Partner Document Number	Partner Document Issue /Revision	Retention category:
SMR0004490	N/A	A

Title

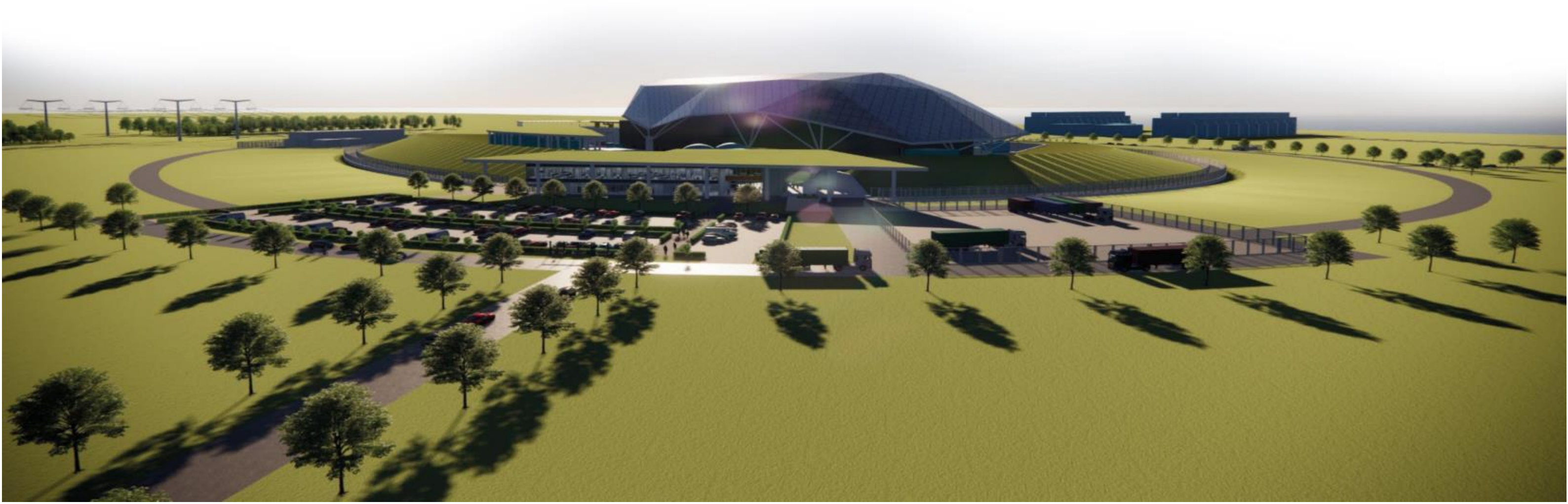
E3S Case Chapter 30: Prospective radiological assessment

Executive Summary

This Chapter outlines the planned programme of work to demonstrate that the impact of discharges of radioactive effluent to the environment from the Rolls-Royce Small Modular Reactor (RR SMR) will be within acceptable limits.

A preliminary assessment of dose to members of the public and to the environment ('non-human species') has been carried out using the Environment Agency's (EA) Initial Radiological Assessment Tool (IRAT). The inputs into the assessment were derived from the radioactive discharge values established from the design information for the RR SMR at Preliminary Concept Definition (PCD), and environmental information from the RR SMR Generic Site Description (GSD). Where information was not yet available, conservative assumptions are made. The prospective annual dose to the most exposed member of the public is estimated as 12.3μSv/y, well below the source dose constraint of 300μSv/y. The dose to the worst-affected non-human species was approximately 0.02μGy/y, significantly lower than the EA screening dose rate of 1μGy/y and guideline dose rate of 40μGy/y.

The design of the RR SMR is still under development. A more tightly constrained estimate of discharges and additional design details (e.g. stack height and shielding requirements) will be available to support dose assessment calculations for GER Revision 2. Detailed radiological assessments will be undertaken using this revised information to demonstrate that the RR SMR applies Relevant Good Practice (RGP) to minimising doses from offsite disposals and meets statutory limits and recommendations for doses to members of the public and non-human species.



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30.1 Introduction

30.1.1 Introduction to Chapter

This report comprises Chapter 30 of the Rolls-Royce Small Modular Reactor (RR SMR) Environment, Safety, Security & Safeguards (E3S) Case. It forms part of the Generic Environment Report (GER) for the RR SMR and is a Tier 1 report as defined in Chapter 1.

Chapter 30 presents the overarching summary and entry point to information on the assessment of radiological dose to members of the public and non-human species from the discharge of radioactive effluents from the RR SMR to the environment under normal operating conditions. It is based on design information available following completion of the RR SMR Preliminary Concept Definition (PCD) in 2022 and will be updated using the information that will become available as the design matures.

30.1.2 Objectives

The information presented in this Chapter describes the impact of radioactive discharges from the RR SMR to the environment on members of the public and non-human species will be addressed.

The key objectives of this Chapter are to:

1. Provide initial results of radiological impact assessments for members of the public and non-human-species performed using preliminary estimates of radioactive effluent discharges from the RR SMR under normal operating conditions at a generic coastal site.
2. Describe the approach for carrying out detailed radiological assessments, including (i) modelling dispersion and accumulation of radionuclides in the environment, and (ii) assessment of individual and collective dose to members of the public from gaseous and aqueous discharge of radioactive effluent from the RR SMR, based on a continuous discharge model.
3. Describe the approach for modelling dispersion and accumulation of radionuclides in the environment and assessment of individual doses to members of the public resulting from short-term gaseous discharge of radioactive effluent from the RR SMR.
4. Describe the approach for assessing the dose rates to non-human species resulting from continuous discharge of gaseous and aqueous discharge of radioactive effluent from the RR SMR.
5. Provide a summary of forward work relating to data collection and design development of the RR SMR, in order to refine the initial estimates, and the sensitivity analysis which will be undertaken to evaluate the impact of key uncertainties in the dose assessment methodology.

30.1.3 Scope

The scope of this Chapter is assessment of the radiological impact to members of the public and non-human species from offsite discharges of aqueous and gaseous radioactive effluent to the environment during normal operations of the RR SMR.

A contribution to radiological dose to members of the public from direct radiation ("shine") will be determined separately (Chapter 12) and added to the dose arising from discharges in order to establish the total dose from the RR SMR.

The following are excluded from this Chapter:

1. The impact from radioactive discharges arising from construction works or from decommissioning at the end of the operational life.

2. Discharges arising from accident scenarios or fault conditions are excluded; however, this assessment does include a contribution from reasonably foreseeable operational occurrences, as detailed in Chapter 29.

3. The radiological dose to employees is not in scope of this Chapter but is considered in Chapter 12.

4. Doses from radioactive waste disposed to offsite waste management facilities permitted under The Environmental Permitting (England and Wales) Regulations 2016 (EPR16) is not considered. The dose to members of the public and the environment from disposal of radioactive waste disposed of to such a facility will be accounted for under the waste management facility's EPR16 permit. The minimisation of radioactive wastes for transfer to such facilities (e.g. solid wastes to landfill, incineration or long-term storage) is captured in Chapter 26.

The Structures, Systems and Components (SSCs) associated with this topic include those SSCs from which discharges to the environment are made; specifically, the emissions stack for gaseous radioactive effluent from the Heating, Ventilation and Air Conditioning system (HVAC) [KL] and Gaseous Waste Treatment System (GWTS) [KPL], the Condenser Air Removal System (CARS) [MAJ], and the liquid effluent discharge point [UPK].

All SSCs within the site which contain radioactive material or waste, or are contaminated with radioactivity, may contribute to the direct dose to members of the public.

30.1.2 Key Interfaces with Other Chapters

This Chapter draws upon the information presented in other Chapters of the RR SMR E3S Case. Notable topic areas within E3S Case that support the production of this Chapter or are otherwise related to the Chapter are detailed in Table 30.1-1 below.

Table 30.1-1. Interfaces with other Chapters

Chapter	Title	Summary of contents
1	Introduction	Chapter 1 provides an overall introduction to the suite of 33 Chapters that make up the E3S Case.
2	Site Characteristics	Presents the overarching summary and entry point to the Generic Site Envelope (GSE) of the RR SMR. It provides details of the site bounding characteristics and parameters within which the RR SMR is designed, including the Generic Site Description (GSD) on which the radiological dose assessment of discharges is based.
11	Management of Radioactive Waste	Presents overall summary for RR SMR radioactive waste treatment, collection and drainage systems for radioactive wastes. Design and performance of these systems will be important in determining waste form and concentrations discharged to the environment.
12	Radiological Protection	Covers Radiation Protection aspects for normal operations, including demonstration of As Low as Reasonably Practicable (ALARP) for collective dose, maximum individual dose and individual averages for onsite workers and members of the public. The contribution of direct radiation ("shine") to the total dose for members of the public will be assessed in this Chapter.
15	Safety Analysis	Covers both deterministic and probabilistic safety assessment, as well as assessment of internal hazards and external hazards. Key elements of the chapter (principally the Fault Schedule) relevant to determining expected events which may contribute to radioactive waste production and discharge.
25	Detailed information about the design	Provides a technical description of the facility's main plants, systems and processes, which have a bearing on radioactive waste (solid, liquid and gaseous) generation, treatment, measurement, assessment and disposal.
26	Detailed Description of Radioactive Waste Management Arrangements (RWMA)	Describes RWMA for RR SMR. This Chapter describes the sources and predicted arisings of radioactive wastes (solid waste, spent fuel (SF) combustible waste etc) over the lifecycle of the RR SMR, outlines the proposed arrangements for managing solid radioactive waste and SF and how these are optimised to ensure the protection of people and the environment.
27	Demonstration of Best Available Techniques (BAT)	Chapter provides detail on the Optimisation and BAT methodology used during the design of the RR SMR. Details Claims, Arguments, and Evidence (CAE) for RR SMR to demonstrate that BAT has been applied.
28	Sampling Arrangements, Techniques and Systems for Measuring and Assessing Discharges and Disposals of Radioactive Waste	Presents information on RR SMR sampling & monitoring arrangements for in-process (key point upstream of the systems that interface with environment e.g., gaseous waste system) and final discharge monitoring (all forms to environment, independent monitoring), relevant to SSC design and monitoring/validation of environmental discharges.

