The Sizewell C Project

6.3 Volume 2 Main Development Site

Chapter 25 Radiological Considerations

Appendices 25A - 25C

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VOLUME 2, CHAPTER 25, APPENDIX 25A: CONSTRUCTION SEDIMENT RADIOLOGICAL IMPACT ASSESSMENT FROM DREDGING OPERATIONS

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Non Technical Summary

NNB Generation Company (SZC) Limited (SZC Co.) plan to build a new nuclear power station comprising two UK EPR^{TM} units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as Sizewell C, will be situated to the north of the operational Sizewell B and the defueled Sizewell A nuclear power stations.

The new power station will require offshore dredging works associated with the installation of cooling water intake and outfall headworks and coastal engineering works to build a temporary jetty and other enabling works (beach landing facility and navigation channels). These activities will require sediment dredging with the proposed disposal route for the dredged material being at sea.

To support this assessment, SZC Co. has obtained sea floor samples on two occasions. The first occasion sampled sediment at various points near-shore at the identified locations of the jetty and the beach landing facility. Further samples were later taken at the identified locations of the cooling water intakes, the outfall headworks, and in likely navigation channels. At these specific points the sea floor was bed rock, however samples were still taken and both samples were analysed for a comprehensive range of determinands including radionuclides.

Concentrations of radionuclides derived from anthropogenic activity were investigated, and this included Co-60, Cs-137 and Am-241.

The near-shore sediment samples were found to contain very low levels of Cs-137, but those of Co-60 and Am-241 were lower than the limit of detection (LLOD). Where values were LLOD, the limit itself has been used in this assessment. This is precautionary, and in reality the actual values may be much lower.

With regards to the second set of samples taken, all results of anthropogenic activity were LLOD. Furthermore, the identified naturally occurring radionuclides had consistent activity concentration values with those taken from the first set of samples, which gave confidence in the validity of their results. Therefore, the first set was taken as a bounding case. This has provided a conservative dose estimate as the first set gave positive results for anthropogenic activity and was also based on mobile sediment, as opposed to immobile bedrock. If considered, the immobility of the bedrock would only reduce dose uptake even further.

The assessment approach uses that of the IAEA. It has considered the annual individual and annual collective dose to the crew of a dredging boat and that to other members of the public. Exposure via a range of pathways has been considered using IAEA dose per unit environmental concentration factors.

The highest annual individual dose summed across the artificial radionuclides; considered for the crew, is a mean value of 0.013 µSv/yr and a maximum value of 0.03 µSv/yr. These values are over two orders of magnitude below the 10 µSv/yr limit published under the London Convention 1972, with guidance on assessment set out in IAEA TECDOC 1759.

The individual public dose summed across all artificial radionuclides is a mean value of 0.00025 µSv/yr and a maximum value of 0.00077 µSv/yr. These values are over three orders of magnitude below the 10 µSv/yr and it should be noted that all these results are based entirely on values that were LLOD, so are likely to be even lower.

If the annual individual dose was summed across all radionuclides considered (artificial and natural), the dose to the crew is a mean value of 2.02 µSv/yr and a maximum value of 3.87 µSv/yr. That to the public is a mean value of 0.74 µSv/yr and a maximum value of 1.41 µSv/yr. This approach is highly precautionary as natural levels of naturally occurring radionuclides would not normally be considered in an assessment such as this. Nonetheless, these combined values are still well below the 10 µSv/yr limit.

The annual collective dose summed across the artificial radionuclides considered for the crew is a mean value of 0.0000013 man Sv/yr and a maximum value of 0.000003 man Sv/yr. These values are over five orders of magnitude below the 1 man Sv/yr limit.

The annual collective dose summed across the artificial radionuclides considered for the public is a mean value of 0.0000021 man Sv/yr and a maximum value of 0.0000077 man Sv/yr. These values are also over five orders of magnitude below the 1 man Sv/yr limit.

If the annual collective dose was summed across all radionuclides considered (artificial and natural), the dose to the crew is a mean value of 0.0002 man Sv/yr and a maximum value of 0.00039 man Sv/yr. That to the public is a mean value of 0.03 man Sv/yr and a maximum value of 0.056 man Sv/yr. This approach is highly precautionary as natural levels of naturally occurring radionuclides would not normally be considered in an assessment such as this. Nonetheless, these combined values are still well below the 1 man Sv/yr limit 1.

Overall, doses predicted from anthropogenic radionuclides are low (at maximum 0.03 µSv per year for the crew and 0.00077 µSv/yr to the public. These are well below the 10 µSv per year level of 'no harm' and many orders of magnitude below the public dose limit of 1,000 µSv per year. Even if naturally occurring radionuclides are included in the dose assessment (which is not necessary), the dose is still trivial (at a maximum, less than 4 µSv per year) and well below the 'no harm' and public dose limit.

No radiological controls associated with dredging and dredged material management are therefore expected.

1 Construction Dredging RIA

1.1 Introduction

a) Description of Development and Project Drivers

1.1.1 NNB Generation Company (SZC) Limited (SZC Co.) plan to build a new nuclear power station comprising two UK EPRTM units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as Sizewell C, will be situated to the north of the operational Sizewell B and the defueled Sizewell A nuclear power stations (**Plate 1.1**).

1.1.2 The new power station will require offshore dredging works associated with the installation of cooling water intake and outfall headworks and coastal engineering work to build a temporary jetty and other enabling works (beach landing facility and navigation channels). These activities will require sediment dredging with the proposed route for disposal of the dredged material at sea.

1.1.3 Within the UK, the environmental agencies in coordination with the Food Standards Agency, jointly publish an annual report on Radioactivity in Food and the Environment (the ‘RIFE’ series). The most recent RIFE-23 publication for 2017 survey results in Ref 1 identifies some, albeit low (< 6 Bq/g fresh weight) levels, of caesium-137 (Cs-137) in marine sediments in the Sizewell area. Cs-137 does not occur naturally and is due to anthropogenic activities (nuclear facilities and also trace levels from nuclear weapons testing). This Cs-137 activity may be due to former operations of the Sizewell A power station or ongoing operation of the Sizewell B power station, or from former operation of the Bradwell reactor site in Essex. It may also be due to more distant discharges from the Cap la Hague reprocessing facility in France (or from that of Sellafield in the UK). Other anthropogenic radionuclides generated by nuclear facilities that are discharged under regulatory approval to the marine environment include cobalt-60 (Co-60) and americium-241 (Am-241). The RIFE-23 publication does not provide Co-60 data for marine sediment from the Sizewell area. Am-241 is analysed for, and results published for, the Sizewell area; however, all results reported are below the analysis limit of detection except for Mussels (0.0035 Bq.kg^{-1}) but still, in all instances, less than 0.8 Bq/g (fresh weight).

1.1.4 RIFE-23 also indicates that total beta emitting radiation may be slightly elevated. This may be due to local or more distant nuclear facility operations, but may also be due to naturally occurring radionuclides (or at least include a component of these). Radionuclides that occur naturally in environmental media such as sediment, include those of the uranium-238 (U-238) decay series (including radium-226, Ra-226) and those of the thorium-232 decay series).

1.1.5 SZC Co. intends to submit an application to the Planning Inspectorate for a Development Consent Order (DCO) to develop Sizewell C. The application will comprise details of all development proposals and will be accompanied by an Environmental Statement (ES) conforming to the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 (SI572) (the EIA Regulations) and other relevant documents. This assessment supports this application.

1.1.6 On behalf of the Hinkley Point C new nuclear power station development project in Somerset, a radiological impact assessment of dredge spoil disposal at sea was undertaken in Ref 2.This was based on the International Atomic Energy Agency (IAEA) TECDOC-1759 assessment approach Ref 3. This approach has been used here and is described below.

b) Purpose and Scope

1.1.7 The purpose of this assessment is to evaluate the radiological exposure of members of the public associated with sea disposal of dredge sediment that contains trace levels of anthropogenic and natural radioactivity. The objective is to assess and quantify the radiological exposure of members of the public and hence consider, and if required, identify control measures that need to be implemented.

1.1.8 This assessment follows the IAEA recommended approach and is consistent with that undertaken for Hinkley Point C.

1.1.9 This radiological impact assessment does not aim to address Sizewell C operational discharges. These will only occur after dredging works have been completed and are not therefore relevant in this assessment. Nonetheless, they have been comprehensively assessed and reported in the Sizewell C Human and Non-Human Biota Radiological Impact Assessment (these assessments have been included in **Appendix B** and **Appendix C** within **Chapter 25 Radiological Effects**) of the ES.

c) Overview of Regulatory Framework

1.1.10 The IAEA provides advice to the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter

(London Convention 1972) on the definition of *de minimis* levels of radioactivity. This includes values below which materials can be regarded as 'non-radioactive' for the purpose of the London Convention 1972 and may be disposed of at sea subject to the other provisions of the Convention.

1.1.11 The London Convention 1972 prohibits the disposal at sea of radioactive wastes and other radioactive matter. However as noted above, natural radionuclides are present in all materials, including natural and inert materials, which can also contain artificial radionuclides from anthropogenic sources.

1.1.12 The IAEA TECDOC-1759 states that radiological assessment for the protection of human health should include estimates of individual and collective doses for comparison with the radiological criteria for exemption. It then notes that:

> *"A practice, or source within a practice, may be exempted without further consideration provided that the following radiological criteria are met in all feasible situations:*
>
> *(a) the effective dose expected to be incurred by any individual due to the exempted practice or source is of the order of 10 μSv or less in a year; and*
>
> *(b) either the collective effective dose committed by one year of performance of the practice is not more than about 1 man Sv or an assessment for the optimization of protection shows that exemption is the optimum option."*

In context, the limit of the effective dose for any member of the public (10μSv/y) is <0.4% of the average annual background radiation of 2.7mSv/y (Public Health England, 2011) which highlights its negligible impact even if a source was found to reach that limit.

1.1.13 Radioactive Substances Regulation (RSR) in England and Wales is delivered through the Environmental Permitting Regulations (England and Wales) 2016 as amended (EPR16). In England, RSR is delivered by the Environment Agency on behalf of the Department of Energy and Climate Change (DECC). This ensures national commitments to meet the requirements of the European Basic Safety Standard (BSSD) are met.

1.1.14 Under RSR, the term '*de minimis*' is not used. Nonetheless, an individual dose of 10 μSv or less in a year is considered trivial, a 'no harm' level. This value should be assessed relative to the presence of anthropogenic radionuclides. Where levels of naturally occurring radionuclides are elevated by nuclear industry operations, this elevation also needs to be considered against the 10 μSv or less in a year value (but can exclude natural levels of natural radioactivity).

1.1.15 Waste materials that contain trace levels of anthropogenic elevated radioactivity do not need to be regulated as radioactive, if the radiological risk posed from their disposal is 10 μSv or less in a year. The Government provides activity concentration values below which materials do not need regulation under RSR Ref 4.

1.1.16 The UK National Discharges Strategy 2005–2030 (Department of Energy & Climate Change, 2009) sets out what the Government wishes to see delivered in relation to its commitments under the 1992 Oslo and Paris (OSPAR) Convention. This relates to reductions in radioactive discharges; reductions in concentrations of radionuclides in the marine environment; and, reductions in human exposure to ionising radiation from radioactive discharges. Any radioactivity in dredged sediment due to anthropogenic activities is due to past discharges, however, disposal following dredging would be regulated under RSR if an individual dose of more than 10 μSv was incurred.

1.1.17 Based on the points above, RSR as applied in England is consistent with the requirements of the London Convention 1972 and the 1992 OSPAR Convention and an exposure of 10 μSv or less in a year is considered to represent ‘no harm’ where no radiological protection activities are required.

1.2 Radioactivity in the environment

1.2.1 To support this assessment, SZC Co. has obtained sea floor samples on two occasions. The first occasion sampled sediment at various points near-shore at the identified locations of the jetty and the beach landing facility. Further samples were later taken at the identified locations of the cooling water intakes, the outfall headworks, and in likely navigation channels. At these specific points the sea floor was bed rock, however samples were still taken and both sets of samples were analysed.

1.2.2 With regards to the second set of samples taken, all results of anthropogenic activity were LLOD. Furthermore, the identified naturally occurring radionuclides had consistent activity concentration values with those taken from the first set of samples, which gave confidence in the validity of their results. Therefore, the first set was taken as a bounding case. This has provided a conservative dose estimate as the first set gave positive results for anthropogenic activity and was also based on mobile sediment, as opposed to immobile bedrock. If considered, the immobility of the bedrock would only reduce dose uptake even further.

1.2.3 All samples have been analysed for a comprehensive range of determinands including radionuclides but not limited to those identified in this report. The radionuclides that have been highlighted in the following discussion are representative of those most likely to be detected in an assessment of this type. All analysed radionuclides not included in this discussion were LLOD and not considered likely to be appear; therefore, deemed unsuitable for inclusion.

a) Sample Collection and Analysis

1.2.4 With regards to the bounding case, vibrocore samples have been taken of the marine sediments at the identified locations. These locations represent areas where there is a risk of disturbing sediment during construction. A total of ten samples were taken, five at surface level and another five at a depth between 2 - 6 m.

1.2.5 The sediment samples were analysed for the presence of a range of radionuclide determinands by high-resolution gamma spectrometry. The results can be divided into two groups:

- Anthropogenic radionuclides typical of the nuclear industry: Co-60, Cs-137 and Am-241.

- Natural radionuclides that may be elevated due to anthropogenic activity, but nonetheless, would still be present in the absence of any nuclear industry activity: Ra-226, Th-232 and U-238.

1.2.6 Prior to analysis, the samples were dried, ground and homogenised. The analysis was completed using high-purity germanium detection – a form of gamma spectrometry - calibrated to measure gamma emitters in the energy range of 30keV and 2MeV. This form of spectrometry provides the highest resolution of all types currently available, making it ideal for detecting low energy radiation from potential trace radionuclides within the samples. The main drawback of this type is the cost and unsuitability for high-energy or large-volume samples; none of which are relevant to the requirements of this assessment.

i. Analysis Results

1.2.7 Tabulated activity concentration data (dry weight) is provided in full in **Table 1.1.** The '<' symbol indicates that the result was LLOD of the counting equipment. The ‘% error’ indicates 1 sigma total counting uncertainty. Note the percentage error does not apply when a result is below the detection limit.

Table 1.1: Sediment Activity Concentration Results

Collection Date	Reference ID / Description	Sediment Activity Concentration Bq/kg (Dry Weight) +/- error (as percentage)					
		Co-60	Cs-137	Am-241	Ra-226	Th-232	U-238
23/04/2015	VC-06. Core 0.00 - 0.20M Mud/Sand/Stones	< 0.16	1.03 ± 8.54%	< 0.31	9.50 ± 5.92%	10.98 ± 5.73%	18.46 ± 8.55%
23/04/2015	VC-06. Core 4.75 - 4.85M Sand/Shell	< 0.10	< 0.10	< 0.23	18.51 ± 5.57%	7.54 ± 5.60%	25.26 ± 6.13%
24/04/2015	VC-09. Core 0.00 - 0.20M Mud	< 0.18	2.30 ± 6.20%	< 0.28	11.23 ± 5.90%	14.65 ± 5.37%	24.97 ± 7.09%
24/04/2015	VC-09. Core 5.29 - 5.39M Sand/Shell	< 0.13	< 0.11	< 0.23	6.02 ± 6.27%	5.08 ± 6.96%	9.62 ± 13.55%
23/04/2015	VC-13. Core 0.00 - 0.20M Sand	< 0.12	0.21 ± 25.38%	< 0.23	8.05 ± 6.01%	5.07 ± 6.85%	8.39 ± 12.62%
23/04/2015	VC-13. Core 5.88 - 6.08M Clay	< 0.09	< 0.09	< 0.16	5.94 ± 6.06%	2.39 ± 9.19%	6.67 ± 11.66%
24/04/2015	VC-22. Core 0.00 - 0.30M Sand/Stones/Mud	< 0.13	1.33 ± 6.90%	< 0.25	6.72 ± 6.21%	6.96 ± 6.35%	11.69 ± 10.39%
24/04/2015	VC-22. Core 5.65 - 5.75M Sand	< 0.12	< 0.12	< 0.25	9.32 ± 5.92%	6.95 ± 6.46%	10.91 ± 11.94%
25/04/2015	VC-31. Core 0.00 - 0.20M Sand/Shell/Mud	< 0.10	0.20 ± 19.87%	< 0.19	6.07 ± 6.04%	4.90 ± 6.33%	10.74 ± 11.32%
25/04/2015	VC-31. Core 2.15 - 2.45M Sand	< 0.13	< 0.13	< 0.28	8.61 ± 5.96%	9.23 ± 5.67%	14.70 ± 9.35%

1.2.8 It is important to note that the U-238 concentrations are consistent with those of soils and sediments from around UK nuclear facilities, even those with little or no discharge of uranium (RIFE23). Equally, Th-232 and U-238 (and Ra-226 as a decay product of U-238), are not radionuclides typical of nuclear power station effluent discharge.

1.2.9 The minimum, arithmetic mean and maximum activity concentration values are summarised in **Table 1.2**.

1.2.10 All Co-60 and Am-241 values are all less than the limit of detection. This assessment has taken the less then values as the actual value used. This is precautionary as a less than value could be between zero and the limit of detection value reported.

Table 1.2: Sediment Activity Concentration Results

Radionuclide	Sediment Activity Concentration Bq/kg (Dry Weight)		
	Min	Mean	Max
Artificial Radionuclides			
Co-60*	0.09	0.13	0.18
Cs-137	0.09	0.56	2.30
Am-241*	0.16	0.24	0.31
Natural Radionuclides			
Ra-226	5.94	9.00	18.51
Th-232	2.39	7.38	14.65
U-238	6.67	14.14	25.26

** Note all Co-60 and Am-241 values were less than the limit of detection.*

1.2.11 Of the radionuclides considered here, only Am-241 is included in RIFE-23 for marine sediment from the Sizewell area. The results reported here ranged from less than values of 0.16 to 0.31 Bq/kg (dry weight) with a mean less than value of 0.24 Bq/kg (dry weight). RIFE-23 results for Am-241 are also all reported as less than the limit of detection (between < 0.30 and < 0.80 Bq/kg) but are given in wet weight values. Hence, direct comparison cannot be made. However, the values do not appear to be inconsistent.

b) Input Data for Assessment

1.2.12 The assessment has used mean and maximum activity concentration data (Bq/kg dry weight) that are reproduced in **Table 1.3.**

Table 1.3: Sediment Activity Concentration Data for Assessment

Radionuclide	Sediment Activity Concentration Bq/kg (Dry Weight)	
	Mean	Max
Artificial Radionuclides		
Co-60*	0.13	0.18
Cs-137	0.56	2.30
Am-241*	0.24	0.31
Natural Radionuclides		
Ra-226	9.00	18.51
Th-232	7.38	14.65
U-238	14.14	25.26

* Note all Co-60 and Am-241 values were less than the limit of detection.

1.3 Assessment Approach

1.3.1 The assessment approach is presented below. It considers artificial radionuclides that are clearly of anthropogenic origin and also radionuclides that occur naturally and are most likely to be presented at natural levels. These radionuclides have been included to ensure that the assessment is robust and bounding.

a) Overview of Approach

1.3.2 As noted the assessment is based on the approach of IAEA-TECDOC-1759 and an outline is provided below.

1.3.3 The assessment considered annual individual dose (to the boat crew undertaking dredging and sediment disposal and other members of the public) and annual collective dose (again to the crew and to the public).

1.3.4 The IAEA assume that the two groups consist of different individuals. Thus, it is not appropriate to sum individual or collective doses between the crew and the public.

1.3.5 The annual collective dose is the sum of individual doses across the individuals exposed. The IAEA methodology assumes that there is one dredging vessel with 10 crew members and that the public is exposed to radioactivity over a 10 km length of coastline.

1.3.6 The following exposure pathways have been considered in developing a specific assessment methodology for members of the crew:

- External exposure to radionuclides in the candidate material;
- Inadvertent ingestion of candidate material; and
- Inhalation of particles re-suspended from the surface of the candidate material.

1.3.7 The following exposure pathways have been considered for members of the public:

- External exposure to radionuclides deposited on the shore;
- Ingestion of seafood caught in the area around the dumping site;
- Inadvertent ingestion of beach sediments;
- Inhalation of particles re-suspended from beach sediments; and
- Inhalation of sea spray.

