has used its model of the food chain. Its assessment has provided a third assessment of impact and is consistent with the RP's and our assessment.

**UKHPR1000-045** - The response from Colchester Borough Council asks how the Council can be reassured that, if approved, GDA for the UK HPR1000 at the generic site has the parameters suitable for specific sites such as Bradwell.

The generic site description takes account of the Bradwell site. The Requesting Party has set up the model based on some of the input data that are characteristic of the Bradwell

environment. However, the habits data used were a combination of generic UK data and habits observed around the Bradwell site. In some cases, data from the Bradwell site were included if there was no equivalent data in the UK generalised habits data. Some of the environmental input data to the model are conservative (cautious). Therefore, the generic site taking account of Bradwell parameters will be a conservative option of the sites outlined in EN-6 (UK Parliament, 2011a). However, if an application were made to deploy UK HPR1000 reactors at Bradwell, the applicant would need to submit a full site-specific impact assessment as part of that application.

**UKHPR1000 047** – This respondent asked:

a) What ecological parameters are used in the GDA to determine that the estimated discharge figures are acceptable?

b) What level of sensitivity and ecological protections are built into the GDA limits, due to the nature of some of the proposed UK sites?

The proposed limits on discharges that the RP has estimated are based on data obtained during reactor operations. The assessment of ecological impact from discharges made at these proposed limits has been presented in the RP's submission PCER07 (GNSL 2021c) and is assessed in this report at section 3.3. The dose rates to non-human species are well below the dose rate criterion and screening values. The assessment is conservative (cautious) as it is based on discharges at the proposed limits, but, in reality, discharges would be expected to be below permitted limits. The RP's submission and our independent verification shows that the dose rates to reference organisms in the terrestrial and marine environments are 0.15 µGy/h or less. This is well below the dose rate criterion of 10 µGy/h. There is a large margin between the dose rates calculated and the dose criterion, which indicates a very low radiological impact on wildlife. It is the outcome of this assessment that indicates that the proposed limits are acceptable.

UKHPR1000-047 also asked for clarification on the generic ecological parameters set in the GDA to account for highly protected terrestrial and marine ecological sites.

The assessment the RP made (GNSL, 2021c) uses a set of reference organisms that are consistent with species that will need to be protected in the UK. The reference organisms are assumed to be located in the environment defined by the generic site. The locations are close to the site where the environmental concentrations and dose rates will tend to be at their highest. Therefore, this approach is conservative and leads to a cautious assessment.

The assessment is based on a generic site, therefore specific protected habitats cannot be identified until we receive a site-specific permit application.

This respondent (UKHPR1000-047) was also concerned that the assessment is based on a generic dose output and that it does not consider all isotopes present in the radioactive wastes.

We confirm that the basis for determining radiological impact does take into account the type of radioactive waste. The radionuclides present in the discharges have been

identified and assessed. This model and methodology takes into account the environmental behaviour of each radionuclide and the radiological impact (dose) from each radionuclide. The RP's submission (GNSL, 2021c) shows the dose from each radionuclide. The single dose we report is the sum of all the individual radionuclides.

This respondent (UKHPR1000-047) was concerned that the generic site was not applicable to Bradwell as this is an estuarine site.

The assessment the RP provided (GNSL, 2021c) has made use of models and data that allow calculation of annual dose arising from discharges to the estuarine environment. The RP has used marine data for the estuary that is close to the current Bradwell site. Therefore, the generic assessment is valid for an estuarine environment. However, if an application were made to deploy UK HPR1000 reactors at Bradwell, the applicant would need to submit a full site-specific impact assessment as part of that application.

**UKHPR1000-050** – This respondent raised 2 points:

a) Whether discharges that accumulate over time are really 'acceptable'.
b) That the assessment does not consider discharges from maintenance failures and unexpected accidents.

Firstly, the modelling of the dispersion of radionuclides from discharges assumes 60 years of discharges. The model used includes accumulation of radionuclides in the environment from the discharges. The dispersion of radionuclides discharged as gases mists and dusts to atmosphere and liquids to the marine environment have been modelled. The assessment is made assuming the discharges are at the proposed limits and the resulting doses are below the dose limit and constraints for the public.