29	Quantification of Radioactive Effluent Discharges and Proposed Limits	Provides an assessment of potential discharges of aqueous and gaseous radioactive effluent from the RR SMR plant to the environment under normal operating conditions. Presents includes the underlying methodologies, including underlying assumptions and parameter values used to calculate the preliminary quantification of radioactive discharges to the environment.

30.1.3 Fundamental Claims

The information presented in this Chapter provides some of the evidence supporting the Fundamental Claims for the radiological impact assessment of gaseous and aqueous effluent discharges from the RR SMR. Further information on the Fundamental Claims for environmental aspects can be found in Chapter 27.

The Fundamental Claim for Chapter 30 is:

Impact on members of the public and the environment from disposals of aqueous and gaseous radioactive effluents from the RR SMR normal operations is minimised and within the radiological dose limits and constraints set out in legislation and guidance.

30.1.4 GDA Context

The following requirements in Table 30.1-2 are those directly relevant to this Chapter and are taken from the Environment Agency (EA) GDA Guidance for Requesting Parties [1]. This Chapter will, on final issue, meet the requirements laid out in Table 30.1-2.

Table 30.1-2. GDA Requirements for assessment of radiological dose from environmental discharges

GDA Requirement	Information source
The RP must provide a radiological assessment of proposed limits for: • *annual dose to most exposed members of the public for liquid discharges** • *annual dose to most exposed members of the public for gaseous discharges (separately identify the dose associated with on-site 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*	Chapter 30 Chapter 12
The RP must also provide: • *annual dose to the representative person for the facility* • *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 the activities of other legitimate users or uses of the land or sea* • *collective dose truncated at 500 years to the UK, European and world populations* • *dose-rate to non-human species**	Chapter 30 (method only in this version)
The RP must state which models they have used to calculate these doses and why the models are appropriate. They must set out all the data and assumptions they have used as input to the models, together with reasoning as to why these assumptions are appropriate.	Chapter 30

*Denotes EA recommend use of their Initial Radiological Assessment Tool (IRAT) to carry out these assessments

Currently the design maturity of the RR SMR is at PCD and the information presented in this Chapter reflects this level of maturity.

30.2 Regulatory Context

30.2.1 Overview of Regulatory Context

International and national obligations on the protection of people and the environment from harm resulting from radioactive discharges are defined in standards, legislation, policy and guidance, summarised below. The requirements outlined in Section 30.130.1.4 are consistent with these obligations.

International context

The International Commission on Radiation Protection (ICRP) Basic Safety Standards (BSS) [2] set out the principles and fundamentals for radiation protection, which are adopted worldwide. Chapter 27 outlines how the fundamental principle of optimisation should be applied to ensure the impact of discharges of radioactive substances on members of the public is kept As Low As Reasonably Achievable (ALARA). However, it is recognised that optimisation is not always sufficient, and there is also a need to set probability-based limits below which the risk of harm (stochastic effects) from exposure to radiation is considered tolerable by society relative to the benefits gained from the practice which causes the exposure (e.g. Reference [3]).

The ICRP sets limits on the dose which may be received from planned exposure situations in different settings, for example medical, occupational or public exposure. The BSS Schedule III (3) sets a whole-body effective dose limit of 1mSv/y for members of the public from all planned exposure situations.

ICRP also recommends the use of public exposure dose constraints from facilities managing radioactive materials or waste to support optimisation. These are not prescribed by ICRP but should be set by national regulatory or governing bodies.

The BSS also explicitly extends protections from exposure to radiation to ‘the environment’. No exposure limits for non-human species are defined in the BSS, but it is expected the impact on species other than human beings should be considered in the regulation of radioactive discharges to the environment.

The EC Directive 2013/59/EURATOM (Basic Safety Standards Directive, or BSSD) [4] requires the BSS dose limits, the requirement for dose constraints and consideration of the impact on non-human species to be transposed into the domestic legislation of the European Union Member States[1].

Regulation in England and Wales

Discharges of radioactive substances from nuclear power stations to the environment are controlled under the Radioactive Substances Regulations (RSR), set out in Schedule 23 of EPR16.

[1] Transposition of 2013/59/Euratom into UK legislation was completed by the deadline of February 2018, prior to the coming into force of the European Union (Withdrawal Agreement) Act 2020 on 31 December 2020

Schedule 23 of EPR16 sets out the controls on the radiological impacts associated with permitted discharges of radioactive effluents from sites discharging radioactive waste to the environment. It stipulates [5]:

> ***Optimisation and dose limits***
>
> 1. *In respect of a radioactive substances activity that relates to radioactive waste, the regulator must exercise its relevant functions to ensure that—*
>   a) *all exposures to ionising radiation of any member of the public and of the population as a whole resulting from the disposal of radioactive waste are kept as low as reasonably achievable, taking into account economic and social factors, and*
>   b) *the sum of the doses resulting from the exposure of any member of the public to ionising radiation does not exceed the dose limits set out in Article 13 of the Basic Safety Standards Directive subject to the exclusions set out in Article 6(4) of that Directive.*
>
> ***Specific dose limits and calculation***
>
> 2. *(1) In exercising those relevant functions in relation to the planning stage of radiation protection, the regulator must have regard to the following maximum doses to individuals which may result from a defined source—*
>   a) *0.3 millisieverts per year from any source from which radioactive discharges are first made on or after 13th May 2000, or*
>   b) *0.5 millisieverts per year from the discharges from any single site.*

Inclusion of the 1mSv/y dose limit in EPR16 implements the BSS/BSSD requirements for protection of members of the public from exposure to ionising radiation. The dose constraint requirements are implemented through Schedule 23(2), restricting the dose to individuals from single sources and sites. Following the introduction of the revised BSS in 2007 [2], the Health Protection Agency (HPA, now the United Kingdom Health Security Agency, UKHSA) recommended a more cautious 150μSv/y dose constraint for new nuclear power stations, on the basis of uncertainties in health effects [6], however this is not currently a formal regulatory requirement or guidance.

The dose assessments above focus on members of the public exposed in the locality of the RR SMR, where environmental radioactivity concentrations and thus exposure are likely to be highest. However, the prospective transboundary impacts of disposals of radioactive waste to the environment must also be assessed for certain RSR permit applications, including for disposals from the operation of nuclear reactors (except small research reactors) [7] [8].

Further Policies and Guidance in England and Wales

United Kingdom (UK) Government's Review of Radioactive Waste Management Policy [9] sets a 'threshold of optimisation' for exposure to members of the public of 20μSv/y, equating to a risk of death of approximately 1 in 1.0E+06, as being broadly acceptable and in line with other common risks to the public.

In 2009, the then Department for Energy and Climate Change (DECC)[2] issued Statutory Guidance [10] to the EA[3] . This guidance provides that, for sources of radiation for which the dose to the

[2] Subsumed into the Department for Business, Energy & Industrial Strategy (BEIS) in July 2016.
[3] Since 2013, regulation of radioactive substances in Wales has been the responsibility of Natural Resources Wales (NRW).

most exposed member of the public is below 10μSv/y the EA should not seek to further reduce the discharge limits that are in place, provided that the holder of the permit continues to apply BAT.

The main guidance document for dose assessments to members of the public is the Environment Agencies' Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment [11]. Further guidance on radiological assessments is provided by competent UK bodies such as the UKHSA (including its predecessor Public Health England (PHE) and earlier incarnations) and the National Dose Assessment Working Group (NDAWG). These sources of guidance are referenced in the latter sections of this report describing the approaches for detailed radiological assessments.

The assessment of potential radiological impact of radioactive effluent discharges on non-human species is not an explicit requirement under Schedule 23 of EPR16; however, it is a material consideration in the determination of applications for RSR environmental permits [12] and in the setting of annual limits on discharges of radioactive effluents to the environment [13]. RPs and prospective permit applicants are therefore required to assess the potential impact of their nuclear power stations on non-human species.

The EA considers that there will be no adverse effects at population level to reference species for a dose below 40μGy/h [14]. A more restrictive screening level of 1μGy/h is used to determine whether a refined dose assessment is required [15].

30.2.2 Alignment with the Regulatory Objectives and Principles

The EA RSR Objective and Principles (ROPs) [16] set out the regulatory principles the EA applies in the delivery of its function as laid out in EPR16 and government policy.

The ROPs are supported by a set of RSR Generic Developed Principles (GDPs), which set out the EA's expectations on permit holders carrying out radioactive substances activities [17]. The key GDPs directly relevant to the radiological assessment of dose to members of the public and the environment are detailed in Table 30.2-1.