1.3.8 The IAEA note that their methodology does not consider other individuals who could be exposed to the radioactivity in the material because the doses that these individuals could receive are negligible compared to the exposure routes considered. Such individuals include, for example, swimmers and boaters who can receive doses through external exposure and ingestion of water while swimming or sailing.

b) Individual Dose Activity Concentration Coefficients

1.3.9 IAEA-TECDOC-1759 dose per unity activity concentration coefficients for annual individual dose (µSv/yr per Bq/kg, dry weight) are given in **Table 1.4**.

Table 1.4: Individual Dose Activity Concentration Coefficients (Ref 3)

Radionuclide	Individual Dose Coefficients (µSv/yr per Bq/kg, Dry Weight)	
	Crew	Public
Artificial Radionuclides		
Co-60	6.20E-02	6.80E-04
Cs-137	8.10E-03	2.80E-04
Am-241	2.30E-03	2.20E-05
Natural Radionuclides		
Ra-226	6.00E-02	2.60E-02
Th-232	7.60E-02	1.70E-02
U-238	6.40E-02	2.70E-02

c) Collective Dose Activity Concentration Coefficients

1.3.10 IAEA-TECDOC-1759 dose per unity activity concentration coefficients for annual collective dose (man Sv/yr per Bq/kg, dry weight) are given in **Table 1.5.**

Table 1.5: Collective Dose Activity Concentration Coefficients (Ref 3)

Radionuclide	Collective Dose Coefficients (man Sv/yr per Bq/kg, Dry Weight)	
	Crew	Public
Artificial Radionuclides		
Co-60	6.20E-06	2.50E-06
Cs-137	8.10E-07	3.10E-06
Am-241	2.30E-07	2.90E-07
Natural Radionuclides		
Ra-226	6.00E-06	1.20E-03
Th-232	7.60E-06	2.60E-04

Radionuclide	Collective Dose Coefficients (man Sv/yr per Bq/kg, Dry Weight)	
	Crew	Public
U-238	6.40E-06	1.20E-03

1.4 Assessment Results

1.4.1 Assessment results for annual individual dose and annual collective dose to crew and public are given below.

a) Individual Dose

1.4.2 The annual individual dose (µSv/yr) for the crew and public, based on mean and maximum concentrations and the IAEA dose coefficients, is given in **Table 1.6.**

Table 1.6: Annual Individual Dose Results

Radionuclide	Annual Individual Dose (µSv/yr)			
	Crew		Public	
	Mean	Max	Mean	Max
Artificial Radionuclides				
Co-60	8.06E-03	1.12E-02	8.84E-05	1.22E-04
Cs-137	4.54E-03	1.86E-02	1.57E-04	6.44E-04
Am-241	5.52E-04	7.13E-04	5.28E-06	6.82E-06
Natural Radionuclides				
Ra-226	5.40E-01	1.11E+00	2.34E-01	4.81E-01
Th-232	5.61E-01	1.11E+00	1.25E-01	2.49E-01
U-238	9.05E-01	1.62E+00	3.82E-01	6.82E-01
Total				
Artificial	1.31E-02	3.05E-02	2.50E-04	7.73E-04
Natural	2.01E+00	3.84E+00	7.41E-01	1.41E+00

Radionuclide	Annual Individual Dose (µSv/yr)			
	Crew		Public	
All	2.02E+00	3.87E+00	7.41E-01	1.41E+00

1.4.3 The annual individual dose summed across the artificial radionuclides considered for the crew is a mean value of 0.01 µSv/yr and a maximum value of 0.03 µSv/yr. These values are over two orders of magnitude below the 10 µSv/yr limit as discussed in Section 1.

1.4.4 The annual individual dose summed across the artificial radionuclides considered for the public is a mean value of 0.0003 µSv/yr and a maximum value of 0.0007 µSv/yr. These values are over four orders of magnitude below the 10 µSv/yr limit as discussed in Section 1.

1.4.5 If the annual individual dose is summed across all radionuclides considered (artificial and natural), the dose to the crew is a mean value of 2.02 µSv/yr and a maximum value of 3.87 µSv/yr. That to the public is a mean value of 0.74 µSv/yr and a maximum value of 1.41 µSv/yr. This approach is highly precautionary as natural levels of naturally occurring radionuclides would not normally be considered in an assessment such as this. Nonetheless, these combined values are still well below the 10 µSv/yr limit as discussed in Section 1.

1.4.6 The percentage contribution of artificial and natural radionuclides to the annual individual dose is shown in **Table 1.7.**

Table 1.7: Percentage Contribution to Individual Dose

Radionuclide	Percentage Contribution to Annual Individual Dose			
	Crew		Public	
	Mean	Max	Mean	Max
Artificial Radionuclides				
Co-60	0.40%	0.29%	0.01%	0.01%
Cs-137	0.22%	0.48%	0.02%	0.05%
Am-241	0.03%	0.02%	0.0007%	0.0005%
Natural Radionuclides				
Ra-226	26.75%	28.69%	31.56%	34.06%

Radionuclide	Percentage Contribution to Annual Individual Dose			
	Crew		Public	
Th-232	27.78%	28.76%	16.92%	17.62%
U-238	44.82%	41.76%	51.49%	48.26%
Total				
Artificial	0.65%	0.79%	0.03%	0.05%
Natural	99.35%	99.21%	99.97%	99.95%
All	100%	100%	100%	100%

1.4.7 In all instances, the individual dose from artificial radionuclides was less than 1% of the overall dose value.

b) Collective Dose

1.4.8 The annual collective dose (man Sv/yr) for the crew and public, based on mean and maximum concentrations and the IAEA dose coefficients, is given in **Table 1.8.**

Table 1.8: Annual Collective Dose Results

Radionuclide	Annual Collective Dose (manSv/yr)			
	Crew		Public	
	Mean	Max	Mean	Max
Artificial Radionuclides				
Co-60	8.06E-07	1.12E-06	3.25E-07	4.50E-07
Cs-137	4.54E-07	1.86E-06	1.74E-06	7.13E-06
Am-241	5.52E-08	7.13E-08	6.96E-08	8.99E-08
Natural Radionuclides				
Ra-226	5.40E-05	1.11E-04	1.08E-02	2.22E-02
Th-232	5.61E-05	1.11E-04	1.92E-03	3.81E-03
U-238	9.05E-05	1.62E-04	1.70E-02	3.03E-02

Radionuclide	Annual Collective Dose (manSv/yr)			
	Crew		Public	
Total				
Artificial	1.31E-06	3.05E-06	2.13E-06	7.67E-06
Natural	2.01E-04	3.84E-04	2.97E-02	5.63E-02
All	2.02E-04	3.87E-04	2.97E-02	5.63E-02

1.4.9 The annual collective dose summed across the artificial radionuclides considered for the crew is a mean value of 0.000001 man Sv/yr and a maximum value of 0.000003 man Sv/yr. These values are over six orders of magnitude below the 1 man Sv/yr limit as discussed in Section 1.

1.4.10 The annual collective dose summed across the artificial radionuclides considered for the public is a mean value of 0.000002 man Sv/yr and a maximum value of 0.000008 man Sv/yr. These values are over six orders of magnitude below the 1 man Sv/yr limit as discussed in Section 1.

1.4.11 If the annual collective dose was summed across all radionuclides considered (artificial and natural), the dose to the crew is a mean value of 0.0002 man Sv/yr and a maximum value of 0.0004 man Sv/yr. That to the public is a mean value of 0.03 man Sv/yr and a maximum value of 0.06 man Sv/yr. This approach is highly precautionary as natural levels of naturally occurring radionuclides would not normally be considered in an assessment such as this. Nonetheless, these combined values are well below the 1 man Sv/yr limit as discussed in Section 1.

1.4.12 The percentage contribution of artificial and natural radionuclides to the annual collective dose is shown in **Table 1.9.**

Table 1.9: Percentage Contribution to Annual Collective Dose

Radionuclide	Percentage Contribution to Annual Collective Dose			
	Crew		Public	
	Mean	Max	Mean	Max
Artificial Radionuclides				
Co-60	0.40%	0.29%	0.001%	0.001%
Cs-137	0.22%	0.48%	0.01%	0.01%

Radionuclide	Percentage Contribution to Annual Collective Dose			
	Crew		Public	
Am-241	0.03%	0.02%	0.0002%	0.0002%
Natural Radionuclides				
Ra-226	26.75%	28.69%	36.38%	39.42%
Th-232	27.78%	28.76%	6.46%	6.76%
U-238	44.82%	41.76%	57.15%	53.80%
Total				
Artificial	0.65%	0.79%	0.01%	0.01%
Natural	99.35%	99.21%	99.99%	99.99%
All	100%	100%	100%	100%

1.4.13 In all instances, the annual collective dose from artificial radionuclides was less than 1% of the overall dose value.

1.4.14 Uncertainties in how analytical results may affect the dose assessment are discussed in the next section.

c) Uncertainty

1.4.15 In dose assessment such as this, it is appropriate to consider how uncertainty in the input data and assessment approach may influence results obtained. Key points are discussed below.

1.4.16 Analysis results are based on ten sediment samples (collected at surface and depth). Radionuclide binding to marine sediment is dependent on the nature of that sediment (finer-grained muds can accumulate more radioactivity). Nonetheless, the samples include mud, sand, shell and stones material and hence are likely to be a good indication of sediment material and activity concentrations of radionuclides present.

1.4.17 There is some analytical uncertainty in the activity concentration results. For radionuclides that include those of natural origin (Ra-226, Th-232 and U-238), this is around plus or minus 10%. However, even if the total annual individual dose values (a maximum value of 3.87 µSv/yr) were increased by 10%, this would still be much less that the 10 µSv/yr level. It is also important to note that no allowance has been made for the fact that some, if not most, of the Ra-226, Th-232 and U-238 measured, will be natural background and as such, does not require consideration in a dose assessment such as this. Nonetheless, it is included here to ensure that results are robust and precautionary.

1.4.18 There is a greater range in analytical uncertainty (up to around plus or minus 25%) for the artificial radionuclides. However, combined, these account for less than 1% of the overall dose and would have to be over two orders of magnitude higher before the 10 µSv per year limit would be reached. Hence, this analytical uncertainty has little bearing on the dose assessment.

1.5 Discussion

1.5.1 The predicted individual and collective doses, whether to crew or the public are trivial, several orders of magnitude below the 10 µSv and 1 man Sv per year limits that would preclude disposal at sea under the London Convention 1972.

1.5.2 The activity concentrations of artificial radionuclides (whether measured or from less than values) are well below values that would require dredged spoil to be managed as radioactive under RSR as set out in Ref 5 (see **Table 1.10**). Note, it is not appropriate to apply these clearance levels to naturally occurring levels of radionuclides.

Table 1.10: Sediment Activity Concentration Data for Assessment

Radionuclide	Sediment Activity Concentration Bq/kg (Dry Weight)		Radioactive Waste Clearance Level (Bq/kg)+
	Mean	Max	
Artificial Radionuclides			
Co-60*	0.13	0.18	100 (0.1 Bq/g)
Cs-137	0.56	2.30	1000 (1 Bq/g)
Am-241*	0.24	0.31	100 (0.1 Bq/g)

** Note all Co-60 and Am-241 values were less than the limit of detection.*

+ Clearance levels are typical given in units of Bq/g. These are given in parenthesise for reference

1.5.3 Overall, doses predicted from anthropogenic radionuclides are low (at maximum 0.03 µSv per year for the crew and 0.0007 µSv/yr to the public). These are well below a 10 µSv per year level of 'no harm' and many orders of magnitude below the public dose limit of 1,000 µSv per year. Even if naturally occurring radionuclides are included in the dose assessment (which is not necessary), the dose is still trivial (at a maximum less than 4 µSv per year) and well below the 'no harm' and public dose limit.

1.5.4 No radiological controls associated with dredging and dredged material management are therefore expected.

1.6 Summary and Conclusions

a) Summary

1.6.1 SZC Co. plan to build a new nuclear power station comprising two UK EPR^{TM} units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as Sizewell C, will be situated to the north of the operational Sizewell B and the defueled Sizewell A nuclear power stations.

1.6.2 The new power station will require offshore dredging works associated with the installation of cooling water intake and outfall headworks and coastal engineering to build a temporary jetty and other enabling works (beach landing facility and navigation channels). These activities will require sediment dredging with the proposed disposal route for the dredged material at sea.

1.6.3 To support this assessment, SZC Co. has obtained sediment core samples at the identified locations of the jetty, beach landing facility, the cooling water intakes and outfall headwork's and in likely navigation channels. These samples have been analysed for a comprehensive range of determinants including radionuclides.

1.6.4 Concentrations of radionuclides derived from anthropogenic activity were investigated, including Co-60, Cs-137 and Am-241. Low levels of Cs-137 were detectable, but those of Co-60 and Am-241 were below detection. Where values were below detection limits, the limit of detection value has been used in this assessment. This is precautionary and in reality, the actual values may be much less.

1.6.5 The assessment approach uses that of the IAEA. It has considered the annual individual and annual collective dose to the crew of a dredging boat and that to other members of the public. Exposure via a range of pathways has been considered using IAEA dose per unit environmental concentration factors.

b) Conclusions

1.6.6 The annual individual dose summed across the artificial radionuclides considered for the crew is a mean value of 0.013 µSv/yr and a maximum value of 0.03 µSv/yr. These values are over two orders of magnitude below the 10 µSv/yr limit as discussed in Section 1.

1.6.7 The annual individual dose summed across the artificial radionuclides considered for the public is a mean value of 0.0003 µSv/yr and a maximum value of 0.00077 µSv/yr. These values are over three orders of magnitude below the 10 µSv/yr limit as discussed in Section 1.

1.6.8 If the annual individual dose is summed across all radionuclides considered (artificial and natural), the dose to the crew is a mean value of 2.02 µSv/yr and a maximum value of 3.87 µSv/yr. That to the public is a mean value of 0.74 µSv/yr and a maximum value of 1.41 µSv/yr. This approach is highly precautionary as natural levels of naturally occurring radionuclides would not normally be considered in an assessment such as this. Nonetheless, these combined values are well below the 10 µSv/yr limit as discussed in Section 1.

1.6.9 The annual collective dose summed across the artificial radionuclides considered for the crew is a mean value of 0.0000013 man Sv/yr and a maximum value of 0.000003 man Sv/yr. These values are over five orders of magnitude below the 1 man Sv/yr limit as discussed in Section 1.

1.6.10 The annual collective dose summed across the artificial radionuclides considered for the public is a mean value of 0.0000021 man Sv/yr and a maximum value of 0.0000077 man Sv/yr. These values are over five orders of magnitude below the 1 man Sv/yr limit as discussed in Section 1.

1.6.11 If the annual collective dose was summed across all radionuclides considered (artificial and natural), the dose to the crew is a mean value of 0.0002 man Sv/yr and a maximum value of 0.00039 man Sv/yr. That to the public is a mean value of 0.03 man Sv/yr and a maximum value of 0.056 man Sv/yr. This approach is highly precautionary as natural levels of naturally occurring radionuclides would not normally be considered in an assessment such as this. Nonetheless, these combined values are well below the 1 man Sv/yr limit as discussed in Section 1.

1.6.12 Overall, doses predicted from anthropogenic radionuclides are low (at maximum 0.03 µSv per year for the crew and 0.00077 µSv/yr to the public. These are well below a 10 µSv per year level of 'no harm' and many orders of magnitude below the public dose limit of 1,000 µSv per year. Even if naturally occurring radionuclides are included in the dose assessment (which is not necessary), the dose is still trivial (at a maximum less than 4 µSv per year) and well below the 'no harm' and public dose limit.

1.6.13 No radiological controls associated with dredging and dredged material management are therefore expected.

1.7 Location of Sizewell C

Plate 1.1: Outline of current Sizewell site (A&B) with additional boundary indicating main development site for Sizewell C

1.8

References

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1.3 IAEA (2015). Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure, IAEA-TECDOC-1759, IAEA, Vienna

1.4 Department for Business, Energy & Industrial Strategy, “Scope of and Exemptions frmo teh Radioactive Substances Legislation in England, Wales and Northern Ireland,” BEIS, London, 2018.

1.5 DECC (2009). UK Strategy for Radioactive Discharges, July 2009

VOLUME 2, CHAPTER 25, APPENDIX 25: RADIOACTIVE SUBSTANCES REGULATIONS PERMIT APPLICATION: SUPPORT DOCUMENT D1 - HUMAN RADIOLOGICAL IMPACT ASSESSMENT FOR SIZEWELL C

Sizewell C Project

Radioactive Substances Regulations (RSR) Permit Application

Appendix D

Support Document D1 - Human Radiological Impact Assessment

EXECUTIVE SUMMARY

NNB Generation Company (SZC) Limited (SZC Co.) plan to construct and operate a new nuclear power station comprising two UK EPR^{TM} units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as Sizewell C (SZC), will be situated to the north of both Sizewell B (SZB) and Sizewell A (SZA) nuclear power stations; SZB and SZA are operational and defueled, respectively. SZC will dispose of low level radioactive waste during operations; this will include operational discharges of lower activity radioactive aqueous and gaseous effluents into the environment.

This report presents the methodology used and the results of an assessment of radiological dose to members of the public associated with the operational phase of SZC. Assessments have been carried out as follows, along with sensitivity analyses and screening assessments.

- Annual doses to Candidates for the Representative Person (CRPs), i.e. an individual receiving a prospective dose that is representative of the more highly exposed individuals in the population arising from continuous discharges of aqueous and gaseous radionuclides into the environment.
- Collective dose to UK, European and world populations.
- Dose from exposure to direct radiation and skyshine from site infrastructure.
- Annual dose to the representative person from aqueous, gaseous and external radiation (including direct radiation and skyshine). This term is equivalent to, and replaces, the term ‘average member of the critical group’.
- Dose from short-term releases of gaseous radionuclides into the atmosphere.
- Build-up of radionuclides in the environment.

Approaches for assessing the impact of continuous discharges from SZC took recognition of approaches advocated by: the National Dose Assessment Working Group (NDAWG); the Environment Agency; and international and national advisory bodies such as: the International Commission on Radiological Protection (ICRP); and Public Health England (PHE, formerly the Health Protection Agency, HPA). An initial assessment using the Initial Radiological Assessment Tool (IRAT) developed by the Environment Agency was carried out, which demonstrated that a more detailed assessment was required. This was undertaken using the PC-CREAM 08 software suite of dispersion and dose assessment modules. Assessment of short-term discharges has been undertaken using the industry standard Atmospheric Dispersion Modelling System (ADMS). Impacts have been assessed at the proposed discharge limits, which were derived based on the limits permitted for Hinkley Point C (HPC).

Candidates considered for the representative person for exposure to aqueous discharges were a fishing family, a houseboat dweller and a wildfowler. The annual dose to the adult, child and infant members of the fishing family from exposure to aqueous discharges from SZC, summed across the relevant marine pathways, was calculated to be 10 µSv/y, 4.9 µSv/y and 1.3 µSv/y, respectively. The dominant pathway for all age groups is the ingestion of fish which contributes around 67%, 86% and 70% to the doses for adult, child and infant respectively. C-14 is the dominant radionuclide, contributing between 93% and 98% of the assessed dose to the fishing family. The annual dose to the adult, child and infant members of the fishing family from exposure to combined aqueous discharges from SZB and C was calculated to be 12 µSv/y, 5.3 µSv/y and 1.4 µSv/y, respectively. Again, C-14 was the dominant radionuclide and ingestion of fish was the dominant exposure pathway. The annual dose to an adult houseboat occupant and a wildfowler from exposure to aqueous discharges from SZC, and from SZB and SZC combined were less than 0.2 µSv/y.

Candidates considered for the representative person for exposure to gaseous discharges were a farming family and a worker at the neighbouring SZB facility. The annual dose to the adult, child and infant members of the farming family from exposure to gaseous discharges from SZC, summed across the relevant terrestrial pathways, was calculated to be

4.0 µSv/y, 3.3 µSv/y and 6.9 µSv/y, respectively. The dominant pathway is the ingestion of cow milk which contributes around 40%, 67% and 87% of the assessed dose to adult, child and infant age groups, respectively. C-14 is the dominant radionuclide, contributing between 89% and 94% of the assessed dose to the farming family. The corresponding dose to the SZB worker is 4.1 µSv/y and is dominated by the ingestion of cow milk and root vegetables. The annual dose to the adult, child and infant members of the farming family from exposure to combined gaseous discharges from SZB and SZC was calculated to be 5.6 µSv/y, 4.7 µSv/y and 9.8 µSv/y respectively. Again, ingestion of milk is the dominant pathway and C-14 was the dominant radionuclide. The annual dose to the SZB worker from the combined discharges of gaseous radionuclides from SZB and SZC was calculated to be 5.9 µSv/y.