Secondly, in the proposed limits allowance has been made for discharges from normal operations, including maintenance, inspections and testing, and also includes expected events that may lead to an increase in discharge. Expected events are those that can be expected to occur over the lifetime of the plant. An example would be occasional fuel pin cladding leaks. We have assessed the impact of these discharges by comparing doses and dose rates with the dose limit for the public and dose constraints for the public and dose rate criteria for non-human species. The doses and dose rates are well below the dose criteria.

ONR is responsible for regulating nuclear safety, which includes ensuring the licensee has and implements adequate arrangements for dealing with any accident or emergency arising on the site and their effects.

# 5. Conclusion

## 5.1. Generic site

Based on the latest generic site description in the RP's submission (GNSL, 2021a) and supporting documents, our conclusions are:

- the RP has selected a coastal site to represent the generic site. As government's National Policy Statement for Nuclear Generation (UK Parliament, 2011a and 2011b) notes that all potential sites for new nuclear power plants are either located on the coast or on large estuaries, we are content that selecting a coastal site is appropriate for GDA
- the generic site takes account of the characteristics of the Bradwell site. Many of the assumptions are those defined by the current Bradwell site. This means that the generic site is an estuarine location with relatively limited water exchange compared with other more open coastal locations. Therefore, the radiological assessment outcomes from liquid discharges are likely to be cautious and bounding
- for discharges to atmosphere, the atmospheric dispersion around the site is representative of all coastal locations and the radiological assessment outcomes are cautious overall
- the RP has assumed that there is no standing water on the site. We consider this to be reasonable and that surface water management will be a site-specific matter
- the RP has assumed that there are no discharges to freshwater. We consider this a reasonable assumption for a coastal nuclear site based on discharges from existing sites. Therefore, the radiological impact on protected freshwater species has not been assessed. This should be considered at site-specific environmental permitting, if appropriate
- we consider that the RP included appropriate factors in its generic site considerations as required by the REPs SEDP1 – General principle for siting of new facilities and SEDP2 - Migration of radioactive material in the environment, and is broadly compliant
- we have no Assessment Findings related to the generic site
- there are no potential GDA issues relating to the generic site at the end of the GDA detailed assessment

## 5.2. Radiological assessment – the public

From the radiological assessment the RP submitted in PCER-007 (GNSL, 2021c), our conclusions are:

- all the doses the RP assessed for discharges from a single UK HPR1000 reactor at the proposed limits are below the source dose constraint for members of the public of 300 μSv/y. Doses would also be below the site dose constraint (500 μSv/y) and the public dose limit (1,000 μSv/y).

- our independent assessment from discharges at the proposed discharge limits showed doses to the public are below the source and site dose constraints and dose limit.
- the RP's assessment is based on a generic site that takes account of the Bradwell site parameters. There is limited aquatic dispersion at the site and therefore, doses are likely to be cautious and are expected to be bounding for the sites currently identified as possible locations for new nuclear power plants listed in the Nuclear National Policy Statement (UK Parliament, 2011a, 2011b)
- it is very unlikely that doses at any site where the UK HPR1000 could be operated including where several units were operated on a single site would exceed the site dose constraint of 500 μSv/y and, therefore, it is very unlikely that the public dose limit of 1,000 μSv/y will be exceeded
- the RP's assessment shows that the highest total dose from discharges and direct radiation is expected to be between 9.6 and 22.8 μSv/y from one reactor
- the RP's assessment included doses from short duration releases which ranges from 5.8 to 9.7 μSv/y
- most of the dose to the public is from discharges of carbon-14 to the atmosphere and carbon-14 in liquid discharges. Carbon-14 contributes more than 95% of the doses from discharges
- our independent assessment provides similar outcomes to the RP's assessment. The independent assessment confirms low doses to the public (similar to the RP) and that the majority of the dose from discharges is from carbon-14
- we consider that the RP included an appropriate range of regulatory factors in its radiological assessment consideration as required by the REPs - see section 3.6 - and is compliant. The RP has also taken into account good practice offered in the dose assessment principles (Environment Agency, 2012) and the relevant guidance from the National Dose Assessment Working Group
- we have no Assessment Findings related to the radiological assessment. However, as carbon-14 discharges contribute most to the dose, the outcomes informs the assessment findings given in the BAT assessment report - requiring a future operator to review the practicability of techniques for abating carbon-14; for a future operator to assess the chemical form of carbon-14 discharged to the environment and use this to inform future dose assessments and to optimise the balance between gaseous, liquid and solid phase of carbon-14 (Environment Agency, 2021c)
- there are no potential GDA Issues related to the radiological assessment at the end of the GDA detailed assessment
- a detailed site-specific radiological assessment would be carried out if an environmental permit is applied for in future. The site-specific assessment should consider the actual environmental characteristics of the site and the number of reactors that will be present. This assessment will have to demonstrate that doses to members of the public from the UK HPR1000 will be ALARA and below relevant dose constraint and dose limits. Comparison against the dose limit should be carried out at site-specific permitting when contributions from all sources of radiation are known and can be included.