Table 30.2-1 RSR Generic Developed Principles relevant to GDA Requirements on quantification of radioactive effluent discharges

GDP ID	Title	Principle
RSMDP12	Limits and Levels on Discharges	*Limits and levels should be established on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment.*
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.*
RPDP2	Dose limits and constraints	*Radiation doses to individual people shall be below the relevant dose limits and in general should be below the relevant constraints.*
RDPD3	Protection of non-human species	*Non-human species should be adequately protected from exposure to ionising radiation.*
RDPD4	Prospective dose assessments for radioactive discharges into the environment	*Assessments of potential doses to people and to non-human species should be made prior to granting any new or revised permit for the discharge of radioactive wastes into the environment.*
SEDP1	General principle for siting of new facilities	*When evaluating sites for a new facility, account should be taken of the factors that might affect the protection of people and the environment from radiological hazards and the generation of radioactive waste.*
SEDP2	Migration of radioactive material in the environment	*Data should be provided to allow the assessment of rates and patterns of migration of radioactive materials in the air and the aquatic and terrestrial environments around sites.*

The above listed principles will be taken into account in the assessment of the prospective radiological impacts of discharges of radioactive effluent from the RR SMR to the environment.

30.3 Initial Radiological Assessment

30.3.1 Overview of initial radiological impact assessment approach

The overall approach for assessing the radiological impacts of routine discharges (including expected events) of aqueous and gaseous radioactive effluents from the RR SMR to the environment is based on the staged approach advocated by the NDAWG [18] [11]. The staged approach comprises the following tiers of radiological assessments, characterised by increasing level of detail and complexity:

1. Stage 1 is a simple and cautious assessment utilising Dose Per Unit Release (DPUR) factors published by the EA [19] [20] based on conservative environmental dispersion parameters and generic assumptions about the habits of exposed persons. This assessment is typically performed using the accompanying spreadsheet-based IRAT available on request from the EA, or proprietary spreadsheets incorporating DPUR values. The IRAT output also contains the dose rate to the worst affected non-human species.

2. Stage 2 assessments are an extension of Stage 1 assessment and generally involve the adjustment of model parameters used in Stage 1 assessments to reflect more realistic assumptions. Typically, the environmental dispersion parameters for aqueous and gaseous discharges to the environment – volumetric exchange rates for liquid discharges and the effective release height for gaseous emissions – are modified using project specific values.

3. Stage 3 assessments entail detailed source and site assessment of radiological impacts from routine aqueous and gaseous discharges to the environment, as well as short-term discharges to air. It involves the assessment of individual and collective doses to members of the public, dose rates to non-human species and the assessment of the build-up of radionuclides in the environment over the life of the facility making the discharges. For site specific assessments, the contribution from any nearby sources of radioactivity and from historic sources is also assessed.

A detailed Stage 3 assessment is not normally required where the outcome of the Stage 1 and 2 assessments does not exceed 20μSv/y [11] – except in the case of large installations such as nuclear power stations, for which a detailed Stage 3 assessment is a requirement of the permitting process [1]. A Stage 3 assessment will therefore be undertaken for the RR SMR regardless of the outcome of the initial radiological assessments, to satisfy corporate business objectives and to provide the additional level of detail specified in GDA guidance [21].

This section sets out the approach used to carry out an initial radiological assessment of predicted discharges of aqueous and gaseous radioactive effluents from the RR SMR, at proposed annual limits. It describes the methods, models and key assumptions that underpin the initial assessment of doses to members of the public and the dose rates to non-human species. A summary of the results of the Stage 1 and 2 assessments performed using the EA's IRAT is also presented.

30.3.2 Outline of assessment methodology

Discharge environment

The philosophy behind the RR SMR is the design of a modular SMR performing to a high environmental standard, which can be deployed in multiple locations. The GSD is the set of characteristics which define the range of sites that the RR SMR will be assessed against to demonstrate environmental performance and show regulatory expectations can be met. It describes meteorological, hydrographic and geographic conditions, local population and habits data, and other characteristics which will be used to determine environmental impacts of offsite radiological and combustion releases.

A coastal site located on a flat plain has been selected for GSD, with aqueous discharge released into a low-dispersion coastal environment. Details of the GSD are provided in Chapter 2. Average UK meteorological conditions are assumed. Key exposure groups of a local inhabitant family and fisherman family, and key reference organisms have been identified.

Discharge source term

The Stage 1 and Stage 2 radiological assessments have been carried out using the annual gaseous and aqueous discharge limits proposed in Chapter 29. The proposed limits are derived using the approach described in the EA guidance on setting limits for new nuclear licenced sites [22]; that is, setting a limit equal to the Worst Case annual Plant Discharge (WCPD). The WCPD for new nuclear plant is determined by multiplying the predicted discharges of radioactive effluent to the environment under normal operating conditions (including expected events such as fuel pin failure), with a headroom factor of 2. Details of the approach used to calculate the predicted discharges and determine the proposed annual limits are presented in Chapter 29.

Annual discharges of aqueous and gaseous radionuclides predicted to arise from the RR SMR, and associated proposed annual limits are presented in Table 30.3-1 and Table 30.3-2.

For purposes of this assessment, annual limits for radioactive effluent discharges determined from the RR SMR interim Primary Source Term (PST) have been determined by applying a nominal headroom factor of 2 to the predicted discharges of radionuclides from the RR SMR, as described in the paragraph above. Further information on the justification for this approach is provided in Chapter 29.

Table 30.3-1 Predicted Discharges of Aqueous Radionuclides at Annual Limits

Radionuclide	Predicted discharges (Bq/y)	Proposed limits (Bq/y)	Radionuclide	Predicted discharges (Bq/y)	Proposed limits (Bq/y)
Ag-110m	2.89E+06	5.78E+06	H-3	8.88E+10	1.78E+11
Ba-140	4.28E+07	8.56E+07	I-131	4.88E+06	9.76E+06
C-14	5.07E+07	1.01E+08	Mn-54	2.36E+06	4.72E+06
Ce-141	5.62E+05	1.12E+06	Nb-95	1.13E+06	2.26E+06
Ce-144	1.58E+07	3.16E+07	Ni-63	1.62E+05	3.24E+05
Co-58	4.07E+06	8.14E+06	Ru-103	2.85E+07	5.70E+07
Co-60	1.83E+06	3.66E+06	Ru-106	4.97E+03	9.94E+03
Cr-51	5.87E+06	1.17E+07	Sb-125	1.06E+06	2.12E+06
Cs-134	2.39E+08	4.78E+08	Sr-89	3.32E+06	6.64E+06
Cs-136	1.52E+08	3.04E+08	Sr-90	3.00E+05	6.00E+05
Cs-137	1.12E+08	2.24E+08	Zn-65	5.82E+06	1.16E+07
Fe-55	2.10E+07	4.20E+07	Zr-95	1.33E+06	2.66E+06
Fe-59	8.25E+05	1.65E+06	Other beta/gamma emitting nuclides[4]	2.89E+06	5.77E+06

[4] This category represents an aggregate of radionuclides which were considered in the aqueous discharge estimates in Chapter 29, but for which the current version of IRAT does not model individual radionuclides (Ag-108m, Nb-94, Ni-59, Pr-143, Sb-124 and Y-91). The contribution from these radionuclides is calculated using the conservative DPUR value assigned to 'other beta/gamma' in the IRAT spreadsheet.

Table 30.3-2 Predicted Discharges of Gaseous Radionuclides at Annual Limits

Radionuclide	Predicted discharges (Bq/y)	Proposed limits (Bq/y)	Radionuclide	Predicted discharges (Bq/y)	Proposed limits (Bq/y)
Ag-110m	9.63E+04	1.93E+05	Kr-85	4.45E+10	8.90E+10
Ar-41	8.04E+11	1.61E+12	Kr-85m	2.39E+10	4.78E+10
Ba-140	2.62E+05	5.24E+05	La-140	5.51E+05	1.10E+06
Br-84[5]	1.45E+09	2.91E+09	Mn-54	2.95E+04	5.90E+04
C-14	1.80E+11	3.59E+11	Mn-56	1.68E+05	3.35E+05
Ce-144	7.73E+04	1.55E+05	Mo-99	9.56E+02	1.91E+03
Co-58	2.10E+06	4.20E+06	Na-24	1.06E+05	2.13E+05
Co-60	4.48E+04	8.96E+04	Nb-95	5.98E+03	1.20E+04
Cr-51	2.58E+05	5.15E+05	Ni-63	5.29E+04	1.06E+05
Cs-134	1.61E+04	3.22E+04	Ru-103	1.49E+05	2.98E+05
Cs-136	2.77E+03	5.54E+03	Sb-125	1.59E+04	3.19E+04
Cs-137	9.82E+03	1.96E+04	Sr-89	2.79E+03	5.58E+03
Fe-55	3.05E+06	6.11E+06	Sr-90	2.38E+02	4.76E+02
Fe-59	1.27E+05	2.55E+05	Tc-99m	4.92E+02	9.83E+02
H-3	4.08E+10	8.16E+10	Xe-133	6.22E+11	1.24E+12
I-131	6.76E+07	1.35E+08	Zn-65	1.43E+05	2.86E+05
I-132	6.22E+08	1.24E+09	Zr-95	6.76E+03	1.35E+04
I-133	2.63E+08	5.25E+08			
I-134	1.02E+09	2.03E+09	Other beta/gamma-emitting nuclides[6]	3.15E+07	6.29E+07
I-135	5.40E+08	1.08E+09	Other noble gases[7]	4.92E+11	9.85E+11

Radiological assessment approach

IRAT calculates the dose to the worst affected individual by multiplying the embedded DPUR factors (μSv/y per Bq/y) with predicted discharges of radionuclides. DPUR factors are provided for over 100 different radionuclides, internal and external exposure pathways, and four age groups (adult, child, infant and offspring). The annual dose for a given discharge route (e.g. discharges to air or sea) is a summation of the doses for each radionuclide–exposure pathway–worst age group combinations.