The exposure of members of the public from direct radiation emanating from the SZC reactor buildings will be negligible due to the shielding incorporated into the design of the reactor buildings (for instance as demonstrated by SZB). Direct radiation from SZC is therewfore largely attributable to the Interim Spent Fuel Store (HHK) and Intermediate Level Waste (ILW) Interim Storage Facilities (HHI) on site. Dose from skyshine associated with radiation from the stores was also considered. Three candidate representative persons were considered in the external dose assessment: a dog walker, a local resident family and a SZB worker. The annual dose to the SZB worker from exposure to direct radiation from SZC was calculated to be 3.7 µSv/y. The dose to a local resident was calculated to be significantly lower (0.0029 µSv/y to an adult, with child and infant doses even lower), as was the dose to a dog walker (0.022 µSv/y). Skyshine doses were at least one order of magnitude smaller than the direct dose for all CRPs. A sensitivity analysis indicated that if skyshine doses were increased by two orders of magnitude, the total dose from radiation emanating from the stores would still be of the order of a few nanosieverts, except in the case of the SZB worker, for whom the total dose would be 3.8 µSv/y.

The representative person was identified as the adult member of a fishing family living close to the Sizewell site. The dose to the representative person from exposure to the combined aqueous and gaseous discharges and from exposure to direct radiation from SZC was 13 µSv/y. This dose is significantly less than the current source dose constraint of 300 µSv/y. The dose to the representative person from the site (i.e. SZB and SZC) was 17 µSv/y, which is 3.4% of the site dose constraint (500 µSv/y), The annual dose to the representative person including historical and future discharges was estimated to be 53 µSv/y, 5.3% of the 1 mSv public dose constraint.

Dose to a foetus as a result of gaseous and aqueous discharges from SZC was calculated assuming that the mother was the representative person. The calculated dose to the foetus was 17 µSv/y, which is higher than the doses calculated for other age groups for combined discharges from SZC. However, the dose constitutes less than 6% of the statutory (source and site) dose constraints of 300 and 500 µSv/y and is considered to be low.

Short-term doses are required to be assessed explicitly, in addition to the doses from continuous releases. The dose to the adult, child and infant members of the farming family from exposure to short-term discharges of gaseous radionuclides from SZC, summed across the relevant terrestrial pathways, is calculated to be 3.8 µSv/y, 3.5 µSv/y and 6.9 µSv/y, respectively. The dominant pathway is the ingestion of cow milk which contributes around 43%, 64% and 87% of the short-term dose to adult, child and infant age groups, respectively. Ingestion pathways account for around 98-99% of the calculated short-term doses. C-14 is the dominant radionuclide, accounting for 99% of the assessed dose to the farming family.

The collective dose is the time-integrated dose to a population from a single year of discharge. The collective dose from discharges of aqueous radionuclides to the marine environment from SZC at the proposed limits was assessed to be 0.035 manSv/y, 0.21 manSv/y and 2.3 manSv/y to UK, European and World populations respectively. The collective dose from gaseous discharges at proposed annual limits from SZC was estimated to be: 0.23 manSv/y, 1.0 manSv/y and 25 manSv/y to UK, European and World populations respectively. In both instances, over 99% of the collective dose to all three population groups was predicted to arise from C-14. The per caput dose to UK, European and World population from both aqueous and gaseous discharges was calculated to be between 2.1 nSv/y and 4.5 nSv/y for discharges from SZC (and between 2.6 nSv/y and 6.0 nSv/y for discharges from SZB and SZC). The UK regulatory agencies and advisory bodies consider that the risks associated with annual average per caput dose in the nanosievert range are trivial and should be ignored in the authorisation decision making processes.

The dose from the build-up of gaseous radionuclides discharged from SZC and deposited on the ground, assessed as total dose to a construction worker was found to be trivial at 0.0034 µSv/y.

The Environment Agency recommends that a review of uncertainty and variability associated with key assumptions used in dose assessment be carried out in the event that the estimated dose to the representative person exceeds 20 µSv/y. The specific assumptions and parameters analysed were:

- Discharges - expected best performance discharges against proposed limits.
- Habits Data - generic food ingestion rate against site specific food ingestion rates.
- Food Source – 100% locally sourced seafood against 50% locally sourced seafood.

The dose to adult, child and infant members of the fishing family arising from discharge at expected best performance was calculated to be 2.4 µSv/y, 1.2 µSv/y and 0.32 µSv/y respectively. This corresponds to approximately 23-24% of the dose predicted to arise from discharges at the annual limits, a reduction in dose by around a factor of four. The dose to adult, child and infant members of the farming family arising from discharges at expected best performance was calculated to be 1.9 µSv/y, 1.5 µSv/y and 3.2 µSv/y respectively. This corresponds to approximately 46% to 48% of the dose predicted to arise from discharges at the annual limits, a reduction in dose by around a factor of two. The use of site-specific food ingestion rates results in a dose estimate that is broadly comparable to that calculated using generic ingestion rates. If only 50% of all seafood is sourced from the local compartment, then this ingestion dose pathway is effectively halved. Overall, it was considered that the approach for assessing the dose to CRPs via food ingestion pathways adopted for this assessment represents a reasonable and robust approach, and has not resulted in a significant underestimation of the dose to CRPs.

All individual doses calculated were significantly less than the corresponding source and site constraints and the public dose limit. Sensitivity analyses have shown that the predicted doses are likely to be bounding and that actual exposure will be less. Collective dose has also been shown to be trivial.

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1 INTRODUCTION

1.1 Purpose

1. EDF Energy plan to build a new nuclear power station comprising two UK EPR^{TM} units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as SZC, will be situated to the north of the operational SZB and the defueled SZA nuclear power stations [Ref 1].

2. The proposed SZC nuclear power station will dispose of very low level radioactive waste, which are unavoidable during operations. This will include operational discharges of radioactive aqueous and gaseous effluent into the environment. As such, it will require an environmental permit granted under Schedule 23 of the Environmental Permitting (England and Wales) Regulations 2016 (as amended) (EPR16) [Ref 2], known as the Radioactive Substances Regulations (RSR). The RSR guidance [Ref 3] require applicants for environmental permits granted under EPR16 to assess the potential impacts of the operations, referred to here as a Radiological Impact Assessment (RIA), associated with planned operational discharges on members of the public at the proposed discharge limits. Such prospective assessments are required to be realistic and to be supported by robust and justifiable assumptions, methodology and input data [Ref 4]. The full RSR application is provided in the Head Document [Ref 2].

3. This report presents the approach and the results of prospective radiological assessments of dose to members of the public associated with the operational phase of SZC. Assessments have been carried out for:

    - Annual doses to CRPs, i.e. an individual receiving a prospective dose that is representative of the more highly exposed individuals in the population arising from continuous discharges of aqueous and gaseous radionuclides into the environment.
    - Collective dose to UK, European Union (EU) and World populations.
    - Dose from exposure to direct external radiation from the site, including from skyshine.
    - Annual dose to the representative person from aqueous, gaseous and external radiation (including direct radiation and skyshine). This term is equivalent to, and replaces, the term ‘average member of the critical group’.
    - Dose arising from short-term releases of gaseous radionuclides into the atmosphere.
    - Build-up of radionuclides in the environment.
    - Sensitivity assessments to consider a number of issues including discharges (expected best performance / proposed limits) and habits data (assumed food ingestion rates and assumed food source).

4. An assessment of the radiological impacts of routine, continuous discharges to air and to the marine environment (collectively referred to as permitted discharges) from the proposed SZC nuclear power station on non-human biota is presented in a separate report [Ref 6].

5. In addition, the cumulative dose to the CRP from the effect of the combined discharges of aqueous and gaseous effluent from SZC and the neighbouring SZB station, and the contribution of other sources of radioactivity have been considered. It is noted that SZA is currently defueled and the lifetime plan states that it is expected to have entered into the care and maintenance (C&M) decommissioning phase before SZC begins power generation [Ref 7]. It is considered that subsequent discharges from SZA while in C&M would be so low as to not warrant inclusion in the assessment of cumulative site impacts, hence, SZA discharges have not been considered as part of the assessment of cumulative impacts for SZC operations. Any future impacts associated with the decommissioning of SZA (or SZB or SZC) will be assessed under the Environmental Impact Assessment for Decommissioning Regulations (EIADR) [Ref 8] and where applicable associated permit variations or applications.

6. All the assessments described in this report have been undertaken with due regard to the guidance and recommendations contained in the Environment Agency's Guidance Document on the Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment ("The Principles Document") [Ref 4] and the NDAWG Guidance Notes [9]. Table 1-1 sets out the locations where the Principles for the Assessment of Prospective Public Doses are applied within this report.

Table 1-1 Locations where the Principles for the Assessment of Prospective Public Doses are applied

Principle	Principle	Location in document
1	Prospective dose assessment methods, data and results should be transparent and made publicly available.	Throughout
2	Workers, who are exposed to discharges of radioactive waste, but who do not work directly with ionising radiation and are therefore not normally exposed to ionising radiation, should be treated as if they are members of the public for the purpose of determining discharge permits or authorisations.	Section 2.4 (dose to a person working at the location of the Sizewell B site)
3	When determining discharge permits or authorisations, the dose to the representative person should be assessed.	Section 4
4	Doses to the most affected age group should be assessed for the purpose of determining discharge permits or authorisations. Assessment of doses to 1 year old, 10 year old and adults (and foetuses when appropriate) is adequate age group coverage.	Sections 2, 4, 5 and Appendix A.
5	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.	Section 4
6	Significant additional doses to the representative person from historical discharges from the source being considered and doses from historical and future discharges and direct radiation from other relevant sources subject to control should be assessed and the total dose compared with the dose limit of 1 mSv/y.	Section 4
7	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.	Section 2.2 contains the initial cautious assessment, the remainder of the document provides a more realistic assessment.
8	The assessment of dose to the representative person should take account of accumulation of radionuclides in the environment from future discharges.	Section 4
9	The realistic habits adopted for the representative person should be those which have actually been observed at the site, within a period of about 5 years. Changes to habits which are reasonably likely to occur should be taken into account.	Discussed in Section 2.

Principle	Principle	Location in document
10	Land use and infrastructure should have sufficient capacity to support the habits of the representative person. Any changes to land use and infrastructure should be reasonably likely to occur over a period of about 5 years and be sustainable year on year for them to be considered.	Discussed in Section 2.
11	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.	Section 5
12	For permitting or authorisation purposes, collective doses to the populations of UK, Europe and the World, truncated at 500 y, should be estimated.	Section 6
13	Where the assessed mean dose to the representative person exceeds 0.02 mSv/y, the uncertainty and variability in the key assumptions used for the dose assessment should be reviewed.	Section 8

1.2 Scope

7. This report forms part of the documentation prepared in support of the RSR permit application for SZC. The scope of this report covers the assessment of potential radiological impacts to members of the public from discharges of radioactive effluent (aqueous and gaseous) at proposed annual limits and at estimated best performance levels, and direct radiation from site infrastructure under normal operating conditions of power generation and refuelling. Doses due to short-term releases (again under normal operating conditions) are also considered.

8. An initial RIA was undertaken in 2015. This current document updates the work previously undertaken, taking new habits data into account [Ref 10].

9. The assessment of potential radiological impacts arising from radioactive discharges under accident scenarios is outside of the environmental permit scope and is covered under the SZC Pre-Construction Safety Report that will be submitted as part of the Nuclear Site Licence application.

1.3 Definitions

Term / Abbreviation	Definition
ADMS	Atmospheric Dispersion Modelling System
ADO	Aquatic Dosimetric Model
AP	Anterior-posterior
BAT	Best Available Techniques
BSS	Basic Safety Standards
C&M	Care and Maintenance
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CF	Concentration Factor
CRP	Candidate for the Representative Person
DEFRA	Department for Environment, Food and Rural Affairs

Term / Abbreviation	Definition
DPUC	Dose per Unit Activity Concentration
DPUR	Dose Per Unit Release
EC	European Commission
EIADR	Environmental Impact Assessment for Decommissioning Regulations
EPR16	Environmental Permitting Regulations 2016 (as amended)
EU	European Union
FGR12	Federal Guidance Report No. 12
FSA	Food Standards Agency
GDA	Generic Design Assessment
HHI	ILW Interim Storage Facility
HHK	Interim Spent Fuel Store
HPA	Health Protection Agency (now PHE)
HPC	Hinkley Point C
HTO	Hydrogen Tritium Oxide
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate Level Waste
IRA	Initial Radiological Assessment
IRAM	Initial Radiological Assessment Methodology
IRAT	Initial Radiological Assessment Tool
IRR99	Ionising Radiations Regulations 1999
MCNP	Monte Carlo N-Particle
Met	Meteorological
NNB GenCo (HPC)	NNB Generation Company (HPC) Limited
NCRP	National Council on Radiation Protection and Measurements
NDAWG	National Dose Assessment Working Group
NRPB	National Radiological Protection Board
NWP	Numerical Weather Prediction
OBT	Organically Bound Tritium
ONR	Office for Nuclear Regulation
PHE	Public Health England (formerly HPA)
RIA	Radiological Impact Assessment
RIFE	Radioactivity in Food and the Environment
Rot	Rotational
RPD	Radiation Protection Division
RSR	Radioactive Substances Regulations
SZA	Sizewell A
SZB	Sizewell B
SZC	Sizewell C
SZC Co.	NNB Generation Company (SZC) Limited

1.4 References

Ref	Title	Document No.	Version	Location	Author
[1]	Sizewell C Detailed Site Layout	SZC-SZ0100-XX-000-DRW-100004	1.0	EDRMS	SZC Co.
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[16]	Initial Radiological Assessment Methodology - Part 1 User Report	SC030162/SR1	1.0	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/631165/IRAT_Science_Report_Part_1.pdf Last Accessed: 19/02/2020	Environment Agency
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[69]	Doses to the embryo/foetus and neonate from intakes of radionuclides by the mother. Part 1: Doses received in utero and from activity present at birth	397/2001	-	http://www.hse.gov.uk/research/crr_pdf/2001/crr01397.pdf Last Accessed: 19/02/2020	HSE
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1.5 Overview of Regulatory Framework

10. Schedule 23 of EPR16 [Ref 2] provides the formal legislative basis for the regulation of radioactive waste disposals into the environment in England and Wales. In England, the requirements of the EPR16 are implemented through the granting of permits to operators of nuclear installations or users of radioactive sources by the Environment Agency, the statutory environmental regulator.

11. The control of radioactive materials on nuclear licensed sites is regulated under the Nuclear Installations Act 1965 in conjunction with RSR (covering storage of radioactive material) and the Ionising Radiations Regulations 1999 (IRR99) (covering occupational exposure to radiation), the requirements of which are enforced by the Office for Nuclear Regulation (ONR) across the UK [Ref 11]. In England, the Environment Agency and ONR work in close collaboration to ensure a consistent approach in the implementation of radioactive substances regulation at nuclear licensed sites.

12. The protection of members of the public from the effects of exposure to sources of radioactivity is achieved, in part, through implementation of dose criteria set out under the EPR16 and IRR99 regimes. These criteria transpose the requirements of the Basic Safety Standards (BSS) Directive [Ref 12] and are largely based on the recommendations of the ICRP [Ref 13]. They include:

    - An annual dose limit of 1,000 µSv/y to a member of the public from all historical, current and future sources of radioactivity subject to control.
    - A site dose constraint of 500 µSv/y to a member of the public from future planned operational discharges (excluding direct radiation) from multiple sources with contiguous boundaries at a single location. This applies to the combined discharges for SZB and SZC.
    - A dose constraint of 300 µSv/y to a member of the public due to future planned operational discharges and direct radiation arising from a single new source. For the purpose of legislation, SZC is considered a single new source. It is noted that in 2009 the HPA, now PHE, recommended that the UK Government implement a dose constraint not exceeding 150 µSv/y for members of the public in respect of new nuclear power stations and waste disposal facilities, in recognition of the fact that the design stage of such facilities presents an opportunity to reduce exposures to the public [Ref 14]. However, this recommendation is not recognised as a statutory requirement[1].

13. The Environment Agency, HPA and the Food Standards Agency (FSA) recognise that where doses are below the former threshold of optimisation (<0.02 mSv/y) or are below regulatory concern (<0.01 mSv/y) then the effort to make assessments more realistic may not be warranted [Ref 4]. An annual dose of 10 to 20 µSv/y (0.01 to 0.02 mSv/y) can be broadly equated to an annual risk of death of about one in a million per year. In terms of the collective dose to population groups, the UK regulatory agencies and advisory bodies have stated that the risks associated with per caput dose in the nSv/y range, or below, are miniscule and should be ignored in the decision-making processes [Ref 2]. Higher doses of the order of a few µSv/y can be considered to be trivial, but may require further consideration particularly if at the upper end. Nonetheless, the standard Environment Agency permit conditions under EPR16 (for instance that for HPC [Ref 15]) is specific in the requirement that the operator shall use the Best Available Techniques (BAT) in respect of the disposal of radioactive waste pursuant to the permit to:

    - Minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment;
    - Minimise the volume of radioactive waste disposed of by transfer to other premises;
    - Dispose of radioactive waste at times, in a form, and in a manner to minimise the radiological effects on the environment and members of the public.

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[1] It was not incorporated in the 2018 revision of EPR 16 which implemented the requirements of the 2013 BSS.

14. The above radiological exposure criteria will serve as benchmarks against which the predicted doses from permitted discharges from the proposed SZC nuclear power station will be compared.

1.6 Document Structure

15. This document is set out in the following way:

- Section 2 – Annual individual dose due to continuous discharges, presents the doses to individuals from routine.
- Section 3 – Annual dose to the candidates for the representative person from direct radiation. An initial dose assessment is carried out, followed by a detailed assessment of doses to CRPs from aqueous discharges, and separately from gaseous discharges. Doses to individuals from direct radiation and skyshine.
- Section 4 – Annual dose to the representative person. The representative person, who is the CRP with the highest prospective dose from aqueous discharges, gaseous discharges and direct radiation and skyshine is identified.
- Section 5 – Short-term dose assessment. Assessment of doses to individuals from a short-term release of radionuclides.
- Section 6 – Collective dose to UK, EU and world populations. Assessment of Collective doses to the UK population, EU population and world population from aqueous and gaseous discharges.
- Section 7 – Build-up of radionuclides in the environment. Build-up of radionuclides in the environment as a result of gaseous and aqueous discharges is presented, along with an assessment of dose to a future land user.
- Section 8 – Sensitivity analyses. Assessment against discharges at expected best performance compared to discharges at proposed limits is presented, along with screening assessments against food intake rates and assumptions.
- Section 9 – Summary and conclusions. Presents the results and conclusions of the Human Radiological Impact Assessment.
- Appendix A – Supporting screening assessments are presented in Appendix A.

2 ANNUAL INDIVIDUAL DOSE DUE TO CONTINUOUS DISCHARGES

2.1 Assessment Methodology

a) Assessment Approach

16. Fission and activation products released from reactor operations are relatively constant throughout the site fuel-use cycle and hence consistent throughout any annual period. Assessment of continuous discharges is therefore appropriate for most radionuclides discharged and is discussed in this section. Short-term discharges relate to radionuclides such as H-3 with low radiotoxicity. Doses associated with short-term gaseous discharges are discussed in Section 5 and those associated with short-term discharges of H-3 to sea are discussed in Appendix A.5. For the assessment of continuous discharges from SZC, the approach advocated by the NDAWG [Ref 9] and the Environment Agency [Ref 4] has been adopted. An initial dose assessment (Stage 1 and 2) was performed using the Excel based IRAT developed by the Environment Agency, based on their Initial Radiological Assessment Methodology (IRAM) [Ref 16] [Ref 17].

17. The initial assessment was then followed by a detailed, more realistic assessment using site-specific assessment parameters in accordance with the regulatory requirements for radiological assessments carried out to support environmental permit applications for nuclear facilities [Ref 18].