## 5.3. Radiological assessment - wildlife

From the radiological assessment the RP submitted in PCER-007 (GNSL 2021c, 2021d), our conclusions are:

- that the atmospheric and liquid radioactive discharges from a UK HPR1000 at the generic site are unlikely to pose a radiological risk to wildlife
- the assessment the RP carried out is cautious and reasonable, and we consider that it has used an appropriate approach to assess the radiological impacts of the UK HPR1000 on wildlife
- for each reference organism, the probability of the dose rates exceeding the dose rate criterion of 10 μGy/h is less than 1%
- the highest dose rate to any reference organism from discharges to atmosphere is 0.15 μGy/h. The highest dose rate to any reference organism from liquid discharges is 0.0063 μGy/h. These dose rates are well below the dose rate criterion of 10 μGy/h
- that our independent radiological assessment for wildlife has broadly the same outcomes as the RP's. The highest dose rate to any reference organism from discharges to atmosphere is 0.13 μGy/h. The highest dose rate to any reference organism from liquid discharges is 0.023 μGy/h. These dose rates are well below the dose rate criterion of 10 μGy/h
- this assessment relates to predictions of impact based on a generic site. A detailed impact assessment would be required at any future site-specific permitting, based on the actual environmental characteristics of the proposed site, to confirm that doses to wildlife will be below relevant dose rate criteria
- we have not identified any Assessment Findings and there are no potential GDA issues related to radiological assessment at the end of the GDA detailed assessment

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# List of abbreviations

| | |
|---|---|
| ADMS | Atmospheric dispersion modelling system |
| AF | Assessment Finding |
| ALARA | As low as reasonably achievable |
| ALARP | As low as reasonably practicable |
| BAT | Best available techniques |
| CR | Concentration ratio |
| ERICA | Environmental Risk from Ionising Contaminants: Assessment and management |
| GDA | Generic design assessment |
| GNSL | General Nuclear System Ltd |
| IAEA | International Atomic Energy Authority |
| ICRP | International Commission for Radiological Protection |
| IRAT | Initial Radiological Protection Tool |
| NDAWG | National Dose Assessment Working Group |
| NRPB | National Radiological Protection Board |
| ONR | Office for Nuclear Regulation |
| P&ID | Process and Information Document |
| PCER | Pre-Construction Environmental Report |
| PCSR | Pre-Construction Safety Report |
| PHE | Public Health England |
| REPs | Radioactive Substances Regulation Environmental Principles |
| RI | Regulatory Issue |
| RO | Regulatory Observation |
| RP | Requesting Party |
| RQ | Regulatory Query |
| Sv | Sievert |
| TSC | Technical support contractor – employed by the regulator to provide specialist assessment support |
| UK HPR1000 | United Kingdom version of the Hualong reactor |

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