[5] A DPUR value for Br-84 is not included in IRAT, so Br-82 has been used as surrogate radionuclide, in line with approach in the IRAT user guide [19].
[6] See footnote 4 for the explanation of the 'other beta/gamma' category. For gaseous discharge, the radionuclides aggregated into this category are: Ce-143, Cs-138, K-42, Nb-97, Ni-59, Pr-143, Rb-88, Rb-89, Ru-105, Sb-122, Sb-124, Sr-91, Sr-92, Te-131, Te-132, Te-133m, Te-134, Y-91m, Y-92 and Zr-97.
[7] The category of 'other noble gases' includes the contribution from Kr-87, Kr-88, e-131m, Xe-133m, Xe-135, Xe-135m and Xe-138. The discharges of these radionuclides were aggregated and assessed as, Xe-133 – the only fission product noble gas in IRAT. This is in line with approach in the IRAT user guide [19].

Details of the assumptions and input data, including the environmental dispersion factors used in the initial radiological assessment, are presented in Chapter 2. The assessments were carried out using the updated 'IRAT 2' spreadsheet tool [23] [24] released in 2022 and supplied by the EA.

Dose rates to non-human species are estimated in a similar manner to that for humans. IRAT multiplies embedded DPURs for non-human species (µGy/h per Bq/y) with predicted radionuclide discharges, and the resulting dose rates for each radionuclide-organism combination are summated to derive the total dose rates for a given discharge route. Stage 1 screening assessments were performed using the IRAT for discharges to coastal environments and discharges to air, adopting the default parameter values embedded within the IRAT. The GSD assumes there are no freshwater bodies or freshwater courses traversing or situated close to the site; these pathways are therefore excluded from this assessment.

The Stage 1 assessment uses the default environmental dispersion parameters in the IRAT model. For the Stage 2 assessments, the default volumetric exchange rates in the coastal IRAT and the effective release height in the atmospheric IRAT were modified to the values, based on the assumptions presented in the GSD:

1. A relatively conservative volumetric exchange rate of 100m^3/s (around 3.2E+09m^3/y) is adopted as being representative of the local marine compartment of the GSD and will be used to refine the assessment of dose from aqueous discharges to sea.

2. An effective release height **{REDACTED FOR PUBLICATION}**, has been assumed on a conservative basis. This accounts for the wake effects of the shell structure and is consistent with established practice [25]. The effective release height will be reviewed in future calculations using the RR SMR stack height defined in GER Revision 2.

30.3.3 Results and discussion

Stage 1 Initial Radiological Assessment

Table 30.3-3 and Table 30.3-4 present the results of the Stage 1 assessments. Radionuclides contributing less than 1% of the total dose (other than tritium[8]) have not been included in the Tables but are reflected in the total dose.

[8] Tritium has been identified as a 'significant radionuclide' for monitoring RR SMR plant performance under the EA's assessment criteria [13], and has thus been included despite its relatively limited dose impact.

Table 30.3-3 Estimated Doses from Stage 1 Initial Radiological Assessment for Aqueous Discharges to the Environment

Radionuclide	External dose (μSv/y)	Fish/shellfish dose (μSv/y)	Total dose (μSv/y)	% Contribution
Tritium	0.0E+00	5.4E-04	5.4E-04	0.1%
Carbon-14	7.0E-08	1.5E-01	1.5E-01	18%
Manganese-54	4.9E-03	5.8E-05	5.0E-03	1%
Cobalt-60	4.4E-02	7.3E-04	4.5E-02	5%
Zinc-65	4.9E-03	1.0E-01	1.1E-01	13%
Silver-110m	4.2E-03	7.0E-02	7.4E-02	9%
Caesium-134	2.3E-01	6.1E-02	2.9E-01	35%
Caesium-136	3.2E-03	3.9E-03	7.1E-03	1%
Caesium-137	1.3E-01	2.0E-02	1.5E-01	17%
Total	4.3E-01	4.1E-01	8.5E-01	

Table 30.3-4 Estimated Doses from Stage 1 Initial Radiological Assessment for Gaseous Discharges to the Environment

Radionuclide	Inhalation dose (μSv/y)	External dose (cloud & deposited) (μSv/y)	Food dose (μSv/y)	Total dose (μSv/y)	% Contribution
Tritium	5.8E-02	0.0E+00	2.2E-02	8.0E-02	0.3%
Carbon-14	1.3E+01	2.3E-05	1.2E+01	2.5E+01	78.7%
Argon-41	0.0E+00	5.3E+00	0.0E+00	5.3E+00	16.5%
Iodine-131	4.8E-02	5.3E-03	5.5E-01	6.0E-01	1.9%
Other beta/gamma-emitting nuclides	6.5E-03	4.1E-01	2.9E-02	4.5E-01	1.4%
Total	1.3E+01	5.9E+00	1.3E+01	3.2E+01	

A total dose of less than 1μSv/y to the worst affected member of a fishing family was estimated for aqueous discharges. The dose due to aqueous discharges was dominated by contributions from the radioisotopes of caesium (52%), carbon-14 (18%) and zinc-65 (13%).

The total dose to the worst affected local inhabitant for gaseous discharges from the RR SMR was estimated at 32μSv/y. The dose from gaseous discharges was comprised largely of the doses from carbon-14 (80%) and argon-41 (17%).

The dose rate to the worst affected organism for aqueous discharges (Polychaete worm) is less than 0.01μGy/h, dominated by barium-140 (52%) and radioisotopes of caesium (35%). The dose rate to the worst affected organisms for gaseous discharges (bird, mammal and reptile) is around 0.04μGy/h, 90% of which is attributable to carbon-14.

Stage 2 Initial Radiological Assessment

Results of the Stage 2 assessments are presented in Table 30.3-5 and Table 30.3-6. Radionuclides contributing less than 1% of the total dose (other than tritium) have not been included in the Tables but are reflected in the total dose.

Table 30.3-5 Estimated Doses from Stage 2 Initial Radiological Assessment for Aqueous Discharges to the Environment

Radionuclide	External dose (µSv/y)	Fish/shellfish dose (µSv/y)	Total dose (µSv/y)	% Contribution
Tritium	0.0E+00	1.6E-04	1.6E-04	0.1%
Carbon-14	2.1E-08	4.6E-02	4.6E-02	18%
Manganese-54	1.5E-03	1.7E-05	1.5E-03	1%
Cobalt-60	1.3E-02	2.2E-04	1.3E-02	5%
Zinc-65	1.5E-03	3.1E-02	3.3E-02	13%
Silver-110m	1.3E-03	2.1E-02	2.2E-02	9%
Caesium-134	7.0E-02	1.8E-02	8.8E-02	35%
Caesium-136	9.6E-04	1.2E-03	2.1E-03	1%
Caesium-137	3.8E-02	6.1E-03	4.4E-02	17%
Total	1.3E-01	1.2E-01	2.5E-01	

Table 30.3-6 Estimated Doses from Stage 2 Initial Radiological Assessment for Gaseous Discharges to the Environment

Radionuclide	Inhalation dose (μSv/y)	External dose (cloud and deposited) (μSv/y)	Food dose (μSv/y)	Total dose (μSv/y)	% Contribution
Tritium	2.4E-03	0.0E+00	1.1E-02	1.3E-02	0.2%
Carbon-14	5.3E-01	9.6E-07	5.9E+00	6.5E+00	92.0%
Argon-41	0.0E+00	2.2E-01	0.0E+00	2.2E-01	3.1%
Iodine-131	2.0E-03	2.2E-04	2.7E-01	2.7E-01	3.8%
Other beta/gamma-emitting nuclides	2.7E-04	1.7E-02	1.4E-02	3.2E-02	0.4%
Total	5.4E-01	2.4E-01	6.3E+00	7.0E+00	

A total dose of around 0.3μSv/y to the worst affected member of a fishing family and 7μSv/y to the worst affected local inhabitant were calculated for aqueous discharges to sea and gaseous discharges to atmosphere, respectively. As with the Stage 1 assessment, the radioisotopes of caesium, zinc-65 and carbon-14 accounted for over 80% of the dose from aqueous discharges, whilst the dose arising from gaseous discharges is largely attributable to the intake of carbon-14 (>90%).

The dose rate to the worst affected organism for aqueous discharges (Polychaete worm) is around 0.002μGy/h, again dominated by barium-140 (52%) and radioisotopes of caesium (35%). The dose rate to the worst affected organism for gaseous discharges (bird, mammal and reptile) is around 0.02μGy/h, over 90% of which is attributable to carbon-14.

Total dose

To assess the total annual dose to an individual that is representative of the more highly exposed individuals in the population (i.e., the representative person) [25], it is assumed that the worst affected local inhabitant also receives the dose predicted to arise from aqueous discharges from the RR SMR.