18. Assessments have been carried out based on the proposed annual discharge limits (and using best performance values as part of a sensitivity analysis in Section 8) for aqueous and gaseous radionuclides anticipated to be discharged by SZC. These assessments assume that radionuclide discharges are made in a continuous, routine and uniform manner and are consistent through a 60-year operational period.

b) Source Term

19. Discharges of aqueous radionuclides into the marine environment will be made via two outfall structures to be constructed at a location approximately 3.5 km offshore [Ref 19]. Releases of gaseous radionuclides into the atmosphere will be made primarily via two emission stacks with physical heights of 70 m above ground level [Ref 20]. Table 2-1 and Table 2-2 present the proposed annual limits for discharges of aqueous and gaseous radionuclides from SZC. These proposed limits are derived based on the annual permit limits granted to the EDF power station to be constructed at Hinkley Point (HPC) [Ref 15] [Ref 21]. Further information on the proposed discharge limits is presented in the SZC RSR Permit Application Supporting Document B [Ref 22]. This approach is pessimistic as the impact assessment is based on the proposed permitted limits, and as noted, assessment under realistic estimated best performance is given in Section 8.

20. The cumulative impacts of the combined discharges from SZC and the neighbouring SZB station have been assessed as part of the permit application process, in accordance with recommended practice [Ref 4]. The annual permitted limits and reported discharges against those limits for the SZB station[2] were taken from the three most recent Radioactivity in Food and the Environment (RIFE) Reports compiled by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) on behalf of the UK Environment Agency[3] [Ref 23] [Ref24] [Ref25] and are presented in Table 2-1 and Table 2-2. As discussed above, the discharges from SZA during C&M coincide with the operational phase of SZC but are anticipated to be so low as to not warrant inclusion in the assessment of cumulative site impacts.

Table 2-1 Annualised Aqueous Discharges for Sizewell C and Sizewell B Facilities

Radionuclide	SZC		SZB	
	Proposed limits (Bq/y)	Expected best performance (Bq/y)	Annual discharge limits (Bq/y)	Annual discharges (Bq/y) (based on a 3 year average)
Ag-110m	1.12E+09	7.51E+07	-	-
C-14	1.90E+11	4.60E+10	-	-
Co-58	4.07E+09	2.73E+08	-	-
Co-60	6.00E+09	3.95E+08	-	-
Cr-51	1.18E+08	7.91E+06	-	-
Cs-134	1.10E+09	7.38E+07	1.30E+11	4.50E+09
Cs-137	1.90E+09	1.10E+08	2.00E+10	7.82E+08
H-3	2.00E+14	1.04E+14	8.00E+13	2.39E+13
I-131	9.83E+07	6.59E+06	-	-

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[2] It is noted that Sizewell B is scheduled to shut down around 2035. The scheduled closure of Sizewell B has not been factored in to cumulative impacts assessments and Sizewell B discharges were assessed in the same manner as Sizewell C (i.e. using a 60 year integration time). This will result in a pessimistic assessment outcome.

[3] Environment Agency, FSA, Northern Ireland Environment Agency and the Scottish Environment Protection Agency (note - National Resources Wales, a body constituted in 2012 have taken over the functions of the Environment Agency in Wales from April 2014).

Radionuclide	SZC		SZB	
	Proposed limits (Bq/y)	Expected best performance (Bq/y)	Annual discharge limits (Bq/y)	Annual discharges (Bq/y) (based on a 3 year average)
Mn-54	5.31E+08	3.56E+07	-	-
Ni-63	1.89E+09	1.27E+08	-	-
Sb-124	9.63E+08	6.46E+07	-	-
Sb-125	1.60E+09	1.07E+08	-	-
Te-123m	5.11E+08	3.43E+07	-	-

Note: SZB is permitted for H-3, Cs-137, and other radionuclides. Here it has been assumed that other radionuclides can be assessed as Cs-134.

21. In the HPC permit, the Environment Agency assigned annual limits on aqueous discharges of H-3, C-14, Co-60 and Cs-137 [Ref 15]. Other fission and activation products were grouped together as 'other radionuclides' and assigned a single annual aqueous discharge limit. For the purpose of the SZC radiological assessments, the typical percentage of the individual radionuclides comprising the 'other radionuclides' group [Ref 26] has been applied to derive the annual limits for the individual radionuclides, based on the limits granted for HPC. The basis for the limits and proposed grouping is presented in the SZC RSR Permit Application Supporting Document B [Ref 22].

22. The annual aqueous discharges for SZB have been derived as the average of reported discharges for 2015-2017, in order to reduce the effect of annual variations in reported discharges from the station (for instance as a result of shut-down for maintenance or other reasons).

23. SZB has annual limits on aqueous discharges of H-3, Cs-137 and other radionuclides' [Ref 25]. Cs-134 is used as a surrogate for SZB discharges of 'other radionuclides'; the dose from this group is estimated by calculating the dose from an equivalent activity of Cs-134. This approach was also used for the HPC RIA [Ref 26].

24. For aqueous discharges it is considered that C-14 and H-3 occur as dissolved CO_2 and tritiated water (Hydrogen Tritium Oxide (HTO)) respectively; corrosion products (e.g. Sb, Mn, Ag, Ni and Co) occur as either soluble or particulate form; and, that fission products (e.g. Cs-137), occur in a soluble form in cooling water. The majority of iodine isotopes are in ionic form in the liquid phase [Ref 27].

Table 2-2 Annualised Gaseous Discharges for Sizewell C and Sizewell B Facilities

Radionuclide	SZC		SZB	
	Proposed limits (Bq/y)	Expected best performance (Bq/y)	Annual discharge limits (Bq/y)	Annual discharges (Bq/y) (based on a 3 year average)[4]
Ar-41	1.31E+12	4.64E+10	3.00E+13	2.94E+12
C-14	1.40E+12	7.00E+11	5.00E+11	2.33E+11
Co-58	1.09E+07	7.24E+05	-	-
Co-60	1.28E+07	8.54E+05	1.00E+08	7.67E+06
Cs-134	9.98E+06	6.65E+05	-	-
Cs-137	8.95E+06	5.96E+05	-	-
H-3	6.00E+12	1.00E+12	3.00E+12	6.73E+11
I-131	4.00E+08	5.00E+07	5.00E+08	1.30E+07
I-133	7.74E+07	5.16E+06	-	-
Kr-85	6.26E+12	2.22E+11	-	-

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[4] There is no discharge value for I-131 in RIFE 21 (2015), so the average value for I-131 is based on 2016 and 2017 data only.

Radionuclide	SZC		SZB	
	Proposed limits (Bq/y)	Expected best performance (Bq/y)	Annual discharge limits (Bq/y)	Annual discharges (Bq/y) (based on a 3 year average)[4]
Xe-131m	1.35E+11	4.80E+09	-	-
Xe-133	2.84E+13	1.01E+12	-	-
Xe-135	8.92E+12	3.17E+11	-	-

Note: Environment Agency permit limits specify noble gases (assessed as Ar-41), particulate beta (assessed as Co-60) and H-3, C-14 and I-131.

25. In the HPC permit, the Environment Agency assigned annual limits on gaseous discharges of H-3, C-14, I-131 and noble gases. Other fission and activation products were grouped together as ‘beta emitting radionuclides associated with particulate matter’ and assigned a single annual gaseous discharge limit. For the purpose of the SZC radiological assessments, the typical percentage of the individual radionuclides comprising the noble gases and the grouped radionuclides [Ref 26] has been applied to derive the annual limits for the individual radionuclides based on the limits granted for HPC.

26. Co-60 is used as a surrogate for SZB discharges referred to as ‘particulate beta’ in the RIFE Reports [Ref 20] [Ref 24] [Ref 24]. The same approach was used in the HPC RIA [Ref 26]. Dose from ‘particulate beta’ is estimated by calculating the dose from an equivalent activity of Co-60.

27. For gaseous discharges, it is considered that tritium is released in the form of tritiated water, HTO, that C-14, I-131 and I-133 are considered to be in the form of vapour and elemental iodine respectively; and, that fission and activation products (e.g. Co-60 and Cs-137) are in the form of fine aerosols [Ref 27].

28. It is evident from Table 2-1 and Table 2-2 above that the actual discharges from SZB are significantly below the permitted discharge limits; similarly, the predicted discharges from SZC will be less than the proposed permit limits. The use of annual discharge limit data for the purpose of this radiological assessment therefore represents a bounding assessment, where actual exposure is likely to be less and this is discussed in Section 8.

c) Dispersion Modelling

29. The dispersion and subsequent accumulation in food and in the environment of radionuclides discharged from SZC under a continuous discharge scenario were modelled using the supporting modules within the PC-CREAM 08 software, version 1.5.1.89, database version 2.0.0 [Ref 28] [Ref 29]. PC-CREAM is an EU code system, which is considered by UK regulators as a suitable model for assessing the radiological consequences of routine releases [Ref 4]. Site-specific model parameters were used to estimate environmental concentrations arising from discharges of radionuclides. As noted earlier, assessment of short-term discharges, where PC-CREAM is not a suitable tool, are discussed in Section 8 and Appendix A.5.

30. The different modules within PC-CREAM 08 model the contribution of radioactive decay chain products (‘progeny’[5]) in slightly different ways. The DORIS, FARMLAND and RESUS modules do not explicitly model progeny that reach equilibrium with the parent radionuclides within one year; rather, such progeny are considered to be present at the same activities as the parent. This time is reduced to three minutes in PLUME, which allows important-short-lived radionuclides to be modelled explicitly. The first progeny not reaching secular equilibrium with the parent radionuclide is modelled explicitly in FARMLAND, RESUS and PLUME. DORIS considers all radionuclides in the decay chain and progeny that are not in equilibrium with the immediate parent are modelled explicitly [Ref 29]. PC-CREAM

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[5] The term ‘progeny’ is generally used to refer to the daughter isotopes in a radioactive decay chain. For example, the parent nuclide U-238 decays through a number of isotopes including U-234, Th-230, Ra-226, Rn-222 and Pb-206. All of these isotopes together are the progeny of U-238.

08 then uses dose per unit concentration (DPUC) factors to assess individual or collected dose based on the predicted environmental concentrations derived from the modules above.

Aqueous Discharges to the Marine Environment

31. The dispersion and accumulation in the marine environment (seawater, sediment and marine biota) from continuous release of radionuclides in aqueous discharges were modelled using the DORIS module of PC-CREAM 08. DORIS calculates the time-dependent activity concentration of aqueous radionuclide discharges in the local and regional marine compartments. The local marine compartment is modelled as a single well-mixed body of water and associated sediment, extending 4 km out to sea and 5 km along the coastline either side of the proposed SZC site (i.e. 10 km in total). The local marine compartment is contained within the larger regional compartment (the 'North Sea South West' default regional compartment within PC-CREAM) with which it interfaces and exchanges water and suspended sediment [Ref 29].

32. Aqueous discharges from the neighbouring SZB station are modelled as being released into the same local marine compartment as SZC discharges.

33. The DORIS model parameters and values used to model the dispersion of aqueous radionuclides discharged into the marine environment from SZC are provided in Table 2-3. The details of other parameters used in assessing the impact of aqueous discharges to the marine environment are provided in Section 2.3 and Appendix C.1.

Table 2-3 Marine Dispersion Parameters

Parameter	**Local compartment**	**North Sea South West compartment**
Volume (m^3)	4.00E+08	4.50E+11
Depth (m)	1.00E+01	3.10E+01
Coastline length (m)	1.00E+04	-
Volumetric exchange rate (m^3/y)	1.10E+10	-
Suspended sediment load (t/m^3)	8.00E-05	6.00E-06
Sedimentation Rate ($t/m^2/y$)	1.00E-04	1.00E-04
Sediment density (t/m^3)	2.60E+00	2.60E+00
Diffusion rate (m^2/y)	3.15E-02	3.15E-02

34. All parameters in Table 2-3 are the PC-CREAM default values, except for the volume of the local compartment, which has been increased from 3.00E+08 m^3 to 4.00E+08 m^3 to ensure that the discharge point (roughly 3.5 km from the coast) is within the local compartment. Sediment distribution coefficients and all properties of the other ocean compartments modelled within PC-CREAM were also default values. The default volumetric exchange rate corresponds to a local compartment volume of 3.00E+08 m^3. This has been retained as a new volumetric exchange rate cannot be derived without hydrographical data relevant to the area [Ref 29]. A local compartment of 4.00E+08 m^3 would have a higher exchange rate, which would result in lower doses, so it is conservative to retain the default value [Ref 17]. The change in volume is small compared to the volume of the regional compartment, so the impact on the regional compartment is expected to be small.

Gaseous Discharges to the Atmosphere

35. The dispersion, deposition and build-up of radionuclides in the terrestrial environment and in food from gaseous discharges into the atmosphere were modelled using the PLUME and FARMLAND modules within PC-CREAM 08. The external dose due to deposited radionuclides and the internal dose from inhalation of the resuspended radionuclides were calculated for unit deposition rates within the GRANIS and RESUS modules of PC-CREAM 08.

36. PC-CREAM 08 does not account for thermal or mechanical buoyancy of gaseous effluents discharged or entrainment of gaseous releases in the wake of nearby buildings; thus an effective stack height (physical stack height accounting for wake effects of nearby buildings) has to be determined and input into PLUME [Ref 29] [Ref 30]. An effective stack height of 20 m, equivalent to one-third of the height of the adjacent reactor building, has been applied in modelling the atmospheric dispersion of gaseous discharges based on the approach described in the National Radiological Protection Board (NRPB)[6] publication NRPB-R157 [Ref 31]. This is recognised as a pessimistic approach and is consistent with the approach adopted during the Generic Design Assessment (GDA) [Ref 32] for the EPR^{TM} and in the radiological assessments undertaken in support of the HPC permit application [Ref 26][7].

37. Hourly sequential meteorological (Met) data for the SZC site for the 10-year period covering 2003-2012 were supplied by the UK Met Office in the Pasquill stability category format compatible with PC-CREAM 08 [Ref 33]. These data are presented in Appendix D and have been used to model the air concentration and deposition rates of gaseous radionuclides released into the atmosphere. Although the dose assessments were updated in 2019, the original Met data was retained given that the modelling impacts are small, and to ensure consistency with other SZC studies. A 10-year data set is considered a robust period of time and it is unlikely that there would be any significant variation with a more recent dataset.

38. Discharges of gaseous radionuclides to the atmosphere from the neighbouring SZB facility were modelled assuming that they were released together with SZC discharges and from the same place.

39. The PLUME model parameters and values used to model the dispersion and deposition of radionuclides in gaseous discharges are summarised in Table 2-4 below. Tritium is considered to deposit and the values of deposition velocity and washout coefficient for tritium are those used in the RIA for HPC [Ref 26]. The details of default PC-CREAM parameters used in assessing the impact of gaseous discharges to the atmosphere are provided in Appendix C.

Table 2-4 Gaseous Dispersion and Deposition Parameters

Parameter	Value
Physical stack height (m)	70
Height of tallest building affecting stack releases (m)	60
Effective stack height (m)	20
Meteorological data	Site specific (Sizewell C centred windrose)
Roughness length (m)*	0.3
Deposition velocity (m/s)	• 5.00E-03 (tritium) • 0 (noble gases and C-14) • 1.00E-02 (iodine) • 1.00E-03 (particulates)
Washout coefficient (1/s)	1.00E-04 (excluding gases, which were set to 0E+00, but including tritium)
Deposition rates (GRANIS, FARMLAND and RESUS) (Bq/m^2/s)	1
Soil model (GRANIS)	Default generic wet soil
Food transfer factors (FARMLAND)	Refer to Appendix C.2

* Surface roughness considers the effects of attributes such as landscape, buildings and vegetation on wind speed. The roughness length is the height above the ground at which the wind speed, due to building and

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[6] The NRPB became the Radiation Protection Division (RPD) of the HPA (now PHE) in 2005.

[7] The application of the 1/3 factor to the height of the tallest building affecting stack releases represents a strict application of the NRPB-R157 methodology; for the GDA and Hinkley Point C assessments, the 1/3 factor was applied to the physical height of the stack. Both approaches have been reported in literature [Ref 26].

vegetation etc., drops to zero. The roughness length value of 0.3 m used corresponds to generic agricultural land [Ref 28], which represents the predominant land use of the area around the SZC site.

d) Dose Assessment

40. ICRP guidance documents, references [Ref 13] and [Ref 34], present revised international recommendations for a system of radiation protection to establish quantified constraints, or limits, on individual dose from specified sources. These dose constraints apply to actual or representative people who encounter occupational, medical, and public exposures. Dose to the public cannot be measured directly and, in some cases, it cannot be measured at all. Therefore, for the purpose of protection of the public, it is necessary to characterise an individual, either hypothetical or specific, whose dose can be used for determining compliance with the relevant dose constraint. This individual is defined as the 'representative person'. The ICRP's goal of protection of the public is achieved if the relevant dose constraint for this individual for a single source is met and radiological protection is optimised. As noted previously, the term representative person is equivalent to, and replaces the former concept of an 'average member of the critical group'. This approach has been adopted by the Environment Agency in their guidance on prospective dose assessment [Ref 4].

41. Effective doses to CRPs were calculated using the ASSESSOR module within PC-CREAM 08. Modelled concentrations (per unit discharge) of radionuclides in food and the environment (PLUME, FARMLAND and DORIS output files) were uploaded into ASSESSOR and combined with habits data taken from the CEFAS Sizewell Habits Survey Report for 2015 (the 2015 CEFAS survey) [Ref 10] and NRPB-W41 [Ref 35]. ICRP dose coefficients [36], embedded in the PC-CREAM 08 code, were used to calculate the effective dose to CRPs via inhalation and ingestion of radionuclides. For the individual terrestrial dose assessments, inhalation dose coefficients for C-14 and iodine were adjusted to reflect assumptions regarding the chemical form of these elements, as set out in paragraph 27. Similarly, for the individual marine dose assessments, inhalation dose coefficients for H-3 were adjusted to reflect the assumed chemical form of H-3, as set out in paragraph 24. The external doses from exposure to radionuclides in the passing plume, and from radionuclides deposited on the ground, were calculated in PLUME and GRANIS respectively, and the results were exported into ASSESSOR where effective doses from all exposure pathways were calculated.

42. The CRPs assessed were identified based on relevant exposure pathways described in the NDAWG Guidance Note 3 [Ref 37] and from reviews of the CEFAS 2010 survey [Ref 38][8]. The CRPs for exposure to aqueous discharges to the marine environment include a fishing family, houseboat occupant and a wildfowler (a wild game bird hunter), whilst the CRPs for exposure to gaseous discharges to air comprise a farming family living near the site and a worker at the adjacent SZB station, who was regarded as being a member of the public for the purpose of the SZC radiological assessments. For the fishing and farming families, the adult, child and infant age groups were assessed; whereas only the adult age group was considered for the houseboat occupant and wildfowler based on observations reported in the 2015 CEFAS survey (i.e. no infants or children were identified associated with these habits) [Ref 10].

43. Food ingestion and occupancy habits were taken largely from the 2015 CEFAS survey [Ref 10] and supplemented with data used in the latest RIFE report [Ref 25]. Inhalation rates were derived based on occupancy times, recommended values for time spent carrying out different activities (e.g. heavy work or sleeping) from ICRP Publication 66 [Ref 39] and NRPB-W41 [Ref 35] and inhalation rates associated with those activities using the methodology applied in NRPB-W41.

44. Following a careful review of NDAWG guidance on the acquisition and use of habits data for prospective dose assessments [Ref 40], and consideration of the food ingestion data reported in the 2015 CEFAS survey [Ref 10], the 'top two approach' using data taken from the 2015 CEFAS survey was adopted. This approach is further explained in the Environment Agency Principles Document [Ref 4]. The NDAWG recommended profiles approach was not used because the 2015 CEFAS survey report noted that dairy cattle were no longer kept in the survey area and hence no data were presented for the ingestion of milk. However, dairy cattle have been kept in the survey area in the past and it is likely that they may be kept in the area in the future. Hence, following the profile method would mean

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[8] The assessment was originally carried out in 2015 using 2010 CEFAS data, then was updated in 2019 using 2015 CEFAS data.

omitting the milk consumption pathway, an important pathway. Using the top-two approach was therefore considered to provide a more robust basis for carrying out the RIA for SZC than the profile approach described in the NDAWG guidance. The top-two approach involves carrying out a screening assessment during which all food categories are set at high (97.5th percentile) ingestion rates. The two food categories making the highest contribution to the resultant dose (which can vary between age groups considered) are then retained at 97.5th percentile ingestion rates and the remaining food categories changed to mean ingestion rates for the actual assessment. The mean of the high-rate group was used as this data is provided explicitly within the CEFAS report; this is a conservative approach.