An assessment of dose rates to members of the public due to direct radiation emanating from an RR SMR plant has not yet been performed. To allow the inclusion of this pathway in calculating the total dose, a direct radiation dose of 5μSv/y has been adopted, based on References [26] and [27]. The RR SMR-specific direct radiation dose to members of the public will be calculated and used in the next revision of this Chapter.

The doses from the aqueous, gaseous and direct radiation exposure pathways from the Stage 2 assessments are summed in

Table 30.3-7. The dose to the representative person from aqueous and gaseous discharges, as well as direct radiation from the RR SMR is estimated to be around 12.3μSv/y.

Table 30.3-7 Total annual dose

Exposure pathway	Stage 2 Dose (μSv/y)
Aqueous discharges	2.5E-01
Gaseous discharges	7.0E+00
Direct radiation	5.0E+00
Total dose	1.23+01

30.3.4 Conclusion

Results of the Stage 2 initial radiological assessment show that the total dose to a representative member of the public from all the pathways considered is well below the source dose constraint of 300μSv/y [11]; as well as the more restrictive constraint of 150μSv/y recommended to be applied at the design stage of new nuclear facilities [6]. Similarly, the estimated dose rate to the worst affected organisms for both aqueous and gaseous discharges predicted to arise from the operation of an RR SMR are well below the statutory guidance value of 40μGy/h [28].

Furthermore, the assessed total dose is below the threshold of 20μSv/y at which further refinement of assessed doses using more realistic data are required [28]. However, as indicated in Section 30.0, a detailed Stage 3 radiological assessment will be undertaken in line with the Rolls-Royce SMR corporate objectives, the GDA requirements detailed in Section 30.130.1.4, and permitting requirements for new nuclear power stations [13]. The remaining sections of this Chapter provide an overview of the methodologies, considerations, and underlying assumptions to support the detailed assessment of radiological impacts associated with the radioactive discharges from the RR SMR that will be performed based on discharge estimates available in GER Revision 2.

30.4 Proposed Methodology for Detailed Assessment of the Radiological Impacts from Continuous Discharges

30.4.1 Overview

This section presents an overview of the approach proposed for carrying out detailed assessment (i.e., Stage 3 of the dose assessment approach outlined in Section 30.0) of the radiological impacts of routine discharges of aqueous and gaseous radionuclides to the environment from the RR SMR.

The detailed assessment of the impacts of routine discharges to the environment will be performed using the PC-CREAM 08 software code and in-built databases. Detailed description of this approach and the underlying justifications are presented in the accompanying methodology report "The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08 (the 'PC-CREAM Methodology')" [29] and the PC-CREAM 08 user manual [30]. The PC-CREAM 08 code and the associated databases and methodology (i.e., the PC-CREAM approach) provide a comprehensive tool for assessing prospective individual and collective doses from routine, continuous discharges of aqueous and gaseous radionuclides to the environment. The UK Environment Agencies recognise this approach as being suitable for performing prospective radiological dose assessments [11] [12].

PC-CREAM 08 code comprises a main radiological dose assessment module, 'ASSESSOR', supported by 5 subroutines or modules (DORIS, PLUME, RESUS, GRANIS and FARMLAND) that model the transfer of radionuclides through the environment (including the food chain) and provide estimates of activity concentrations in various environmental media for continuous discharges to the environment. The outputs from these modules, combined with the habits data of representative members of the public, form the input into ASSESSOR where annual doses to the members of the public are calculated. A summary of these 5 modules is provided in Section 30.0.

PC-CREAM 08 is not suitable for assessing radiological impacts arising from short-term releases to the environment (e.g. enhance discharges to air during shutdown or maintenance outages) and this section addresses only impacts arising from routine continuous discharges. The approach for assessing the impacts of short-term radioactive discharges is discussed in Section 30.5.

Source term definition

A definitive source term specific to the RR SMR is currently in development and will supersede the interim source term used to carry out the initial radiological assessment presented in Section 30.0. The definitive source term will form the basis for the detailed assessment to be performed in GER Revision 2. A summary of the definitive source term and how it has been used to determine RR SMR discharges will be presented in future revisions of Chapter 29.

30.4.2 Environmental distribution

Subroutines of the PC-CREAM 08 code will be used to model the dispersion and accumulation of radionuclides in food and the environment, arising from routine discharges from the RR SMR. Model parameters consistent with the GSD characteristics will be used to provide realistic estimates of environmental concentrations arising from radionuclide releases.

Aqueous Discharges to the Marine Environment

The dispersion and accumulation of aqueous radioactive discharges to the marine environment (seawater, sediment and marine biota) is typically modelled using the DORIS module of PC-CREAM 08 [29]. DORIS calculates the time-dependent activity concentration of aqueous radionuclides discharged into the local marine compartment taking account of advection-diffusion processes with adjoining waters, radioactive decay and partitioning of elements between liquid and sediment fractions of seawater. The local marine compartment is modelled as a single well mixed body of water and associated sediment, extending a few kilometres (typically 10km) from the discharge point. The local compartment is contained within the larger regional compartment with which it interfaces and exchanges water and suspended sediment.

The DORIS module comprises two groups of model parameters [29]:

1. Site dependent parameters that model sedimentation processes and the movement of masses of water (advection-diffusion processes) between the local and regional marine compartments. These include hydrographic parameters such as sediment load and sedimentation rates, bathymetry (volume, depth, etc.) and volumetric exchange rates between local and regional waters of the marine compartments. Appropriate data representative of the generic site [31] will be used for the assessment.

2. Element dependent parameters include distribution coefficients (Kd) and concentration factors (Cf) for marine biota, which describe the partitioning of elements between sediment and liquid fractions of marine water, and the build-up of radionuclides in marine biota (fish, shellfish and seaweed) respectively. Default PC-CREAM 08 parameter values will be used except in circumstances where more recent data are available.

The output from DORIS (activity concentrations in seawater, seabed and beach sediment, and marine biota) feed into the ASSESSOR module and (together with the relevant habits data) are used to assess the impact of routine aqueous discharges on individual members of the public and the collective doses to defined population groups.

It is recognised that the soluble boron-free, potassium-based chemistry adopted for the RR SMR operating regime does facilitate minimal discharge of aqueous radioactive effluent to the environment under normal operating conditions; discharges to the environment are likely to only be required on rare occasions, for instance in the event of fuel pin failure or for water management purposes. Such infrequent discharges to the environment are akin to a short-term discharge (defined as the release of 2% or more of annual discharges over a relatively short period of 1 day or less).

However, NDAWG [32] observed that:

1. Dispersion in estuarine and coastal environments is driven by tidal currents which do not vary significantly over the course of a year.

2. The dose from aqueous discharges to coastal or estuarine waters is dominated by the ingestion of fish and shellfish; given the preference for consumption of fresh seafood among fishermen, the worst affected group for this discharge, the associated habits (bait digging and seafood consumption) do not show significant seasonal variation.

3. Fish are mobile in coastal and estuarine waters and are therefore unlikely to be constantly exposed to a plume from a short-term release.

The NDAWG concluded that the total dose predicted to arise if the 12 monthly limits are discharged as short-term releases will not differ significantly from the dose that would arise if the same discharges occurred as a continuous release [32].

Thus, for purposes of the RR SMR Stage 3 assessment, discharges of aqueous radioactive effluent are assumed to follow a continuous discharge profile to facilitate the assessment of the radiological impacts from this effluent stream using DORIS. The effects of this simplification will be evaluated as part of the sensitivity analysis for the RR SMR radiological assessments.

Gaseous Discharges to Atmosphere

The dispersion, deposition and build-up of radionuclides in terrestrial environments and in food from continuous discharges of gaseous effluents will be modelled using the PLUME and FARMLAND subroutines in PC-CREAM 08. The GRANIS and RESUS subroutines use output from PLUME to calculate the external dose due to deposited radionuclides and the internal dose from inhalation of resuspended radionuclides (respectively). These modules are summarised below.

PLUME

PLUME constitutes the atmospheric dispersion model within PC-CREAM 08. It is based on a Gaussian plume model [29] which utilises defined meteorological conditions, surface roughness and the physical characteristics of the radionuclides discharged to calculate air concentrations, deposition rates and external gamma dose rates (from the gaseous plume) at various distances downwind of the gaseous effluent release point [29]. Meteorological conditions are defined using meteorological classification schemes which represent a range of meteorological conditions (atmospheric turbulence, described in terms of wind speed and height of the mixing layer) downwind of the release point. The main schemes comprise 6 meteorological categories A to F, with class A being the most unstable/turbulent and class F the most stable; rainfall is assumed to fall only in categories C (slightly unstable) and D (neutral) at a rate of 1mm/h and 10% of the time [33]. The default PC-CREAM 08 scheme (Hosker Smith) and setting will be used to model the dispersion of gaseous discharges from the RR SMR plant and output corrected using the set of meteorological conditions characteristic of the generic site [31].

The entrainment of gaseous releases in the wake of nearby buildings close to the release point is not modelled by PLUME; thus an effective release height (physical stack height plus buoyancy and wake effects of nearby buildings) has to be determined and input into PLUME in circumstances where the emission stack is not taller than two and a half times the height of the dominant building [29] [34]. For emission stacks located on or above a building, an effective release height equivalent to 1/3rd of the height of the dominant building is recommended to account for the wake of buildings [35]. This approach is conservative and does not take account of gaseous release parameters (for instance the temperature and exit velocity of gaseous releases). An effective release height **{REDACTED FOR PUBLICATION}** has been adopted for the initial radiological assessment (see Section 30.0). Future modelling and engineering assessment on the required stack height will better define the stack height, which will be used to better define the effective release height and atmospheric dispersion of gaseous releases from the RR SMR in advance of GER Revision 2

RESUS

Radionuclide concentration in air from resuspension of previously deposited radionuclides caused by wind-driven disturbances is modelled in the RESUS module of PC-CREAM 08. RESUS is a simple empirical based model that calculates the activity concentration in air using a time dependent resuspension factor, K, which expresses the observed relationship between radionuclide concentrations on ground surfaces to concentrations in air [29].