45. Annual effective doses to all CRPs were assessed for unit discharge rates in ASSESSOR using a 60-year output time (i.e. equivalent to the operational life of SZC). It is also consistent with the integration of effective dose over a 50-year period for adults in line with ICRP recommendations. The results were then scaled to the proposed discharge rates presented in Table 2-1 and Table 2-2 using a spreadsheet tool that was subject to peer review and quality assurance checks.

46. Table 2-5 below provides a summary of the parameters used to assess annual effective doses to the CRPs identified from exposure to aqueous and gaseous discharges from SZC. Further details regarding the habits of the CRPs assessed, exposure pathways considered, input data used and other more specific information are provided in the ensuing sections, under the relevant headings.

Table 2-5 Key Dose Assessment Parameters (ASSESSOR Input)

Parameter	Value
Output times (y)	60
Number of gaseous release stacks	2
Bearing of 2nd stack relative to the reference stack (°)	0
Distance between stacks (m)	230
Effective stack height (m)	20
Met data	Site specific (Sizewell C centred windrose)
Age groups	Adult, child (10 y) and infant (1 y)
Receptor location (aqueous discharges)	Local compartment (fishing family) Regional compartment (houseboat occupant & wildfowler)
Receptor location (gaseous discharges)*	1.04 km (farm residential location) 552 m, (farm livestock grazing location) 330 m (Sizewell B worker – working hours only) These distances are from the south stack.
CRP habits and exposure pathways	Described in the ensuing sections under the relevant headings.
Roughness length (m)	0.3

* These prospective locations will remain robust over the lifetime of the facility as the ecological status of land around the site precludes any closer development.

2.2 Initial Dose Assessment

a) Assessment Methodology

47. An initial radiological assessment (IRA) has been carried out in respect of the proposed SZC facility using the Environment Agency's IRAT. The IRAT incorporates simple and cautious dose per unit release (DPUR) factors for different radionuclides, release routes (e.g. to air, coastal waters, etc.); exposure pathways (e.g. external dose from deposited radionuclides, internal dose from ingestion of contaminated foodstuff, etc.); and age groups. Details of the parameters, assumptions and approach used to derive DPUR values are provided in the counterpart Environment Agency IRAM report [Ref 17]. For each radionuclide, dose to four age groups is calculated: offspring (collectively denoting the embryo, foetus and newborn child), infant (1 year old), child (10 year old) and adult. The total dose is taken to be the sum of the highest doses for each radionuclide across all age groups, which is very pessimistic.

48. The assessment was based on the proposed annual limits for SZC (Table 2-1 and Table 2-2) and was performed at both assessment Stages 1 and 2 of the IRAM. The Stage 1 assessment involved the use of default assumptions regarding environmental dispersion (a volumetric exchange rate of 30 m^3/s for aqueous discharges to the marine environment and ground releases for gaseous discharges to atmosphere). The Stage 2 assessment involved the use of site-specific dispersion parameters for a more realistic outcome.

b) Assessment Parameters

49. For aqueous discharges to coastal/estuarine waters, the CRPs are assumed to be members of a fishing family, exposed through ingestion of seafood incorporating radionuclides and via external irradiation from radionuclides deposited in beach sediments. Some key assumptions in the derivation of the DPURs for coastal/estuarine waters are summarised below:

- All shellfish and 50% of fish are caught from a 'local compartment', which might be the estuary or a theoretical compartment along the coast. The other 50% of the fish are assumed to be caught in the adjacent regional compartment.
- A default volumetric exchange rate of 30 m^3/s between the local compartment and regional marine compartments is used, representative of the minimum exchange rate for large estuaries and coastal areas around the UK.
- The habit data, including consumption rates, are generic values taken from NRPB W41 [Ref 35].

50. For gaseous discharges to air, the CRPs are assumed to be members of a local resident family exposed through inhalation of radionuclides in the gaseous plume, external irradiation from radionuclides in the gaseous plume and from radionuclides deposited on the ground, and the ingestion of locally grown terrestrial foodstuff. Key pessimistic assumptions in the derivation of the DPURs for gaseous discharges to air that maximise concentrations of radioactivity and hence radiological dose include:

- Gaseous radionuclides released at ground level (minimising dispersion compared to the actual release).
- Local family residing at a distance of 100 m from the release point (i.e. a factor of ten closer to the site compared to current and possible future conditions).
- Terrestrial foodstuff produced at a distance of 500 m from the release point (comparable to livestock grazing that occurs, but for other foodstuffs a factor of two closer compared to current and possible future conditions).

51. The default DPUR values for the radionuclides of interest taken from the IRAT are provided in Table 2-6 and

52. Table 2-7 below. Note these are pessimistic because they add all age groups together.

Table 2-6 DPUR for Aqueous Discharges

Radionuclide	External DPUR (µSv/y per Bq/y)	Fish / shellfish DPUR (µSv/y per Bq/y)	Total DPUR (µSv/y per Bq/y)	Worst age group
Ag-110m	1.2E-10	3.9E-09	4.0E-09	Adult
C-14	1.6E-16	4.6E-10	4.6E-10	Offspring
Co-58	5.4E-11	1.5E-11	6.9E-11	Adult
Co-60	2.7E-09	7.5E-11	2.8E-09	Adult
Cr-51	3.7E-13	2.3E-13	6.0E-13	Adult
Cs-134	8.4E-11	4.0E-11	1.2E-10	Adult
Cs-137	1.2E-10	2.8E-11	1.5E-10	Adult
H-3	0.0E+00	8.9E-16	8.9E-16	Offspring
I-131	2.5E-15	2.5E-12	2.5E-12	Adult
Mn-54	2.2E-10	5.0E-12	2.3E-10	Adult
Ni-63	0.0E+00	3.6E-12	3.6E-12	Adult
Other beta/gamma (Sb-124, Sb-125 & Te-123m)	1.2E-10	2.8E-11	1.5E-10	Adult

Table 2-7 DPUR for Gaseous Discharges

Radionuclide	Inhalation DPUR (µSv/y per Bq/y)	External DPUR (cloud and deposited) (µSv/y per Bq/y)	Food DPUR (µSv/y per Bq/y)	Total DPUR (µSv/y per Bq/y)	Worst age group
Ar-41	0.0E+00	3.2E-12	0.0E+00	3.2E-12	Adult
C-14	3.5E-11	6.4E-17	3.3E-11	6.8E-11	Infant
Co-58	3.6E-11	2.7E-10	4.4E-12	3.1E-10	Adult
Co-60	2.2E-10	1.1E-08	5.3E-11	1.2E-08	Adult
Cs-134	1.5E-10	3.6E-09	4.7E-10	4.2E-09	Adult
Cs-137	1.0E-10	6.5E-09	3.8E-10	7.0E-09	Adult
H-3	6.9E-13	0.0E+00	2.7E-13	9.6E-13	Offspring
I-131	3.9E-10	3.8E-11	4.1E-09	4.5E-09	Infant
Kr-85	0.0E+00	1.3E-14	0.0E+00	1.3E-14	Adult
Xe-133	0.0E+00	7.0E-14	0.0E+00	7.0E-14	Adult

53. The Stage 1 IRA was undertaken using the conservative DPUR values and default environmental dispersion parameters embedded in the IRAT tool without modification.

54. The Stage 2 IRA involved the modification of the IRAT default environmental dispersion parameters to take account of conditions specific to SZC to enable a more realistic dose assessment. The modifications made were:

- Marine dispersion parameters: volumetric exchange rate of 349 m^3/s based on the PC-CREAM 08 DORIS model for the local Sizewell marine compartment.
- Atmospheric dispersion parameters: an effective release height of 20 m.

c) Results and Discussion

Annual Dose from Exposure to Aqueous and Gaseous Discharges from Sizewell C

55. Table 2-8 below presents results of the Stages 1 and 2 IRA for aqueous discharges from SZC. The annual dose to a fisherman is calculated as 370 µSv/y and 32 µSv/y for the Stage 1 and 2 assessments, respectively. The assessed dose from both stages is dominated by ingestion pathways (84% of total dose in both cases), with C-14 contributing 79% of the calculated dose across all pathways. Co-60 contributes approximately 15% of the assessed dose, mostly via external pathways.

Table 2-8 Annual Dose (µSv/y) to Fisherman from Aqueous Discharges from Sizewell C

	Stage 1 - SZC discharges (30 m/s volumetric exchange rate)			**Stage 2 - SZC discharges (349 m/s volumetric exchange rate)**		
Radionuclides	**External dose (µSv/y)**	**Fish/ shellfish dose (µSv/y)**	**Total dose (µSv/y)**	**External dose (µSv/y)**	**Fish/ shellfish dose (µSv/y)**	**Total dose (µSv/y)**
Ag-110m	4.5E-01	1.5E+01	1.5E+01	3.9E-02	1.3E+00	1.3E+00
C-14	1.0E-04	2.9E+02	2.9E+02	8.7E-06	2.5E+01	2.5E+01
Co-58	7.3E-01	2.0E-01	9.4E-01	6.3E-02	1.8E-02	8.1E-02
Co-60	5.4E+01	1.5E+00	5.6E+01	4.6E+00	1.3E-01	4.8E+00
Cr-51	1.5E-04	9.0E-05	2.4E-04	1.3E-05	7.8E-06	2.0E-05
Cs-134	3.1E-01	1.5E-01	4.4E-01	2.6E-02	1.3E-02	3.8E-02
Cs-137	7.6E-01	1.8E-01	9.5E-01	6.5E-02	1.5E-02	8.2E-02
H-3	0.0E+00	5.9E-01	5.9E-01	0.0E+00	5.1E-02	5.1E-02
I-131	8.2E-07	8.2E-04	8.2E-04	7.0E-08	7.0E-05	7.0E-05
Mn-54	3.9E-01	8.9E-03	4.1E-01	3.3E-02	7.6E-04	3.5E-02
Ni-63	0.0E+00	2.3E-02	2.3E-02	0.0E+00	2.0E-03	2.0E-03
Other beta/gamma*	1.2E+00	2.9E-01	1.5E+00	1.1E-01	2.5E-02	1.3E-01
Total dose	5.8E+01	3.1E+02	**3.7E+02**	5.0E+00	2.7E+01	**3.2E+01**

*Modelled as Cs-137 and includes the discharges of Sb-124, Sb-124 and Te-123m.

56. Table 2-9 below presents results of the Stages 1 and 2 IRA for gaseous discharges from SZC. The annual dose to the most exposed local inhabitant is calculated as 110 µSv/y and 19 µSv/y for the Stage 1 and 2 assessments, respectively. The Stage 1 dose is dominated by inhalation and ingestion pathways (48% and 45% of total dose, respectively), with C-14 contributing 87% of the calculated dose across all pathways. The Stage 2 dose is dominated by ingestion pathways (84%), with C-14 accounting for 92% of the calculated dose across all pathways.

Table 2-9 Annual Dose (µSv/y) to Local Inhabitant from Gaseous Discharges from Sizewell C

	Stage 1 - SZC discharges (ground release)				Stage 2 - SZC discharges (20m release)			
Radionuclide	**Inhalation dose (µSv/y)**	**External dose (cloud and deposited) (µSv/y)**	**Food dose (µSv/y)**	**Total dose (µSv/y)**	**Inhalation dose (µSv/y)**	**External dose (cloud and deposited) (µSv/y)**	**Food dose (µSv/y)**	**Total dose (µSv/y)**
Ar-41	0.0E+00	4.2E+00	0.0E+00	4.2E+00	0.0E+00	1.7E-01	0.0E+00	1.7E-01
C-14	4.9E+01	9.0E-05	4.6E+01	9.5E+01	2.0E+00	3.6E-06	1.5E+01	1.7E+01
Co-58	3.9E-04	2.9E-03	4.8E-05	3.4E-03	1.6E-05	1.2E-04	1.6E-05	1.5E-04
Co-60	2.8E-03	1.4E-01	6.8E-04	1.4E-01	1.1E-04	5.6E-03	2.2E-04	6.0E-03
Cs-134	1.5E-03	3.6E-02	4.7E-03	4.2E-02	6.0E-05	1.4E-03	1.5E-03	3.0E-03
Cs-137	9.0E-04	5.8E-02	3.4E-03	6.2E-02	3.6E-05	2.3E-03	1.1E-03	3.5E-03
H-3	4.1E+00	0.0E+00	1.6E+00	5.8E+00	1.7E-01	0.0E+00	5.3E-01	7.0E-01
I-131	1.6E-01	1.5E-02	1.6E+00	1.8E+00	6.2E-03	6.1E-04	5.4E-01	5.5E-01
I-133	7.5E-03	5.9E-04	5.6E-03	1.4E-02	3.0E-04	2.4E-05	1.8E-03	2.2E-03
Kr-85	0.0E+00	8.1E-02	0.0E+00	8.1E-02	0.0E+00	3.3E-03	0.0E+00	3.3E-03
Xe-133*	0.0E+00	2.6E+00	0.0E+00	2.6E+00	0.0E+00	1.0E-01	0.0E+00	1.0E-01
Total dose	5.3E+01	7.1E+00	4.9E+01	**1.1E+02**	2.1E+00	2.9E-01	1.6E+01	**1.9E+01**

*Includes the discharges of Xe-131m and Xe-135.

2.3 Annual Dose to the CRPs from Exposure to Aqueous Discharges

a) Assessment Methodology

57. Based on the results of Stage 1 and 2 assessments, some of which were above the Environment Agency screening value of 20 µSv/y, a detailed site-specific assessment was undertaken.

58. The annual dose to the CRPs exposed to aqueous discharges was calculated using the DORIS and ASSESSOR modules of PC-CREAM 08. The source term and dispersion parameters used are described in Section 2.1. The assessment was carried out for unit discharge rates and the results scaled to the proposed annual discharge limits shown in [Ref 5] using an Excel spreadsheet which was then quality assured.

59. The default ingestion dose coefficients within PC-CREAM were used for all radionuclides. The default inhalation dose coefficients in PC-CREAM were used for all radionuclides, except for tritium: the type M inhalation dose coefficient from ICRP 119 [Ref 41] was used for tritium. This value is higher than the values for soluble or reactive gases given in ICRP 119. The same value was used in the HPC RIA [Ref 26]. External dose coefficients used were the PC-CREAM default values, except for external exposure to the houseboat dweller whilst on the houseboat and the wildfowler whilst on the saltmarsh; the approach in these cases is detailed in e) Habits Data below.

b) Exposure Pathways and Candidates for the Representative Person

60. CRPs were identified based on relevant exposure pathways described in the NDAWG Guidance Note 3 [Ref 37] and from reviews of the 2010 CEFAS survey, current at the time of the original assessment [Ref 38]. Whilst the assessment was updated using the 2015 CEFAS habits data [Ref 10], it was not deemed necessary to change the CRPs. For aqueous discharges, three exposure groups were considered to be representative of the most exposed members of the public on account of their seafood ingestion and coastal occupancy habits. These groups are a fishing family, an adult occupant of a houseboat and an adult wildfowler. Dose to a foetus and to a breast-fed infant are considered in Appendix A.2.

Fishing Family

61. These CRPs comprise the adult, child and infant members of a family who spend time along the coastal area close to SZC. It is assumed that these CRPs have higher than average ingestion rates of locally caught seafood.

62. Members of the fishing family are considered to be exposed through the following pathways:

- Internal exposure from the ingestion of locally caught seafood (fish, crustaceans, molluscs and sea plants[9]) incorporating radionuclides discharged into the marine environment.
- Internal exposure from inhalation of radionuclides entrained in sea spray.
- External irradiation (equivalent dose to skin for beta radionuclides and equivalent dose for gamma radionuclides) from radionuclides incorporated into beach sediment.
- External irradiation (equivalent dose to skin for beta radionuclides and equivalent dose for gamma radionuclides) from handling fishing equipment contaminated with radionuclides (this includes limited infant and child handling of crab lines).

63. Exposure through inadvertent ingestion of seawater and beach sediment are considered to be minor pathways. The contribution of these pathways to the annual dose is considered separately as part of a sensitivity analysis.

Houseboat Occupant

64. This CRP refers to an adult residing part-time on a houseboat that is moored at a harbour situated approximately 8 km from SZC. It is assumed that the houseboat is towards the high-tide mark and therefore rests over contaminated mud for a substantial proportion (around 67%) of the time. The habits of this CRP are largely consistent with those of the adult member of the fishing family with the exception that the houseboat is situated within the regional compartment[10], and that the CRP sources all seafood from this regional marine compartment.

65. This CRP is considered to be exposed via the following pathways:

- Internal exposure from the ingestion of seafood caught in the regional compartment (fish, crustaceans, molluscs and sea plants) incorporating radionuclides discharged into the marine environment.
- Internal exposure from inhalation of radionuclides entrained in sea spray.
- External irradiation from beta/ gamma radionuclides incorporated into beach sediment.
- External irradiation due to occupancy of a houseboat (afloat on contaminated water or resting on contaminated mud).

66. The exposure from external irradiation due to houseboat occupancy was calculated using an Excel spreadsheet by applying dose coefficients (for exposure over contaminated land and submersion in contaminated water) based on the Federal Guidance Report No. 12 (FGR12) [Ref 42] to the activity concentration in seabed sediment and unfiltered seawater modelled within DORIS. The FGR12 effective dose coefficients, taken from the Radiological Toolbox software (Version 3.0.0) developed by the Oak Ridge National Laboratory [Ref 43], were corrected using ICRP Publication 60 radiation weighting factors embedded in the software. A factor of 0.75 was applied to account for the shielding provided by the hull of the boat based on the Environment Agency's assessment of potential houseboat dweller and wildfowler exposure on the Ribble Estuary [Ref 44].

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[9] The exposure due to ingestion of sea plants was assessed using the PC-CREAM 08 parameters for seaweed. This applies to all CRPs for exposure to aqueous discharges.

[10] The local compartment is considered to be centred upon, and to extend approximately 5 km on either side of, the discharge point. The houseboat is therefore regarded to be situated in the regional marine compartment, i.e. outside of the local marine compartment.

Wildfowler

67. This CRP refers to an adult member of the public that shoots wildfowl on a coastal saltmarsh situated approximately 8 km from SZC. The habits of this CRP are assumed to be largely consistent with those of the houseboat occupant, the main difference being residency in a houseboat or time spent on saltmarsh. This CRP is considered to be exposed via the following pathways:

- Internal exposure from the ingestion of seafood caught in the regional compartment (fish, crustaceans, molluscs and sea plants) incorporating radionuclides discharged into the marine environment.
- Internal exposure from inhalation of radionuclides entrained in sea spray.
- External irradiation from beta/ gamma radionuclides incorporated into beach sediment.
- External irradiation due to time spent over contaminated saltmarsh.

68. Similar to the houseboat occupant, the dose from external irradiation due to saltmarsh occupancy was calculated by applying dose coefficients for exposure over contaminated land taken from FGR12 [Ref 42] (and corrected using ICRP Publication 60 radiation weighting factors) to the activity concentration in seabed sediment modelled within DORIS, which is assumed to deposit onto saltmarsh areas. It was assumed that the wildfowler lies on contaminated saltmarsh sediment for a significant proportion (75%) of shooting time and stands in an upright position for the remainder of the time. Correction factors based on the Environment Agency's assessment of potential houseboat dweller and wildfowler exposure on the Ribble Estuary [Ref 44] were applied to account for the effect of exposure geometry on the external dose to the wildfowler. Shielding provided by clothing against beta irradiation was not considered.

c) Habits Data

Food Intake

69. Table 2-10 and Table 2-11 below present the food ingestion rates of the fishing family as well as those for the houseboat occupant and wildfowler used to assess the exposure to aqueous discharges.

Table 2-10 Food Intake Data for Fishing Family

Parameter	**Adult**	**Child**	**Infant**
Fraction of seafood caught in the local compartment	1	1	1
Fraction of seafood caught in the regional compartment	0	0	0
Fish ingestion rates (kg/y) (97.5th percentile)	39	17.5	1.95
Crustaceans ingestion rates (kg/y) (97.5th percentile)	12.1	1.7	0.605
Molluscs ingestion rates (kg/y) (mean)	3.2	0.8	0.16
Sea plants ingestion rates (kg/y) (mean)	0.6	0	0

70. No consumption of sea plants by children or infants was recorded in the 2015 CEFAS survey and there is no conversion factor provided to convert the adult consumption rate. There is also no consumption rate provided in RIFE, so the ingestion rates were set to 0 kg/y for the child and infant CRPs. No consumption of mollusc or crustaceans was recorded for infants, so the adult values were scaled to derive a rate for infants using the scaling factors provided in the CEFAS 2015 report for converting adult doses to infant doses.