GRANIS

The GRANIS module of PC-CREAM 08 models the migration of radionuclides deposited from atmospheric releases through soil and estimates external irradiation due to photons from deposited activity at a height of 1m from the ground surface. GRANIS takes account of shielding provided by soil material and fabric of buildings for indoor occupancy. It considers two soil models (disturbed and undisturbed profiles), with generic wet/dry attributes [29]. An undisturbed soil profile is considered suitably conservative for the purpose of assessing beta and gamma dose from ground deposition. A generic wet soil is regarded as broadly representative of the average conditions of soils in maritime climates such as that of Britain, especially along coastal locations such as the generic site.

FARMLAND

The dynamic food chain model FARMLAND embedded in PC-CREAM 08 simulates the transfer of radionuclides deposited from the atmosphere through a series of compartments constituting the terrestrial food chain [29] [36]. The models within FARMLAND are contained in three compartments which describe the processes controlling the transfer of radionuclides through the terrestrial food chain to humans: (a) radionuclide migration in soil (b) transfer to plants and (c) transfer to animals.

Radionuclide transfer through different compartments within the food chain is generally modelled using equilibrium concentration ratios and transfer coefficients, with assumptions about farming practices, and plant and animal specific parameters (e.g. plant yield and animal ingestion and inhalation rates).

The transfer of tritium and carbon-14 in food is modelled using the specific activity approach, which takes account of the complex interactions of, and fundamental roles played by, carbon and hydrogen in biological systems. This approach assumes that rapid equilibrium is attained between atmospheric concentrations and concentrations in plant material and environmental media. The specific activity model is dependent on the degree of atmospheric dispersion of gaseous releases and the concentrations of water vapour and carbon in the atmosphere – taken as 8g/m^3 and 0.15g/m^3 [29] [36].

FARMLAND calculates activity concentrations (for unit deposition rates) in food categories considered important to the diet of EU populations, namely green vegetables, root vegetables, grain and fruit, as well as cattle and sheep products (cow milk, cow milk products, cow meat, cow liver, sheep meat, and sheep liver). It is not normally necessary to include grain in dose assessments because there is no evidence to indicate that grain is farmed, processed and consumed at the local level in the UK [11] [37]. Similarly, food products from pigs and poultry are normally excluded from assessments because, in most instances, these animals are reared indoors and fed from a number of sources most of which are likely to be produced at some distance from the locations of interest [11] [20]. A detailed account of the FARMLAND model can be found in Reference [36].

Outputs from all the four modules (PLUME, RESUS, GRANIS and FARMLAND) that model the dispersion, transfer and accumulation of gaseous discharges will form an input into the ASSESSOR module, which (together with the relevant habit data) will calculate the doses to members of the public.

30.4.3 Approach for individual dose assessment

Exposure Pathways

Potential exposure pathways associated with discharges of aqueous and gaseous radionuclides and direct radiation emissions from the RR SMR have been considered and the pathways outlined below are deemed the relevant for the generic site defined.

Marine Pathways

1. Internal exposure from the ingestion of locally caught seafood (fish, crustaceans, molluscs and seaweed) incorporating radionuclides discharged into the marine environment.
2. Internal exposure from inhalation of radionuclides entrained in sea spray originating from radionuclides discharged into the marine environment.
3. External irradiation from beta/gamma radionuclides incorporated into beach sediment, and from handling fishing equipment contaminated with radioactivity.

Terrestrial Pathways

1. Internal irradiation from inhalation of radionuclides in gaseous plume and from resuspension of deposited radionuclides from discharges to atmosphere.
2. Skin absorption of tritium[9].
3. Internal irradiation from the ingestion of radionuclides incorporated into locally produced terrestrial foods incorporating radionuclides discharged to atmosphere.
4. External irradiation from exposure to radioactivity in the gaseous plume and from material deposited on the ground following discharges to atmosphere.

Other Pathways

1. Potential exposure of members of the public to direct radiation (including shine) emanating from RR SMR facilities will be assessed, in consultation with the Radiation Protection team. A cumulative annual direct radiation dose of 5μSv/y is currently assumed based on precedent (see Section 30.0).
2. Other minor pathways such as the inadvertent ingestion of beach sediment or seawater incorporating discharged radionuclides are not included as the contributions from these pathways are trivial in comparison to the pathways listed above [11] [38]. Similarly, the consumption of wild game and other food such as honey have been excluded from further consideration because wild animals roam and forage across large expanses of land and their food source may not necessarily come from impacted areas. Further, the rate of consumption of these food sources (and therefore the consequent dose) is generally low among representative members of the public compared to consumption of the food categories assessed.

[9] This is accounted for within PC-CREAM 08 through the application of a multiplicative factor of 1.5 to the inhalation dose [29]. This is consistent with ICRP Publication 71 [56] which estimates that for a sedentary adult, around a third of the intake of atmospheric tritium is via skin absorption.

Habits Data

The level of exposure to radioactivity originating from the RR SMR (in the form of discharges to environment and direct radiation) through the pathways identified above is linked to the food consumption and occupancy habits and behaviours of affected members of the public. Data on such habits are normally obtained from published sources such as NRPB-W41 [39] or specific surveys such as those undertaken by Cefas e.g. Reference [40]. Relevant Good Practice (RGP) is to use realistic habits data for dose assessments [11], especially for habits that show strong dependence on geographical factors (e.g. high rates of fish consumption or beach occupancy will be more prevalent in communities living close to the shore compared to those in the hinterland). Nevertheless, prospective dose assessments are required to take account of reasonably foreseeable changes in behavioural patterns and the use of cautious habits data is often necessary to account for uncertainties in future behaviours.

Generalised habits data published in NRPB-R41 [39] will be used as the basis for assessing the impacts of discharges from the RR SMR to exposed members of the public through marine, terrestrial and direct radiation pathways.

Food Consumption Habits

The NDAWG has published a paper providing guidance on the selection and use of habits data for prospective dose assessments [41]. The paper identifies the various approaches available regarding the use of food ingestion habits data and identified the 'top two approach' using generic UK-wide habits data to be appropriate where site-specific habits data are not available. This approach is described as generating a reasonably realistic assessment of doses over a 5 to 10-year period and is more conservative than the alternative habits profiles approach.

The top two approach assumes that the two seafood and terrestrial foodstuff categories contributing the highest dose are consumed at critical levels, whilst the remaining foods are ingested at median (50th percentile) levels.

The top two approach using the generalised habits data [39] is proposed for the RR SMR dose assessments. A screening assessment will be performed to identify the top two seafood and terrestrial foodstuff in advance of the main assessment.

Seafood and terrestrial foodstuff ingested by the assessed population are assumed to be sourced from the local area. All terrestrial foods are assumed to be 100% locally sourced; milk, cattle meat and sheep meat are assumed to be produced at a local farm, whilst green vegetables, root vegetables and fruit are assumed to be grown in a garden or allotment near the habitation of the assessed population. For seafood, it is assumed that 100% of shellfish and 50% of sea fish are caught in marine waters adjacent to the generic site, with the remaining 50% of fish assumed to be caught further offshore in the regional compartment [20].

Candidates for the Representative Person

The Candidates for the Representative Person (CRP) refer to groups of individuals that are exposed to sources of radioactivity via multiple pathways associated with their habits. These groups of people could receive doses that are representative of the more highly exposed individuals in the population. The representative person refers to the individual CRP expected to receive the highest average dose [11].

It is good practice to consider full range of exposure pathways for each of the CRP given that individuals are normally exposed via more than one pathway [11]. It also recommended that a combination of habits typical of average and most exposed people may be assumed – for instance it is reasonable to assume that CRPs for discharges to the marine environment have a high intake of seafood and average intakes of terrestrial foodstuffs, and vice versa.

Three CRPs have been identified on the basis of exposure pathways identified earlier and the corresponding habits (described in previous sections) that could potentially result in the highest exposure to radioactive sources originating from the RR SMR. These are:

1. CRPs for aqueous discharges to the marine environment – the adult, child and infant members of a fishing family that spend time along the coastal area close to the discharge point for aqueous effluent from the RR SMR. These CRPs are exposed through the ingestion of seafood, as well as inhalation of sea-spray, handling of fishing equipment and by spending time over beach sediment incorporating radioactivity from the discharges.

2. CRPs for gaseous discharges to the atmosphere – the adult, child and infant members of a farming family that reside at a dwelling close to and in the path of the gaseous releases from the RR SMR. These CRPs are assumed to be exposed through ingestion of terrestrial foodstuff, inhalation of the radioactive plume, direct radiation from immersion in the radioactive plume and from deposited material and from inhalation of resuspended material. The building structure at their dwelling is considered to provide some shielding against external radiation from the gaseous plume or deposited material.

3. CRPs for direct radiation – these are considered to comprise of local residents (which may include the two CRPs identified above) living close to the RR SMR and individuals accessing the adjacent beach, who are assumed to be exposed to direct radiation emanating from the RR SMR, for the fraction of time they are in close proximity to the plant.

Individual Dose Calculation

The effective dose to CRPs will be calculated within the ASSESSOR module of PC-CREAM 08. The overall approach for effective dose assessment embedded in the ASSESSOR module is based on the ICRP system of protection against the risk of exposure from ionising radiation. This system describes the uptake and distribution of radionuclides in the body and the consequent irradiation of tissues and organs using dynamic (dosimetric and biokinetic) models that approximate human systems. An overview of the ICRP system is provided in Reference [29]. The ICRP has published effective dose coefficients (effective dose per unit intake) for intakes of radionuclides (via inhalation and ingestion pathways) by 3-month-old infants, 1-, 5-, 10-, and 15-year-old children, and adults [42].

The ASSESSOR module combines the modelled concentration (per unit discharge) of radionuclides in food and the environment (PLUME, FARMLAND and DORIS output) with CRP habits data to estimate the intake of radionuclides via inhalation and ingestion pathways. The module then scales the radionuclide intakes to the input discharge rates and calculates the effective dose to CRPs using the ICRP dose coefficients embedded within the programme.

The ICRP have also published dose coefficients for assessing the dose to embryos and fetuses, recognising that there are circumstances in which this category may receive substantially higher doses than the mother [43]. The HPA (UKHSA), advised that doses to this receptor category need only be considered for phosphorus-32 and 33, calcium-45 and strontium-90) in situations where these radionuclides form a significant part of discharges to the environment [44].

Default external dose factors embedded in PC-CREAM08 databases will be adopted. External gamma dose rates from immersion in the radioactive cloud and from material deposited on the ground are calculated for unit discharge rates in PLUME and GRANIS (respectively) and input into ASSESSOR, which combines them with selected meteorological conditions and input discharge rates to calculate the annual dose via these pathways. Indoor location factors are applied within PC-CREAM 08 to account for the shielding provided by building structures against airborne gamma and deposited gamma activity. Skin equivalent dose rate factors for beta irradiation due to immersion in plume and from ground deposition are based on References [45] and [46] respectively. Irradiation from beta activity incorporated in fishing gear is calculated using an empirical approach described in Reference [47].

Annual effective doses to the CRPs identified earlier will be assessed in the 60th year of discharges from the RR SMR, consistent with recommended practice [11]. To determine the annual dose to most exposed members of the public from both aqueous and gaseous discharges from the proposed Sizewell C facility, the following assumptions are made:

1. The fishing family consume two types of seafood at high rates (97.5th percentile) and the remaining seafood and terrestrial foodstuff at mean rates. The fishing family is also considered to reside at a habitation close to the site and to be exposed to the passing gaseous plume (through inhalation and immersion in radioactive cloud) and from deposited material (through direct radiation and inhalation of resuspended material).

2. The farming family consume two terrestrial foodstuffs at high rates and the remaining foodstuffs and seafood at mean rates. The farming family is also considered to spend time at the beach and to be exposed via irradiation from radionuclides in beach sediment and from inhalation of sea spray.

The CRP with the highest dose from the combination of exposure pathways arising from all discharge routes, including exposure due to direct radiation from the site (a direct radiation dose of 5μSv/y is currently assumed), will be designated as the representative person. The dose to the representative person will be compared to the source and site dose constraint of 300μSv/y and the dose constraint recommended by PHE (now UKHSA) for new nuclear facilities of 150μSv/y [48].

30.4.4 Approach for collective dose assessment

Collective dose to the UK, European and world populations from routine discharges of gaseous and aqueous radioactive effluent to the environment, truncated at 500 years, will be assessed using the ASSESSOR subroutine for collective dose assessment. Truncation at 500 years allows the long-term dose impact of long-lived radionuclides such as carbon-14, which remain in circulation long after their discharge has stopped, to be assessed.

ASSESSOR considers 'first pass' and 'global circulation' of radionuclides. The first pass component is the contribution to collective dose that arises as the dispersing plume initially passes over the target population; whereas the global component applies to certain long-lived radionuclides (tritium, carbon-14, krypton-85 and iodine-129) which are globally dispersed in the biosphere and continue to contribute to the collective dose over long time periods [29] [30]. Collective doses to world populations are only calculated for globally circulating radionuclides.

The collective dose calculation step draws upon the results of all the supporting models within PC-CREAM 08 (PLUME, GRANIS, FARMLAND and RESUS for discharges to air; and DORIS for discharges to the marine environment) and combines these with embedded database of population grids and the associated food production data. Per-caput dose (dose per unit head of population) will be determined by dividing the collective doses for UK, Europe and World populations to the number of individuals within each population group [11] [49].

30.4.5 Approach for evaluating the build-up of radionuclides in the environment

An assessment of the build-up of radionuclides in the local terrestrial (soil) and marine (seawater and sediment) environments around the generic site after 60 years of continuous discharges will be undertaken, to evaluate the potential for RR SMR operation to prejudice legitimate future users or uses of the surrounding areas [1].

Build-up of depositing radionuclides in soil will be calculated by modelling the deposition rates of relevant radionuclides (isotopes of caesium, cobalt and iodine) in the PLUME and ASSESSOR modules of PC-CREAM 08; the corresponding soil concentrations will be modelled using the FARMLAND module. The location chosen for assessing the build-up of radionuclides will be based on the location of maximum deposition rates, which may be different to the dwelling and farm locations used to assess the dose to members of the public.

The build-up of radionuclides in seawater and marine (seabed and coastal) sediment will be modelled within the DORIS module, using marine parameter values characteristic of the generic site [31].

The potential impact of build-up in the environment will be compared to the impacts to the CRPs for terrestrial and marine pathways described earlier.

30.5 Proposed Methodology for Assessing the Radiological Impact of Planned Short-term Discharges

30.5.1 Overview

An assessment of the radiological impact of short-term discharges of gaseous radioactive effluent to air from normal operations (including expected events), which may arise from routine shutdown, plant maintenance operations will be performed. Such discharges are characterised by enhanced releases of radionuclides and could result in higher doses to members of the public, especially in situations where the timing of discharges coincide with seasonal factors such as peak growing season, or if they occur during a time of day when people are outdoors for occupational or leisure reasons.

The short-term dose assessment will be based on the NDAWG Guidance Note 6B 'Guidance on Short Term Release Assessments' [32] and the methodology described in the NDAWG publication 'Short Term Releases to the Atmosphere Technical Methods & Examples' [50] and NRPB-W54 [37]. This approach is considered to represent RGP and is firmly established in the UK radiological assessments toolkit.

Operational releases fall into the short-term release category when such releases constitute 2% or more of predicted 12-monthly discharges and occur over a relatively short period of time (typically ≤1 day) [11] [32].

Assessment of the impact of short-term releases to the environment will be limited to the discharge of gaseous radioactive effluent. Potential impacts of short duration releases of aqueous radionuclides to the environment have not been assessed on the strength of the arguments proffered by NDAWG [32], summarised in Section 30.0.

30.5.2 Proposed methodology

Source Term

Short-term discharges of radioactive gaseous effluent are anticipated to arise during plant shutdown and maintenance outages. Such discharges are expected to be dominated by volatile tritium originating from the Spent Fuel Pool (SFP) [FAB10] and Refuelling Pool, and noble gases from the GWTS [KPL]. These discharges are anticipated to peak during the first few days of the outage phase - when the Reactor Pressure Vessel (RPV) head is lifted, and radioactive gases purged from vessels containing primary coolant and exhausted from containment to allow personnel to access the building for maintenance.

The inventory of radionuclides predicted to be discharged during short-term dose assessment will be derived from the definitive PST for shutdown operating mode, with 100% of the inventory assumed to be discharged over a 24-hour period. The effective release height determined in Section 30.0 will be used to model the atmospheric dispersion of gaseous releases from the RR SMR.

Atmospheric Dispersion

The atmospheric dispersion code ADMS 5 [51] will be used to model atmospheric dispersion of radionuclides entrained in short term gaseous effluent discharges from the RR SMR. The ADMS 5 is an advanced, new generation Gaussian plume air dispersion code which uses the boundary layer depth and the Monin-Obukhov length to characterise the atmospheric boundary layer properties, rather the single parameters associated with the traditional Pasquil stability categories. This allows for more realistic estimation of atmospheric concentration of gaseous emissions than traditional Gaussian plume models such as NRPB-R91 [33]. Further, the ADMS 5 comprises subroutines that facilitate modelling the effects (on a dispersing plume) of buildings, complex terrain, coastlines and variable surface roughness; dry and wet deposition; short term releases (puffs); and allowance for radioactive decay including gamma-ray dose [51].

The code is frequently validated against measured data from field campaigns and wind tunnel experiments by the model developers, Cambridge Environmental Research Consultants (CERC), and is shown to have good agreement with the measured data. Details of validation studies for buildings, complex terrain and flat terrain can be found on the CERC website [51].

The ADMS 5 code has good precedence over comparable codes such as AERMOD [52] for assessing short-term discharges to the atmosphere in the UK and has been widely adopted in previous GDA and permit application submissions. It has therefore been selected over other dispersion modelling codes such as AERMOD and NRPB-R91 [33].

For the RR SMR assessments, the ADMS 5 will be used to calculate air concentrations and deposition rates at receptor locations (dwelling and food source locations) for a 24-hour short-term gaseous discharge from the RR SMR, using meteorological conditions characteristic of the generic site, summarised in Chapter 2.