71. Fish and crustaceans were identified as the seafood categories making the highest contribution to the dose to the fishing family when critical ingestion rates were used for all food categories in a screening assessment. These two

food categories were therefore set at high (97.5th percentile) rates in the final assessment, whilst other food categories were set to mean rates in accordance with the top-two approach.

Table 2-11 Food Intake Data for Houseboat Occupant and Wildfowler

Parameter	Value
Fraction of seafood caught in the local compartment	0
Fraction of seafood caught in the regional compartment	1
Fish ingestion rates (kg/y) (97.5th percentile)	39
Crustaceans ingestion rates (kg/y) (97.5th percentile)	12.1
Molluscs ingestion rates (kg/y) (mean)	3.2
Sea plants ingestion rates (kg/y) (mean)	0.6

72. The food ingestion rates for the houseboat occupant and wildfowler are based on the ingestion rates for the adult member of the fishing family.

Occupancy Habits

73. Table 2-12 to Table 2-14 below present the occupancy habits of the fishing family as well as those of the houseboat occupant and wildfowler used to assess the exposure to aqueous discharges.

Table 2-12 Occupancy Rates for Fishing Family

Parameter	Adult	Child	Infant
Occupancy on beach (h/y) (97.5th percentile) for external exposure	2960	331	94
Time spent near the sea (h/y) for sea spray inhalation and external exposure (97.5th percentile)	2627	98	36
Handling of fishing equipment (h/y) (97.5th percentile)	2113	18*	18*
Fraction of time spent in local compartment	1		
Fraction of time spent in regional compartment	0		
Inhalation rates (m^3/h)	1.69	1.12	0.35
Distance from the sea (m) for sea spray dose	10	50	50
Shoreline attenuation factor	0.5		

* This relates to observations of children and infants handling crab lines at Walberswick [Ref 10].

^ A shoreline attenuation factor based on shielding from seawater along one side of the beach is applied as used for SZB [Ref 45].

74. The values for occupancy on the beach in Table 2-12 above were derived as the sum of time spent on the beach for recreational purposes and time spent handling fishing equipment, which has been cautiously assumed to be on the beach for all age groups. The adult value for handling of fishing equipment includes 188 h for handling of sediment [Ref 10] (associated with, for instance, bait digging or mollusc collection). No sediment handling data were reported for child and infant age groups. Sea spray inhalation was assumed to occur during the period spent on the beach, including time handling fishing equipment. All values used are 97.5th percentile values.

75. The inhalation rate for adult was derived based on the approach used in NRPB-W41 [Ref 35] and assuming that 1 hour of the working day was spent doing heavy work and the remainder was spent doing light work. Inhalation rates

for child and infant members were based on ICRP Publication 66 [Ref 39] and it was assumed that all time was spent doing light work[11].

Table 2-13 Parameters for Calculating Exposure to the Adult Houseboat Dweller

Parameter	Value
Occupancy on beach (h/y) (97.5th percentile)	847
Time spent near the sea (h/y) (97.5th percentile)	2101
Fraction of time spent in local compartment	0
Fraction of time spent in regional compartment	1
Inhalation rate (m^3/h)	1.06
Time spent on the houseboat (h/y)	1253.7
Fraction of time spent inside houseboat	0.75
Fraction of time houseboat rests on mud	0.67
Fraction of time houseboat floats on water	0.33
Boat shielding factor	0.75
Soil density (kg/m^3)	1600
Shoreline attenuation factor (beach only)	0.5
Distance from the sea (m) for sea spray dose	10

76. The total time spent on a houseboat is not recorded in the CEFAS surveys. In the 2015 CEFAS survey [Ref 10], one houseboat dweller was observed, who was living on the boat for part of the year. This is different to the 2010 CEFAS survey [Ref 38], in which a houseboat dweller was observed to live on their boat all year. The fraction of time that the boat rests on mud was therefore derived based on the 2010 CEFAS survey, calculated as the ratio of the total time the boat rests on mud recorded in the 2010 CEFAS survey (5,901 h/y) to the number of hours in a year. The total time spent by the houseboat dweller on their boat was therefore derived based on the time spent on a boat in the mud recorded in the 2015 CEFAS survey and the fraction of time a boat rests on mud, derived based on the 2010 survey.

77. The houseboat is located on the River Alde at Slaughden [Ref 10], which is beyond the area covered by the local compartment, but is within the regional compartment.

78. The boat-shielding factor is based on a large, keeled, sailing vessel with fibreglass hull and wooden decking, taken from the Environment Agency's assessment of potential houseboat dweller and wildfowler exposure on the Ribble Estuary [Ref 44]. Soil and water density values were taken from FGR12 [Ref 42].

79. The houseboat dweller's beach occupancy was based on the 2015 CEFAS survey data for adult exposure over sand and stone [Ref 10]. The time spent near the sea was taken to be the sum of the beach occupancy and the time spent on the houseboat. The inhalation rate was derived based on the non-occupational breathing rates provided in NRPB-W41 [Ref 35].

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[11] Throughout the assessment, ICRP Publication 66 values are used in cases where there is not sufficient information in NRPB-W41 to calculate the inhalation rate based on the habits of the CRP.

Table 2-14 Parameters for Calculating Exposure due to Wildfowling Activities and Beach Occupancy

Parameter	Value
Occupancy on beach (h/y) (97.5th percentile)	847
Time spent near the sea (h/y) (97.5th percentile)	847
Fraction of time spent in local compartment	0
Fraction of time spent in regional compartment	1
Inhalation rates (m^3/h)	1.5
Shoreline attenuation factor (beach only)	0.5
Time spent on saltmarsh (h/y)	88
Fraction of time spent standing upright on saltmarsh	0.25
Fraction of time spent lying down on saltmarsh	0.75
Correction factor applied to dose coefficient for exposure over saltmarsh to account for the fraction of time spent lying down	1.29
Soil density (kg/m^3)	1600
Distance from the sea (m) for sea spray dose	100

80. The time spent on saltmarsh was taken from the 2005 Sizewell habits survey [Ref 46], which gives a more pessimistic assessment than the data from the more recent 2015 CEFAS survey (which was 35 h/y[12]) and hence is likely to result in an overestimate of the dose calculated. The fraction of time spent upright (walking, standing) is based on the Environment Agency's assessment of potential houseboat dweller and wildfowler exposure on the Ribble Estuary [Ref 44].

81. The beach occupancy rate and time spent by the wildfowler near the sea were based on the 2015 CEFAS survey data for adult exposure over sand and stone [Ref 10]. The inhalation rate was based on the breathing rate for light work in NRPB-W41 [Ref 35].

82. The FGR12 external dose coefficients [Ref 42] used to calculate the dose to the wildfowler from occupancy over saltmarsh were derived based on a rotational (Rot) geometry, which corresponds to an upright/standing position. However, it has been reported that wildfowlers spend a significant proportion (around 75%) of their time lying on the ground or crouching close to the ground surface i.e. in hide pits [Ref 44]. The lying position is best described by an anterior-posterior (AP) geometry which would generally result in a higher exposure. Thus, a correction factor for lying down has been derived as the ratio of the dose conversion factors for AP to Rot geometry, taken from the Environment Agency's assessment of potential houseboat dweller and wildfowler exposure on the Ribble Estuary [Ref 44]. This factor is applied to the FGR12 dose coefficients [Ref 42] for exposure over sediment for the fraction of time the wildfowler lies down on saltmarsh.

d) Results and Discussion

Annual dose from Exposure to Aqueous Discharges from Sizewell C

83. The annual dose to the adult, child and infant members of the fishing family from exposure to aqueous discharges from SZC, summed across the relevant marine pathways, is calculated to be 10 µSv/y, 4.9 µSv/y and 1.3 µSv/y, respectively. Table 2-15 below presents a summary of the assessed effective doses to the fishing family. A breakdown of the assessed doses for exposure to aqueous discharges from SZC by radionuclides and exposure pathways is presented in Section 2.5.

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[12] It is noted that a maximum value of 240 h/y is reported in the 2015 CEFAS survey for exposure over saltmarsh. However, this relates to angling activities not wildfowling activities.

Table 2-15 Annual Effective Dose (µSv/y) to Fishing Family from Exposure to Aqueous Discharges from Sizewell C

	Crustaceans	Fish	Molluscs	Sea plant	External beta (beach)	External beta (fishing equipment)	External gamma (beach)	External gamma (fishing equipment)	Sea spray inhalation	Total
Adult	2.1E+00	6.8E+00	5.7E-01	5.4E-02	1.1E-03	3.0E-03	5.8E-01	8.3E-03	2.2E-05	**1.0E+01**
Child	4.2E-01	4.2E+00	2.0E-01	0.0E+00	1.3E-04	2.5E-05	6.5E-02	7.1E-05	2.9E-06	**4.9E+00**
Infant	3.0E-01	9.4E-01	8.0E-02	0.0E+00	3.6E-05	2.5E-05	1.9E-02	7.1E-05	8.4E-07	**1.3E+00**

84. The dominant pathway for all age groups is the ingestion of fish which contributes around 67%, 86% and 70% to the doses for adult, child and infant respectively. C-14 is the dominant radionuclide, contributing between 93% and 98% of the assessed dose to the fishing family. The contribution of external radiation pathways to the assessed doses is considerably less significant than ingestion pathways.

85. The annual dose to an adult houseboat occupant and a wildfowler from exposure to aqueous discharges from SZC, summed across the relevant pathways, is calculated to be around 0.13 µSv/y in both cases. Table 2-16 below provides a summary of the assessed effective doses to the houseboat occupant and wildfowler.

Table 2-16 Annual Effective Dose (µSv/y) to Houseboat Occupant and Wildfowler from Exposure to Aqueous Discharges from Sizewell C

	Crustaceans	Fish	Molluscs	Sea plant	External beta (beach)	External gamma (beach)	Sea spray inhalation	External exposure during Houseboat occupancy/ wildfowling	Total
Houseboat Dweller	2.9E-02	9.1E-02	7.6E-03	7.2E-04	5.1E-06	3.2E-03	1.1E-07	1.9E-03	**1.3E-01**
Wildfowler	2.9E-02	9.1E-02	7.6E-03	7.2E-04	5.1E-06	3.2E-03	6.1E-08	3.0E-04	**1.3E-01**

86. The dominant pathway for the houseboat occupant and wildfowler is fish ingestion which contributes around 68% and 69% of the assessed dose to these CRPs respectively. C-14 is the dominant radionuclide, contributing around 95% and 96% of the assessed dose to houseboat occupant and wildfowler respectively.

87. The external dose arising from houseboat occupancy (0.0019 µSv/y) and wildfowling activities (0.0003 µSv/y) represent approximately 1.4% and 0.2% of the annual dose to these CRPs (respectively). The dose from these external pathways is dominated by Co-60 which accounts for around 98% of the assessed dose.

Annual dose from Exposure to the Combined Aqueous Discharges from Sizewell B and C

88. The cumulative annual dose to the adult, child and infant members of the fishing family from exposure to combined aqueous discharges from SZB and C, summed across the relevant marine pathways, is calculated to be 12 µSv/y, 5.3 µSv/y and 1.4 µSv/y, respectively. Again, C-14 was the dominant radionuclide contributing 79% to 92% to the assessed doses. Ingestion of fish represented the dominant pathway for adult, child and infant age groups (63%, 85% and 69% respectively). A breakdown of the assessed doses for exposure to the aqueous discharges from SZC and from the combined discharges from SZB and SZC by radionuclides and exposure pathways is presented in Section 2.5.

Table 2-17 Annual Effective Dose (µSv/y) to Fishing Family from Exposure to Aqueous Discharges from Sizewell B and Sizewell C

	Crustaceans	Fish	Molluscs	Sea plant	External beta (beach)	External beta (fishing equipment)	External gamma (beach)	External gamma (fishing equipment)	Sea spray inhalation	Total
Adult	2.2E+00	7.6E+00	5.9E-01	6.0E-02	8.3E-03	5.5E-03	1.6E+00	2.3E-02	3.2E-05	**1.2E+01**
Child	4.3E-01	4.5E+00	2.0E-01	0.0E+00	9.3E-04	4.7E-05	1.8E-01	2.0E-04	4.1E-06	**5.3E+00**
Infant	3.0E-01	9.8E-01	8.1E-02	0.0E+00	2.6E-04	4.7E-05	5.1E-02	2.0E-04	1.2E-06	**1.4E+00**

89. Cs-134 accounts for 13%, 6.2% and 4.1% of the annual dose to the adult, child and infant members of the fishing family respectively. This radionuclide was used as a surrogate for 'other radionuclides' in the SZB permitted discharges.

90. The annual dose to the houseboat occupant and wildfowler from the combined discharges of aqueous radionuclides from SZB and C is calculated to be 0.15 µSv/y and 0.14 µSv/y respectively. Fish ingestion is the dominant pathway contributing approximately 68% and 69% of the assessed dose to the houseboat occupant and wildfowler respectively.

Table 2-18 Annual Effective Dose (µSv/y) to Houseboat Occupant and Wildfowler from Exposure to Aqueous Discharges from Sizewell B and Sizewell C

	Crustaceans	Fish	Molluscs	Sea plant	External beta (beach)	External gamma (beach)	Sea spray inhalation	External Exposure During Houseboat occupancy/ wildfowling	Total
Houseboat Dweller	2.9E-02	1.0E-01	7.8E-03	7.9E-04	3.0E-05	6.6E-03	1.6E-07	3.5E-03	**1.5E-01**
Wildfowler	2.9E-02	1.0E-01	7.8E-03	7.9E-04	3.0E-05	6.6E-03	8.8E-08	5.4E-04	**1.4E-01**

91. C-14 accounted for around 86% and 88% of the assessed dose to the houseboat occupant and wildfowler respectively. Cs-134 (used as a surrogate for the group of other radionuclides) contributed around 8.5% and 7.7% of the dose to the houseboat occupant and wildfowler respectively.

2.4 Annual Dose to the CRPs from Exposure to Gaseous Discharges

a) Assessment Methodology

92. The annual dose to the CRPs exposed to gaseous discharges was calculated using the PLUME, FARMLAND, GRANIS, RESUS and ASSESSOR modules of PC-CREAM 08. Details of the source term and dispersion parameters used are described in Section 2.1. The assessment was carried out for unit discharge rates and the results scaled to the proposed annual discharge limits shown in Table 2-2 using an Excel spreadsheet which was then quality assured.

93. The default ingestion dose coefficients within PC-CREAM were used for all radionuclides. The default inhalation dose coefficients in PC-CREAM were used for all elements, except for carbon and iodine, which were assumed to be in the vapour phase and in elemental form, respectively. The inhalation dose coefficients for C-14, I-131 and I-133 were taken from ICRP publication 119 [Ref 41]. External dose coefficients used were the PC-CREAM default values.

b) Exposure pathways and Candidates for the Representative Person

94. CRPs were identified based on relevant exposure pathways described in the NDAWG Guidance Note 3 [Ref 40] and from reviews of the 2010 CEFAS survey [Ref 38]. Whilst the assessment was updated using the 2015 CEFAS habits data, it was not deemed necessary to change the CRPs. A local farming family was considered to be representative of the most exposed members of the public to gaseous discharges from SZC on account of their food intake and

occupancy habits. In addition to the farming family, it was considered that an adult worker at the neighbouring SZB station may be regarded as a member of the public for the purpose of the SZC radiological assessments.

Farming Family

95. The farming family is considered to comprise the adult, child and infant members of a family that reside at a location around 1 km from the reference emission stack[13]. This location was identified as the nearest possible dwelling location that could be impacted by gaseous releases from SZC. Nearer dwelling locations are not possible at present, or likely in the future, due to the ecological designation of the land around the site. The adult member of this family is assumed to spend time working on adjacent land and the child and infant are assumed to spend some time playing outdoors. This family is assumed to consume fruit, green vegetables and root vegetables grown at their residence / farm, and animal products derived from livestock that feed on a grazing marsh approximately 550 m from the reference emission stack[14].

96. These CRPs are considered to be exposed via the following pathways:

- Internal exposure from inhalation of radionuclides in the gaseous plume and from resuspension of ground deposited radionuclides from discharges to atmosphere.
- Skin absorption of tritium[15].
- Internal exposure from the ingestion of radionuclides incorporated into locally produced terrestrial foods following deposition of radionuclides discharged to atmosphere.
- External irradiation from exposure to beta/ gamma radionuclides in the gaseous plume and from material deposited on the ground following discharge to atmosphere.

Sizewell B Worker

97. The SZB worker is analogous to the adult member of the farming family, with the exception that this individual spends 2,000 h/y at the SZB station. It is assumed that half this time (50%) is spent outdoors at a location approximately 330 m from the reference emission stack[16]. The exposure of this CRP to sources of radioactivity associated with SZB operations (excluding permitted discharges) during working hours has not been included in the assessment, as this is part of his occupational exposure.

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[13] The closest farms to Sizewell C are more than 1 km away from the gaseous emission stack. However, there is a dwelling approximately 1 km from the site, so there is potential for a farming family to live at this distance in the future.

[14] A literature review indicated that the marshland to the west of the site is grazed by livestock. Three potential farm locations were assessed and the area that resulted in the highest doses was selected to represent the point from which the farming family derive animal products for consumption.

[15] The PC-CREAM 08 dose coefficient for inhalation includes a multiplier for skin absorption pathways.

[16] To determine the location of Sizewell B worker relative to the reference emission stack, four points at 125°, 150°, 180° and 210° bearing (representing the four wind sectors covering Sizewell B) relative to the reference stack were considered. A screening assessment of the four points was carried out at a distance corresponding to the closest point within the Sizewell B site at each bearing and the point resulting in the highest dose (125°) was used to assess the dose to Sizewell B worker.

Food Intake

98. Table 2-19 presents the food ingestion rates of the farming family. The adult rates apply to the SZB worker.

Table 2-19 Food Intake Data for Farming Family

Parameter	**Adult**	**Child**	**Infant**
Faction of food produced locally	1	1	1
Cow milk (kg/y)	240*	240*	320*
Green vegetables (kg/y)	88.3	16.3	11.8
Cow meat (kg/y)	19.2	15.7*	4.3
Sheep meat (kg/y)	7.2	2.88	0.86
Root vegetables (kg/y)	167.7*	30.2	16.3*
Fruit (kg/y)	36.9	12.5	3.1

* 97.5th ingestion rate (unmarked values are mean rates).

99. The food ingestion data for green vegetables in Table 2-19 is a sum of the ingestion rates for ‘green vegetables’ and ‘other vegetables’ taken from the 2015 CEFAS survey [Ref 10]; similarly, the ingestion data for root vegetables is a sum of rates for ‘root vegetables’ and ‘potatoes’ taken from the 2015 CEFAS survey [Ref 10]. It is noted that ingestion rates for milk are taken from RIFE 23 [Ref 25], as no consumption of milk was identified in the 2015 CEFAS survey for any age group. Child and infant ingestion rates for cow meat and sheep meat were not provided in the 2015 CEFAS survey. These data have been extrapolated from adult ingestion rates using CEFAS scaling factors [Ref 10].

100. For the adult and infant, cow milk and green vegetables were identified as the food categories with the highest contribution to the dose, whereas cow milk and cow meat provided the highest contribution for the child. In accordance with the top-two approach, these categories were set at high (97.5th) ingestion rates and the remaining categories were set to mean rates for each age group.

Occupancy Habits

101. Table 2-20 below presents the occupancy habits of the farming family and SZB worker used to assess the exposure to gaseous discharges from SZC.

Table 2-20 Occupancy Data for Farming Family and Sizewell B worker

Parameter	Adult	Child	Infant	SZB worker
Time at location (h/y)	8620	8620	8620	6620
Fraction of time spent indoors	0.75	0.8	0.9	0.9
Cloud gamma location factor	0.2	0.2	0.2	0.2
Deposited gamma location factor	0.1	0.1	0.1	0.1
Cloud beta location factor	1.0	1.0	1.0	1.0
Deposited beta location factor	1.0	1.0	1.0	1.0
Inhalation location factor	1.0	1.0	1.0	1.0
Inhalation rates at home (m^3/h)	1.11	0.63	0.21	0.91
Inhalation rates at work (Sizewell B worker only) (m^3/h)	-	-	-	1.5
Time spent by worker at the Sizewell B station (h/y)	-	-	-	2000
Fraction of time spent outdoors by Sizewell B worker	-	-	-	0.5
Distance of Sizewell B worker from Sizewell C stack (m)	-	-	-	330

102. Time at location and the fraction of time spent indoors for the adult member of the farming family are based on the maximum occupancy rates for direct radiation taken from the 2015 CEFAS survey [Ref 10] for the area >0.5 to 1 km from Sizewell. The fraction of time spent indoors for the child and infant and for the SZB worker when at home are taken from NRPB-W41 [Ref 35]. Gamma and beta location factors are based on default PC-CREAM 08 values.

103. The inhalation rate for the adult member of the farming family was derived following the approach used in NRPB-W41 for workers. The inhalation rate for the SZB worker at work is equal to the inhalation rate for light work and the rate for the worker when at home was derived using the NRPB-W41 non-occupational approach. Time spent doing different activities and inhalation rates during those activities for the farming child and infant were taken from ICRP Publication 66 [Ref 39] and were used to derive inhalation rates following the approach used in NRPB-W41 [Ref 35].

c) Results and Discussion

Annual Dose from Exposure to Gaseous Discharges from Sizewell C

104. The annual dose to the adult, child and infant members of the farming family from exposure to gaseous discharges from SZC, summed across the relevant terrestrial pathways, is calculated to be 4.0 µSv/y, 3.3 µSv/y and 6.9 µSv/y, respectively. The corresponding dose to the SZB worker is 4.1 µSv/y. Table 2-21 below presents a summary of the assessed effective doses to the farming family and SZB worker. A breakdown of the assessed doses described above, by radionuclide and exposure pathway, is presented in Section 2.5.

Table 2-21 Annual Effective Dose (µSv/y) to Farming Family and Sizewell B Worker from Exposure to Gaseous Discharges from Sizewell C

	Inhalation	External Beta/ gamma (Plume)	External Beta/ gamma (Ground)	Resuspension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat	Total
Adult	1.3E-01	2.0E-02	1.7E-03	3.5E-06	3.5E-01	1.6E+00	2.2E-01	5.3E-01	1.0E+00	1.3E-01	**4.0E+00**
Child	9.9E-02	1.8E-02	1.5E-03	4.8E-06	4.0E-01	2.2E+00	1.0E-01	1.4E-01	2.5E-01	7.3E-02	**3.3E+00**
Infant	6.8E-02	1.4E-02	1.0E-03	5.4E-06	2.2E-01	6.0E+00	5.2E-02	2.0E-01	2.7E-01	4.4E-02	**6.9E+00**
Sizewell B Worker	2.0E-01	3.9E-02	2.9E-03	5.8E-06	3.5E-01	1.6E+00	2.2E-01	5.3E-01	1.0E+00	1.3E-01	**4.1E+00**

105. The dominant pathway is the ingestion of cow milk which contributes around 40%, 67% and 87% of the assessed dose to adult, child and infant age groups respectively. The dose arising from non-ingestion pathways constitutes less than 4% of the dose to all three age groups.

106. C-14 is the dominant radionuclide, contributing between 89% and 94% of the assessed dose to the farming family. Other important radionuclides are H-3 and I-131; H-3 contributes approximately 4% of the total dose to all three age groups, whilst I-131 accounts for around 1%, 3% and 6% of the assessed dose to adult, child and infant age groups respectively.

107. The annual dose to the SZB worker is dominated by the ingestion of cow milk (39%) and root vegetables (25%); non-ingestion pathways account for around 6% of the assessed dose. C-14 and H-3 account for around 94% and 4% respectively of the assessed dose from all terrestrial pathways.

Annual Dose from Exposure to the Combined Gaseous Discharges from Sizewell B and C

108. The cumulative annual dose to the adult, child and infant members of the farming family from exposure to combined gaseous discharges from SZB and SZC, summed across the relevant terrestrial pathways, is calculated to be 5.6 µSv/y, 4.7 µSv/y and 9.8 µSv/y respectively. Ingestion of milk is the dominant pathway accounting for 39%, 66% and 87% of the assessed dose to adult, child and infant age groups respectively. C-14 was the dominant radionuclide contributing between 85% and 91% to the assessed dose from all terrestrial pathways. A breakdown of the assessed doses described above, by radionuclide and exposure pathway, is presented in Section 2.5.

Table 2-22 Annual Effective Dose (µSv/y) to Farming Family and Sizewell B Worker from Exposure to Gaseous Discharges from Sizewell B and Sizewell C

	Inhalation	Beta/ gamma (Plume)	Beta/ gamma (Ground)	Resuspension	Cow meat	Cow milk	Fruit	Green veg.	Root veg.	Sheep meat	Total
Adult	1.8E-01	1.5E-01	8.9E-03	8.1E-06	4.8E-01	2.2E+00	3.1E-01	7.3E-01	1.4E+00	1.8E-01	**5.6E+00**
Child	1.4E-01	1.4E-01	7.6E-03	1.1E-05	5.4E-01	3.1E+00	1.4E-01	1.9E-01	3.4E-01	1.0E-01	**4.7E+00**
Infant	9.5E-02	1.1E-01	5.2E-03	1.2E-05	3.0E-01	8.6E+00	7.2E-02	2.8E-01	3.7E-01	6.0E-02	**9.8E+00**
Sizewell B Worker	2.8E-01	3.1E-01	1.5E-02	1.3E-05	4.8E-01	2.2E+00	3.1E-01	7.3E-01	1.4E+00	1.8E-01	**5.9E+00**

109. The annual dose to the SZB worker from the combined discharges of gaseous radionuclides from SZB and SZC is calculated to be 5.9 µSv/y. Ingestion of milk and root vegetables account for around 37% and 24% of the assessed dose, respectively. C-14 and H-3 contribute around 88% and 4% of the assessed dose, respectively.

2.5 Breakdown of Annual Doses by Radionuclides and Exposure Pathways

110. Table 2-23 to Table 2-40 provide a breakdown of annual dose to all the CRPs for exposure to aqueous and gaseous discharges assessed in Sections 2.3 and 2.4 by radionuclide and exposure pathways.

111. A breakdown of doses to members of the fishing family, the houseboat dweller and the wildfowler as a result of aqueous discharges from SZC are given in Table 2-23 to Table 2-27. In each of the age groups for the fishing family, internal exposure to C-14 through the consumption of marine foodstuffs accounted for >90% of the cumulative dose. There was also a minor contribution to the total dose from Co-60 of 5.6% for the adult, 1.5% for the child and 1.8% for the infant, mainly as a result of external exposure. The slightly higher percentage contribution of Co-60 to the infant dose compared to the child was due to the infant having a more limited internal exposure as a result of lower seafood consumption. The contribution from any other radionuclide considered was 0.5% or less. The dose for adult houseboat and wildfowler individuals was similarly dominated by C-14 (mainly via internal exposure) and Co-60 (mainly via external exposure), with contributions of 95.3% from C-14 and 4.0% from Co-60 for the houseboat dweller and 96.4% C-14 and 2.8% Co-60 for the wildfowler from all pathways. The contribution from any other radionuclide considered was ≤0.2%.

112. A breakdown of doses to members of the fishing family, the houseboat dweller and the wildfowler as a result of aqueous discharges from SZB and SZC is given in Table 2-28 to Table 2-32. As for aqueous discharges from SZC alone, the dose to the fishing family was dominated by C-14 in each age group (78.6% for adults, 90.7% for children and 92.3% for infants). Again, there was a minor contribution from Co-60 (4.7%, 1.4% and 1.7% to adults, children and infants respectively). There is also a contribution from Cs-134 and Cs-137. Cs-134 was used in the modelling of radionuclides from SZB as a surrogate for the permit category of 'other radionuclides' where no specific breakdown exists. This approach is pessimistic and followed that used by the Environment Agency [Ref 41]. The dose contribution from Cs-134 (as a surrogate for 'other radionuclides') was 13.1%, 6.2% and 4.1% and that from Cs-137 3.0%, 1.1% and 0.9% to adults, children and infants, respectively. The dose for adult houseboat and wildfowler

individuals was similarly dominated by C-14 via internal exposure and Co-60 via external exposure with contributions from other radionuclides (modelled as Cs-134) and Cs-137 (85.9% C-14, 8.5% Cs-134, and 3.6% Co-60, 1.5% Cs-137 for the houseboat dweller and 87.7% C-14, 7.7% Cs-134, 2.6% Co-60 and 1.5% Cs-137 for the wildfowler). The contribution from any other radionuclide considered was ≤0.2%.

113. A breakdown of doses to members of the farming family and the SZB worker as a result of gaseous discharges from SZC is given in Table 2-33 to Table 2-36. In each of the age groups for the farming family, internal exposure through the consumption of terrestrial foodstuffs of C-14 accounted for ~90% of the cumulative dose. There was also a contribution to the total dose from H-3 of 3.8% for the adult, 4.1% for the child and 4.5% for the infant, and from I-131 of 1.2%, 2.9% and 6.1% for the adult, child and infant respectively, mainly as a result of milk consumption. For all three age groups less than 4% of the cumulative dose was due to external doses. The percentage contribution of H-3 and I-131 to the infant dose was higher than that to the child dose due to increased internal exposure from higher milk consumption. The contribution from any other radionuclide considered was ≤0.3%. The dose for a SZB worker was similarly dominated by C-14 (93.7%), mainly via internal exposure, with minor H-3 (4.0%) and I-131 (1.2%) contributions, due predominantly to milk consumption. The contribution from any other radionuclide considered was <0.5%.

114. A breakdown of doses to members of the farming family and the SZB worker as a result of gaseous discharges from SZB and C is given in Table 2-37 to Table 2-40. As for gaseous discharges from SZC alone, the dose to the farming family from combined gaseous discharges from SZB and C was dominated by C-14 in each age group (i.e. 91.2% for adults, 87.9% for children and 84.6% for infants). Again there was a minor contribution from H-3 (4.0%, 4.3% and 4.7% to adults, children and infants respectively) and I-131 (1.9%, 4.6% and 9.5% to adults, children and infants respectively). There is also a contribution from Ar-41 of 2.5%, 2.7% and 1.0% for adult, child and infant age groups respectively via the external pathway. Ar-41 was used to represent all noble gases from SZB, hence there is a much larger contribution from this radionuclide than for the SZC only assessment. The contribution from any other radionuclide considered was <0.2%. The dose for a SZB worker was similarly dominated by C-14 (88.4%), mostly via internal exposure, with minor contributions from Ar-41 (4.8%), H-3 (4.2%) and I-131 (1.9%). The contribution from any other radionuclide considered was ≤0.3%.

a) Doses Resulting from Aqueous Discharges from Sizewell C

Table 2-23 Annual Dose (µSv/y) to Adult Member of Fishing Family from Exposure to Aqueous Discharges from Sizewell C

	Pathway									
Radionuclide	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External beta from fishing equipment	External gamma from beaches	External gamma from fishing equipment	Sea spray inhalation	Total	% contribution by radionuclide
Ag-110m	1.5E-02	4.9E-03	8.1E-03	3.0E-04	2.6E-05	3.7E-06	1.8E-03	2.5E-05	1.3E-08	3.1E-02	0.3%
C-14	2.1E+00	6.8E+00	5.6E-01	5.2E-02	2.8E-04	2.5E-03	0.0E+00	0.0E+00	6.0E-07	9.5E+00	93.3%
Co-58	1.5E-03	5.0E-04	2.0E-04	7.6E-05	7.2E-06	3.0E-06	6.3E-03	9.0E-05	8.0E-09	8.7E-03	0.1%
Co-60	1.2E-02	3.8E-03	1.6E-03	5.9E-04	4.2E-04	2.9E-04	5.4E-01	7.7E-03	8.4E-08	5.7E-01	5.6%
Cr-51	3.4E-07	4.4E-07	1.4E-07	6.7E-08	1.3E-10	0.0E+00	1.8E-06	2.6E-08	4.6E-12	2.8E-06	0.0%
Cs-134	5.4E-04	5.8E-03	1.4E-04	4.5E-05	2.7E-05	9.6E-06	6.6E-03	9.5E-05	1.1E-08	1.3E-02	0.1%
Cs-137	6.6E-04	7.1E-03	1.7E-04	5.4E-05	3.8E-04	1.3E-04	2.3E-02	3.2E-04	1.4E-08	3.1E-02	0.3%
H-3	4.0E-03	1.3E-02	1.1E-03	2.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-05	1.8E-02	0.2%
I-131 (Xe-131m)*	1.1E-05	3.6E-05	2.9E-06	5.5E-05	1.3E-09	5.9E-10	4.9E-08	7.0E-10	5.3E-10	1.0E-04	0.0%
Mn-54	1.1E-05	2.7E-05	2.8E-04	6.3E-06	3.7E-08	0.0E+00	3.2E-03	4.6E-05	1.1E-09	3.6E-03	0.0%
Ni-63	3.4E-05	1.1E-04	1.8E-05	3.4E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-09	1.6E-04	0.0%
Sb-124	5.3E-05	2.7E-03	1.1E-05	2.1E-06	1.9E-06	2.2E-07	2.2E-04	3.2E-06	8.2E-09	3.0E-03	0.0%
Sb-125 (Te-125m)*	2.5E-04	2.9E-03	6.3E-05	1.0E-04	7.6E-06	9.4E-06	1.5E-03	2.2E-05	1.3E-08	4.9E-03	0.0%
Te-123m (Te-123)*	6.7E-04	2.2E-03	1.8E-04	3.3E-04	5.6E-08	1.9E-07	2.1E-05	2.9E-07	2.9E-09	3.4E-03	0.0%
Total	2.1E+00	6.8E+00	5.7E-01	5.4E-02	1.1E-03	3.0E-03	5.8E-01	8.3E-03	2.2E-05	1.0E+01	100.0%
% contribution by pathway	21.0%	67.0%	5.6%	0.5%	0.0%	0.0%	5.7%	0.1%	0.0%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-24 Annual Dose (μSv/y) to Child Member of Fishing Family from Exposure to Aqueous Discharges from Sizewell C

Radionuclide	Pathway									Total	% contribution by radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External beta from fishing equipment	External gamma from beaches	External gamma from fishing equipment	Sea spray inhalation		
Ag-110m	4.0E-03	4.1E-03	3.8E-03	0.0E+00	2.9E-06	3.1E-08	2.0E-04	2.2E-07	1.5E-09	1.2E-02	0.2%
C-14	4.1E-01	4.2E+00	1.9E-01	0.0E+00	3.2E-05	2.2E-05	0.0E+00	0.0E+00	6.1E-08	4.8E+00	97.7%
Co-58	5.0E-04	5.1E-04	1.2E-04	0.0E+00	8.1E-07	2.6E-08	7.1E-04	7.7E-07	8.7E-10	1.8E-03	0.0%
Co-60	5.4E-03	5.6E-03	1.3E-03	0.0E+00	4.7E-05	2.4E-06	6.1E-02	6.6E-05	9.2E-09	7.3E-02	1.5%
Cr-51	9.8E-08	4.0E-07	7.4E-08	0.0E+00	1.5E-11	0.0E+00	2.0E-07	2.2E-10	6.1E-13	7.7E-07	0.0%
Cs-134	5.6E-05	1.9E-03	2.6E-05	0.0E+00	3.0E-06	8.2E-08	7.4E-04	8.1E-07	6.4E-10	2.7E-03	0.1%
Cs-137	7.1E-05	2.4E-03	3.4E-05	0.0E+00	4.2E-05	1.1E-06	2.5E-03	2.7E-06	8.0E-10	5.1E-03	0.1%
H-3	7.2E-04	7.4E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.8E-06	8.4E-03	0.2%
I-131 (Xe-131m)*	3.7E-06	3.8E-05	1.7E-06	0.0E+00	1.5E-10	5.0E-12	5.5E-09	5.9E-12	9.9E-11	4.3E-05	0.0%
Mn-54	2.7E-06	2.2E-05	1.3E-04	0.0E+00	4.1E-09	0.0E+00	3.6E-04	3.9E-07	1.2E-10	5.2E-04	0.0%
Ni-63	8.9E-06	9.2E-05	8.4E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-10	1.1E-04	0.0%
Sb-124	1.5E-05	2.5E-03	5.8E-06	0.0E+00	2.1E-07	1.9E-09	2.5E-05	2.7E-08	9.0E-10	2.6E-03	0.1%
Sb-125 (Te-125m)*	7.4E-05	2.6E-03	3.4E-05	0.0E+00	8.5E-07	8.0E-08	1.7E-04	1.9E-07	1.3E-09	2.9E-03	0.1%
Te-123m (Te-123)*	1.9E-04	1.9E-03	8.9E-05	0.0E+00	6.3E-09	1.6E-09	2.3E-06	2.5E-09	3.0E-10	2.2E-03	0.0%
Total	4.2E-01	4.2E+00	2.0E-01	0.0E+00	1.3E-04	2.5E-05	6.5E-02	7.1E-05	2.9E-06	4.9E+00	100.0%
% contribution by pathway	8.5%	86.1%	4.0%	0.0%	0.0%	0.0%	1.3%	0.0%	0.0%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-25 Annual Dose (µSv/y) to Infant Member of Fishing Family from Exposure to Aqueous Discharges from Sizewell C

Radionuclide	Pathway									Total	% contribution by radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External beta from fishing equipment	External gamma from beaches	External gamma from fishing equipment	Sea spray inhalation		
Ag-110m	3.8E-03	1.2E-03	2.0E-03	0.0E+00	8.3E-07	3.1E-08	5.7E-05	2.2E-07	3.0E-10	7.1E-03	0.5%
C-14	2.9E-01	9.4E-01	7.7E-02	0.0E+00	9.0E-06	2.2E-05	0.0E+00	0.0E+00	1.3E-08	1.3E+00	97.1%
Co-58	4.6E-04	1.5E-04	6.1E-05	0.0E+00	2.3E-07	2.6E-08	2.0E-04	7.7E-07	2.1E-10	8.6E-04	0.1%
Co-60	4.7E-03	1.5E-03	6.3E-04	0.0E+00	1.3E-05	2.4E-06	1.7E-02	6.6E-05	1.9E-09	2.4E-02	1.8%
Cr-51	1.0E-07	1.3E-07	4.3E-08	0.0E+00	4.2E-12	0.0E+00	5.7E-08	2.2E-10	1.7E-13	3.4E-07	0.0%
Cs-134	2.3E-05	2.4E-04	6.0E-06	0.0E+00	8.6E-07	8.2E-08	2.1E-04	8.1E-07	7.8E-11	4.8E-04	0.0%
Cs-137	3.0E-05	3.3E-04	8.0E-06	0.0E+00	1.2E-05	1.1E-06	7.2E-04	2.7E-06	1.0E-10	1.1E-03	0.1%
H-3	5.3E-04	1.7E-03	1.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.2E-07	2.4E-03	0.2%
I-131 (Xe-131m)*	4.5E-06	1.5E-05	1.2E-06	0.0E+00	4.2E-11	5.0E-12	1.6E-09	5.9E-12	3.3E-11	2.0E-05	0.0%
Mn-54	2.3E-06	5.9E-06	6.0E-05	0.0E+00	1.2E-09	0.0E+00	1.0E-04	3.9E-07	2.8E-11	1.7E-04	0.0%
Ni-63	9.5E-06	3.1E-05	5.0E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-11	4.5E-05	0.0%
Sb-124	1.7E-05	8.7E-04	3.6E-06	0.0E+00	6.0E-08	1.9E-09	7.1E-06	2.7E-08	2.0E-10	9.0E-04	0.1%
Sb-125 (Te-125m)*	8.5E-05	8.7E-04	2.2E-05	0.0E+00	2.4E-07	8.0E-08	4.8E-05	1.9E-07	2.8E-10	1.0E-03	0.1%
Te-123m (Te-123)*	2.1E-04	6.8E-04	5.6E-05	0.0E+00	1.8E-09	1.6E-09	6.6E-07	2.5E-09	6.1E-11	9.5E-04	0.1%
Total	3.0E-01	9.4E-01	8.0E-02	0.0E+00	3.6E-05	2.5E-05	1.9E-02	7.1E-05	8.4E-07	1.3E+00	100.0%
% contribution by pathway	22.4%	70.3%	6.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-26 Annual Dose (μSv/y) to Adult Houseboat Occupant from Exposure to Aqueous Discharges from Sizewell C.