Exposure Pathways

The same pathways considered for the assessment of doses from routine, continuous releases to air will be used for the short-term dose assessment.

For the food ingestion exposure pathway, the concentration of radionuclides released during short term discharges in terrestrial food stuff will be modelled using NDAWG published food concentration factors [50]. These food concentration factors were derived using the FARMLAND model [36], except for carbon-14 which is based on the Food Standards Agency's (FSA) foodchain model PRISM 3.7.0. These factors will be applied to the ADMS 5 model output and the discharge source term to calculate radionuclide concentration in terrestrial foodstuff. Where food concentration factors are not available for important radionuclides, the concentration factors of suitable analogues will be adopted.

Habits Data

The same food sources, intake rates and receptor locations used for assessing effective doses from routine, continuous releases to air will be used for the short-term dose assessment. These habits data will largely be taken from NRPB-W41 [39], supplemented with data from Reference [20].

Assessment of Short-Term Dose

Air concentration and deposition rates from the ADMS 5 modelling will be entered into a spreadsheet tool incorporating food concentration factors, habits data of the farming family and

ICRP dose coefficients to calculate the effective dose to adult, child and infant age groups in the first year following the short-term release.

Internal (inhalation/ingestion) dose coefficients will be taken from ICRP Publication 119 [42]. External dose coefficients (for immersion in plume and from deposited activity) will be taken from US Environment Protection Agency's Federal Guidance Report No. 15 (FGR15) [53].

The assessed short-term dose will be compared to the source dose constraint (300μSv/y and the PHE proposed 150μSv/y), taking account of the contribution from releases of the remaining fraction of the annual discharge limits via the continuous discharge mode.

30.6 Proposed Methodology for Assessing the Radiological Dose to Non-Human Species

30.6.1 Overview

An assessment of potential dose rates to non-human species predicted to arise from discharges of aqueous and gaseous radioactive effluents from the RR SMR will be performed. The assessment will be limited to species inhabiting the terrestrial and marine environments adjacent to the power plant, consistent with assumptions in the GSD.

The non-human species assessment will be carried out using the environmental concentration data generated by the PC-CREAM 08 dispersion models described in Section 30.4, which will be based on discharges to the environment at the proposed annual limits.

30.6.2 Proposed methodology

Potential dose rates to non-human species will be calculated using the EA's IRAT, described in Section 30.3. If appropriate, supplementary assessments will be performed using the ERICA tool [54].

The ERICA Tool is a multi-tiered software programme that allows dose rates to biota in different ecosystems to be assessed. Several reference organisms representative of the types of organisms that are likely to be present in each type of ecosystem are included within the ERICA tool. Consistent with the staged radiological impact assessment described in Section 30.0, the three tiers of ERICA progress from simple and conservative to more complex and bespoke, and are summarised as follows:

1. Tier 1 of the ERICA Tool is a simple conservative step that compares radionuclide concentration in environmental media (Bq/l for water, Bq/kg for soil or sediment or Bq/m^3 for air) with precalculated environmental media concentration limits (EMCL) to estimate the Risk Quotient (RQ)[10] or each radionuclide assessed. The output is a table of risk quotients for the limiting organism for each radionuclide assessed and a sum of the RQs for all the radionuclides. This tier requires minimum data input and is suitable for screening assessment or in circumstances where site specific data are lacking.

2. Tier 2 of the ERICA Tool is a more interactive stage that provides the user with more flexibility in the choice of parameters for the assessment. This tier allows the user to introduce non-default reference organism and radionuclides to the assessment and to edit or change default parameter values such as concentration ratios, distribution coefficients, radiation weighting factors and occupancy factors. The output from Tier 2 assessments includes RQs as well as radionuclide-specific and total dose rates to each reference organism.

3. Tier 3 of the ERICA Tool is similar to Tier 2 but allows probabilistic risk assessment and access to the FREDERICA database [55]. This allows up-to-date scientific literature to be applied

[10] RQ is a ratio of media activity concentration to the EMCL. If the sum of RQs is <1, the risk to non-human species can be considered negligible. If the sum of RQs is > 1, then there is a high probability of exceeding the pre-defined screening dose rate and the assessment is progressed to Tier 2.

(which may not be available at Tier 2) on the biological effects of exposure to ionising radiation in a number of different species.

Should supplementary assessments be required, the assessments will be performed in a proportionate manner, beginning with Tier 1, and then progressing to Tier 2 if the sum of RQs is greater than 1. Default ERICA reference organisms and model parameter values will be adopted for the assessment.

30.7 Uncertainty and Sensitivity Analysis

30.7.1 Overview

In accordance with recommendations in Reference [11], an assessment of uncertainty and variability arising from key assumptions and model parameter values used in the RR SMR radiological impacts assessments will be undertaken if the annual dose to the representative person exceeds 20µSv/y. In any case, a semi-quantitative analysis would be carried out irrespective of the dose outcome to provide an understanding of the impact of assumptions and selected input data.

The evaluation of uncertainty and sensitivity analysis will focus on continuous discharges of aqueous and gaseous effluent to the environment, normally responsible for the bulk of annual dose to the public.

30.7.2 Indication of topics to be evaluated

The sensitivity analysis is likely to cover the following topics:

1. Source term – differences in the committed effective dose arising from expected discharges vs. proposed limits.
2. Aqueous discharge parameters:
    a. impacts of the assumption of continuous discharge against short term of aqueous effluent to the environment.
    b. effects of the choice of model parameter values for volumetric exchange rates and sediment loading/sedimentation rates (e.g. using more restrictive estuarine parameter values).
3. Gaseous discharge parameters
    a. effects of assumptions regarding effective release height.
    b. assumptions regarding meteorological conditions (i.e., adopted Pasquill stability category).
4. Habits data – evaluation of the effects of using generic habits data vs. site specific data, particularly food ingestion rates (e.g. Cefas habits survey data for Wylfa [40]).
5. Consideration of the potential impacts of climate change on the assumptions (e.g. habits) underpinning assessed radiological impacts

The above list of topics is not conclusive. It will be reviewed, refined and updated as required as part of the detailed radiological assessment to be carried out in GER Revision 2.

30.8 Conclusions

30.8.1 Conclusion

An initial assessment of the radiological impacts associated with radioactive effluent discharges (at proposed annual limits) and direct radiation emanating from the RR SMR has been carried out using the EA's IRAT and information presented in the GSD. Results of the assessment demonstrate that the total dose to a representative member of the public from all the pathways considered is well below the source dose constraint of 300μSv/y [9] and the more restrictive constraint of 150μSv/y recommended to be applied at the design stage of new nuclear facilities by the HPA (now UKHSA) [24]. Similarly, the estimated dose rates to the worst affected organisms predicted to arise from the operation of an RR SMR are well below the statutory guidance value of 40μGy/h and investigation level of 1μGy/h [28].

Proposed approaches and methodologies for carrying out detailed radiological assessments, consistent with RGP, have been articulated. These assessments are planned to be performed using the definitive source term for discharges and the RR SMR in GER Revision 2.

30.8.2 Assumptions and Commitments on Future Permit Holders/Dutyholders

The intention is that the E3S Case will capture assumptions and commitments for future permit holders/dutyholders/licensees. Environmental assumptions and commitments for permit holders have not been formally captured at this stage in the process, but will be included in future revisions of the GER.

30.9 Forward Action Plan

{REDACTED FOR PUBLICATION}

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30.11 Acronyms and Abbreviations

ALARP	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
BAT	Best Available Technique
BSS	Basic Safety Standards
BSSD	Basic Safety Standards Directive (2013/59/Euratom)
CARS [MAJ]	Condenser Air Removal System
CAE	Claims, Arguments, Evidence
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CERC	Cambridge environmental Research Consultants
CRP	Candidate for the Representative Person
DECC	Department for Energy and Climate Change
DPUR	Dose Per Unit Release
E3S	Environment, Safety, Security & Safeguards
EA	Environment Agency
EMCL	Environmental Media Concentration Limit
EPR16	Environmental Permitting (England and Wales) Regulations 2016
FA	Forward Actions

FGR15	US Environment Protection Agency's Federal Guidance Report No. 15
FSA	Food Standards Agency
GDA	Generic Design Assessment
GDP	Generic Developed Principles
GER	Generic Environment Report
GSD	Generic Site Description
GWTS [KPL]	Gaseous Waste Treatment System
HPA	Health Protection Agency
HVAC [KL]	Heating, Ventilation & Air Conditioning
NDAWG	National Dose Assessment Working Group
NRW	Natural Resources Wales
ONR	Office for Nuclear Regulation
PCD	Preliminary Concept Definition
PHE	Public Health England
PST	Primary Source Term
RD	Reference Design
RGP	Relevant Good Practice
ROP	Regulatory Objectives and Principles
RP	Requesting Party
RPV	Reactor Pressure Vessel

RQ	Risk Quotient
RR SMR	Rolls-Royce Small Modular Reactor
RSR	Radioactive Substances Regulations
RWMA	Radioactive Waste Management Arrangements
SF	Spent Fuel
SFP [FAB10]	Spent Fuel Pool
SMR	Small Modular Reactor
SSC	Structures, Systems and Components
UK	United Kingdom
UKHSA	UK Health Security Agency
US	United States
WCPD	Worst Case annual Plant Discharge
μGy/h	Micrograys per hour
μSv/y	Microsieverts per year
mSv/y	Millisieverts per year