Radionuclide	Pathway								Total	% Contribution by Radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External gamma from beaches	Sea spray inhalation	Houseboat occupancy		
Ag-110m	1.2E-04	4.0E-05	6.5E-05	2.4E-06	6.0E-08	4.1E-06	4.2E-11	2.8E-06	2.4E-04	0.2%
C-14	2.8E-02	9.1E-02	7.4E-03	6.9E-04	1.1E-06	0.0E+00	3.1E-09	5.1E-08	1.3E-01	95.3%
Co-58	1.9E-05	6.0E-06	2.5E-06	9.3E-07	2.5E-08	2.2E-05	5.6E-12	1.4E-05	6.4E-05	0.0%
Co-60	2.4E-04	7.7E-05	3.2E-05	1.2E-05	2.4E-06	3.1E-03	9.7E-11	1.9E-03	5.3E-03	4.0%
Cr-51	2.1E-09	2.7E-09	8.7E-10	4.1E-10	2.3E-13	3.1E-09	3.3E-15	1.9E-09	1.1E-08	0.0%
Cs-134	5.9E-06	6.3E-05	1.6E-06	4.9E-07	8.4E-08	2.1E-05	4.3E-11	1.3E-05	1.0E-04	0.1%
Cs-137	8.8E-06	9.4E-05	2.3E-06	7.3E-07	1.4E-06	8.6E-05	6.6E-11	3.1E-08	1.9E-04	0.1%
H-3	4.6E-05	1.5E-04	1.2E-05	2.3E-06	0.0E+00	0.0E+00	1.1E-07	0.0E+00	2.1E-04	0.2%
I-131 (Xe-131m)*	8.0E-09	2.6E-08	2.1E-09	4.0E-08	3.6E-13	1.1E-11	1.7E-13	1.4E-10	7.6E-08	0.0%
Mn-54	1.6E-07	4.2E-07	4.3E-06	9.6E-08	1.6E-10	1.4E-05	9.4E-13	8.9E-06	2.8E-05	0.0%
Ni-63	1.2E-06	3.8E-06	6.3E-07	1.2E-07	0.0E+00	0.0E+00	3.8E-12	0.0E+00	5.8E-06	0.0%
Sb-124	2.1E-07	1.1E-05	4.5E-08	8.5E-09	2.2E-09	2.6E-07	1.4E-11	2.2E-07	1.2E-05	0.0%
Sb-125 (Te-125m)*	1.1E-05	5.9E-05	3.0E-06	5.4E-06	2.3E-08	4.7E-06	7.9E-11	2.8E-06	8.7E-05	0.1%
Te-123m (Te-123)*	4.0E-06	1.3E-05	1.1E-06	2.0E-06	9.6E-11	3.5E-08	7.3E-12	2.3E-08	2.0E-05	0.0%
Total	2.9E-02	9.1E-02	7.6E-03	7.2E-04	5.1E-06	3.2E-03	1.1E-07	1.9E-03	1.3E-01	100.0%
% Contribution by Pathway	21.5%	68.4%	5.7%	0.5%	0.0%	2.4%	0.0%	1.4%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-27 Annual Dose (µSv/y) to Wildfowler from Exposure to Aqueous Discharges from Sizewell C

Radionuclide	Pathway								Total	% Contribution by Radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External gamma from beaches	Sea spray inhalation	Saltmarsh occupancy		
Ag-110m	1.2E-04	4.0E-05	6.5E-05	2.4E-06	6.0E-08	4.1E-06	2.3E-11	4.0E-07	2.4E-04	0.2%
C-14	2.8E-02	9.1E-02	7.4E-03	6.9E-04	1.1E-06	0.0E+00	1.7E-09	7.9E-09	1.3E-01	96.4%
Co-58	1.9E-05	6.0E-06	2.5E-06	9.3E-07	2.5E-08	2.2E-05	3.1E-12	2.2E-06	5.2E-05	0.0%
Co-60	2.4E-04	7.7E-05	3.2E-05	1.2E-05	2.4E-06	3.1E-03	5.3E-11	3.0E-04	3.7E-03	2.8%
Cr-51	2.1E-09	2.7E-09	8.7E-10	4.1E-10	2.3E-13	3.1E-09	1.8E-15	3.0E-10	9.4E-09	0.0%
Cs-134	5.9E-06	6.3E-05	1.6E-06	4.9E-07	8.4E-08	2.1E-05	2.4E-11	2.0E-06	9.4E-05	0.1%
Cs-137	8.8E-06	9.4E-05	2.3E-06	7.3E-07	1.4E-06	8.6E-05	3.6E-11	4.8E-09	1.9E-04	0.1%
H-3	4.6E-05	1.5E-04	1.2E-05	2.3E-06	0.0E+00	0.0E+00	5.9E-08	0.0E+00	2.1E-04	0.2%
I-131 (Xe-131m)*	8.0E-09	2.6E-08	2.1E-09	4.0E-08	3.6E-13	1.1E-11	9.3E-14	9.9E-13	7.6E-08	0.0%
Mn-54	1.6E-07	4.2E-07	4.3E-06	9.6E-08	1.6E-10	1.4E-05	5.2E-13	1.4E-06	2.1E-05	0.0%
Ni-63	1.2E-06	3.8E-06	6.3E-07	1.2E-07	0.0E+00	0.0E+00	2.1E-12	0.0E+00	5.8E-06	0.0%
Sb-124	2.1E-07	1.1E-05	4.5E-08	8.5E-09	2.2E-09	2.6E-07	7.6E-12	2.5E-08	1.2E-05	0.0%
Sb-125 (Te-125m)*	1.1E-05	5.9E-05	3.0E-06	5.4E-06	2.3E-08	4.7E-06	4.3E-11	4.2E-07	8.4E-05	0.1%
Te-123m (Te-123)*	4.0E-06	1.3E-05	1.1E-06	2.0E-06	9.6E-11	3.5E-08	4.0E-12	3.1E-09	2.0E-05	0.0%
Total	2.9E-02	9.1E-02	7.6E-03	7.2E-04	5.1E-06	3.2E-03	6.1E-08	3.0E-04	1.3E-01	100.0%
% Contribution by Pathway	21.7%	69.3%	5.8%	0.5%	0.0%	2.5%	0.0%	0.2%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Doses Resulting from Combined Aqueous Discharges from Sizewell B and C

Table 2-28 Annual Dose (µSv/y) to Adult Member of Fishing Family from Exposure to Aqueous Discharges from Sizewell B and C

	Pathway										
Radionuclide	**Crustaceans**	**Fish**	**Molluscs**	**Seaweed**	**External beta from beaches**	**External beta from fishing equipment**	**External gamma from beaches**	**External gamma from fishing equipment**	**Sea spray inhalation**	**Total**	**% contribution by radionuclide**
Ag-110m	1.5E-02	4.9E-03	8.1E-03	3.0E-04	2.6E-05	3.7E-06	1.8E-03	2.5E-05	1.3E-08	3.1E-02	0.3%
C-14	2.1E+00	6.8E+00	5.6E-01	5.2E-02	2.8E-04	2.5E-03	0.0E+00	0.0E+00	6.0E-07	9.5E+00	78.6%
Co-58	1.5E-03	5.0E-04	2.0E-04	7.6E-05	7.2E-06	3.0E-06	6.3E-03	9.0E-05	8.0E-09	8.7E-03	0.1%
Co-60	1.2E-02	3.8E-03	1.6E-03	5.9E-04	4.2E-04	2.9E-04	5.4E-01	7.7E-03	8.4E-08	5.7E-01	4.7%
Cr-51	3.4E-07	4.4E-07	1.4E-07	6.7E-08	1.3E-10	0.0E+00	1.8E-06	2.6E-08	4.6E-12	2.8E-06	0.0%
Cs-134	6.5E-02	6.9E-01	1.7E-02	5.3E-03	3.2E-03	1.1E-03	7.9E-01	1.1E-02	1.3E-06	1.6E+00	13.1%
Cs-137	7.6E-03	8.1E-02	2.0E-03	6.3E-04	4.3E-03	1.5E-03	2.6E-01	3.7E-03	1.6E-07	3.6E-01	3.0%
H-3	5.6E-03	1.8E-02	1.5E-03	2.8E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-05	2.5E-02	0.2%
I-131 (Xe-131m)*	1.1E-05	3.6E-05	2.9E-06	5.5E-05	1.3E-09	5.9E-10	4.9E-08	7.0E-10	5.3E-10	1.0E-04	0.0%
Mn-54	1.1E-05	2.7E-05	2.8E-04	6.3E-06	3.7E-08	0.0E+00	3.2E-03	4.6E-05	1.1E-09	3.6E-03	0.0%
Ni-63	3.4E-05	1.1E-04	1.8E-05	3.4E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-09	1.6E-04	0.0%
Sb-124	5.3E-05	2.7E-03	1.1E-05	2.1E-06	1.9E-06	2.2E-07	2.2E-04	3.2E-06	8.2E-09	3.0E-03	0.0%
Sb-125 (Te-125m)*	2.5E-04	2.9E-03	6.3E-05	1.0E-04	7.6E-06	9.4E-06	1.5E-03	2.2E-05	1.3E-08	4.9E-03	0.0%
Te-123m (Te-123m)*	6.7E-04	2.2E-03	1.8E-04	3.3E-04	5.6E-08	1.9E-07	2.1E-05	2.9E-07	2.9E-09	3.4E-03	0.0%
Total	2.2E+00	7.6E+00	5.9E-01	6.0E-02	8.3E-03	5.5E-03	1.6E+00	2.3E-02	3.2E-05	1.2E+01	100.0%
% contribution by pathway	18.3%	62.8%	4.9%	0.5%	0.1%	0.0%	13.2%	0.2%	0.0%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-29 Annual Dose (µSv/y) to Child Member of Fishing Family from Exposure to Aqueous Discharges from Sizewell B and C

Radionuclide	Pathway									Total	% contribution by radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External beta from fishing equipment	External gamma from beaches	External gamma from fishing equipment	Sea spray inhalation		
Ag-110m	4.0E-03	4.1E-03	3.8E-03	0.0E+00	2.9E-06	3.1E-08	2.0E-04	2.2E-07	1.5E-09	1.2E-02	0.2%
C-14	4.1E-01	4.2E+00	1.9E-01	0.0E+00	3.2E-05	2.2E-05	0.0E+00	0.0E+00	6.1E-08	4.8E+00	90.7%
Co-58	5.0E-04	5.1E-04	1.2E-04	0.0E+00	8.1E-07	2.6E-08	7.1E-04	7.7E-07	8.7E-10	1.8E-03	0.0%
Co-60	5.4E-03	5.6E-03	1.3E-03	0.0E+00	4.7E-05	2.4E-06	6.1E-02	6.6E-05	9.2E-09	7.3E-02	1.4%
Cr-51	9.8E-08	4.0E-07	7.4E-08	0.0E+00	1.5E-11	0.0E+00	2.0E-07	2.2E-10	6.1E-13	7.7E-07	0.0%
Cs-134	6.7E-03	2.3E-01	3.1E-03	0.0E+00	3.6E-04	9.7E-06	8.8E-02	9.6E-05	7.6E-08	3.3E-01	6.2%
Cs-137	8.2E-04	2.8E-02	3.9E-04	0.0E+00	4.8E-04	1.3E-05	2.9E-02	3.2E-05	9.2E-09	5.9E-02	1.1%
H-3	1.0E-03	1.0E-02	4.7E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.9E-06	1.2E-02	0.2%
I-131 (Xe-131m)*	3.7E-06	3.8E-05	1.7E-06	0.0E+00	1.5E-10	5.0E-12	5.5E-09	5.9E-12	9.9E-11	4.3E-05	0.0%
Mn-54	2.7E-06	2.2E-05	1.3E-04	0.0E+00	4.1E-09	0.0E+00	3.6E-04	3.9E-07	1.2E-10	5.2E-04	0.0%
Ni-63	8.9E-06	9.2E-05	8.4E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-10	1.1E-04	0.0%
Sb-124	1.5E-05	2.5E-03	5.8E-06	0.0E+00	2.1E-07	1.9E-09	2.5E-05	2.7E-08	9.0E-10	2.6E-03	0.0%
Sb-125 (Te-125m)*	7.4E-05	2.6E-03	3.4E-05	0.0E+00	8.5E-07	8.0E-08	1.7E-04	1.9E-07	1.3E-09	2.9E-03	0.1%
Te-123m (Te-123)*	1.9E-04	1.9E-03	8.9E-05	0.0E+00	6.3E-09	1.6E-09	2.3E-06	2.5E-09	3.0E-10	2.2E-03	0.0%
Total	4.3E-01	4.5E+00	2.0E-01	0.0E+00	9.3E-04	4.7E-05	1.8E-01	2.0E-04	4.1E-06	5.3E+00	100.0%
% contribution by pathway	8.1%	84.7%	3.8%	0.0%	0.0%	0.0%	3.4%	0.0%	0.0%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-30 Annual Dose (µSv/y) to Infant Member of Fishing Family from Exposure to Aqueous Discharges from Sizewell B and C

Radionuclide	Pathway									Total	% contribution by radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External beta from fishing equipment	External gamma from beaches	External gamma from fishing equipment	Sea spray inhalation		
Ag-110m	3.8E-03	1.2E-03	2.0E-03	0.0E+00	8.3E-07	3.1E-08	5.7E-05	2.2E-07	3.0E-10	7.1E-03	0.5%
C-14	2.9E-01	9.4E-01	7.7E-02	0.0E+00	9.0E-06	2.2E-05	0.0E+00	0.0E+00	1.3E-08	1.3E+00	92.3%
Co-58	4.6E-04	1.5E-04	6.1E-05	0.0E+00	2.3E-07	2.6E-08	2.0E-04	7.7E-07	2.1E-10	8.6E-04	0.1%
Co-60	4.7E-03	1.5E-03	6.3E-04	0.0E+00	1.3E-05	2.4E-06	1.7E-02	6.6E-05	1.9E-09	2.4E-02	1.7%
Cr-51	1.0E-07	1.3E-07	4.3E-08	0.0E+00	4.2E-12	0.0E+00	5.7E-08	2.2E-10	1.7E-13	3.4E-07	0.0%
Cs-134	2.7E-03	2.9E-02	7.2E-04	0.0E+00	1.0E-04	9.7E-06	2.5E-02	9.6E-05	9.3E-09	5.8E-02	4.1%
Cs-137	3.5E-04	3.8E-03	9.3E-05	0.0E+00	1.4E-04	1.3E-05	8.2E-03	3.2E-05	1.2E-09	1.3E-02	0.9%
H-3	7.4E-04	2.4E-03	2.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-06	3.3E-03	0.2%
I-131 (Xe-131m)*	4.5E-06	1.5E-05	1.2E-06	0.0E+00	4.2E-11	5.0E-12	1.6E-09	5.9E-12	3.3E-11	2.0E-05	0.0%
Mn-54	2.3E-06	5.9E-06	6.0E-05	0.0E+00	1.2E-09	0.0E+00	1.0E-04	3.9E-07	2.8E-11	1.7E-04	0.0%
Ni-63	9.5E-06	3.1E-05	5.0E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-11	4.5E-05	0.0%
Sb-124	1.7E-05	8.7E-04	3.6E-06	0.0E+00	6.0E-08	1.9E-09	7.1E-06	2.7E-08	2.0E-10	9.0E-04	0.1%
Sb-125 (Te-125)*	8.5E-05	8.7E-04	2.2E-05	0.0E+00	2.4E-07	8.0E-08	4.8E-05	1.9E-07	2.8E-10	1.0E-03	0.1%
Te-123m (Te-123)*	2.1E-04	6.8E-04	5.6E-05	0.0E+00	1.8E-09	1.6E-09	6.6E-07	2.5E-09	6.1E-11	9.5E-04	0.1%
Total	3.0E-01	9.8E-01	8.1E-02	0.0E+00	2.6E-04	4.7E-05	5.1E-02	2.0E-04	1.2E-06	1.4E+00	100.0%
% contribution by pathway	21.5%	69.1%	5.7%	0.0%	0.0%	0.0%	3.6%	0.0%	0.0%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-31 Annual Dose (µSv/y) to Adult Houseboat Occupant from Exposure to Aqueous Discharges from Sizewell B and C

Radionuclide	Pathway								Total	% Contribution by Radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External gamma from beaches	Sea spray inhalation	Houseboat occupancy		
Ag-110m	1.2E-04	4.0E-05	6.5E-05	2.4E-06	6.0E-08	4.1E-06	4.2E-11	2.8E-06	2.4E-04	0.2%
C-14	2.8E-02	9.1E-02	7.4E-03	6.9E-04	1.1E-06	0.0E+00	3.1E-09	5.1E-08	1.3E-01	85.9%
Co-58	1.9E-05	6.0E-06	2.5E-06	9.3E-07	2.5E-08	2.2E-05	5.6E-12	1.4E-05	6.4E-05	0.0%
Co-60	2.4E-04	7.7E-05	3.2E-05	1.2E-05	2.4E-06	3.1E-03	9.7E-11	1.9E-03	5.3E-03	3.6%
Cr-51	2.1E-09	2.7E-09	8.7E-10	4.1E-10	2.3E-13	3.1E-09	3.3E-15	1.9E-09	1.1E-08	0.0%
Cs-134	7.0E-04	7.5E-03	1.8E-04	5.8E-05	1.0E-05	2.5E-03	5.2E-09	1.6E-03	1.2E-02	8.5%
Cs-137	1.0E-04	1.1E-03	2.7E-05	8.4E-06	1.6E-05	9.9E-04	7.6E-10	3.6E-07	2.2E-03	1.5%
H-3	6.4E-05	2.1E-04	1.7E-05	3.2E-06	0.0E+00	0.0E+00	1.5E-07	0.0E+00	2.9E-04	0.2%
I-131 (Xe-131m)*	8.0E-09	2.6E-08	2.1E-09	4.0E-08	3.6E-13	1.1E-11	1.7E-13	1.4E-10	7.6E-08	0.0%
Mn-54	1.6E-07	4.2E-07	4.3E-06	9.6E-08	1.6E-10	1.4E-05	9.4E-13	8.9E-06	2.8E-05	0.0%
Ni-63	1.2E-06	3.8E-06	6.3E-07	1.2E-07	0.0E+00	0.0E+00	3.8E-12	0.0E+00	5.8E-06	0.0%
Sb-124	2.1E-07	1.1E-05	4.5E-08	8.5E-09	2.2E-09	2.6E-07	1.4E-11	2.2E-07	1.2E-05	0.0%
Sb-125 (Te-125m)*	1.1E-05	5.9E-05	3.0E-06	5.4E-06	2.3E-08	4.7E-06	7.9E-11	2.8E-06	8.7E-05	0.1%
Te-123m (Te-123)*	4.0E-06	1.3E-05	1.1E-06	2.0E-06	9.6E-11	3.5E-08	7.3E-12	2.3E-08	2.0E-05	0.0%
Total	2.9E-02	1.0E-01	7.8E-03	7.9E-04	3.0E-05	6.6E-03	1.6E-07	3.5E-03	1.5E-01	100.0%
% Contribution by Pathway	19.9%	67.5%	5.3%	0.5%	0.0%	4.5%	0.0%	2.4%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-32 Annual Dose (µSv/y) to Wildfowler from Exposure to Aqueous Discharges from Sizewell B and C

Radionuclide	Pathway								Total	% Contribution by Radionuclide
	Crustaceans	Fish	Molluscs	Seaweed	External beta from beaches	External gamma from beaches	Sea spray inhalation	Saltmarsh occupancy		
Ag-110m	1.2E-04	4.0E-05	6.5E-05	2.4E-06	6.0E-08	4.1E-06	2.3E-11	4.0E-07	2.4E-04	0.2%
C-14	2.8E-02	9.1E-02	7.4E-03	6.9E-04	1.1E-06	0.0E+00	1.7E-09	7.9E-09	1.3E-01	87.7%
Co-58	1.9E-05	6.0E-06	2.5E-06	9.3E-07	2.5E-08	2.2E-05	3.1E-12	2.2E-06	5.2E-05	0.0%
Co-60	2.4E-04	7.7E-05	3.2E-05	1.2E-05	2.4E-06	3.1E-03	5.3E-11	3.0E-04	3.7E-03	2.6%
Cr-51	2.1E-09	2.7E-09	8.7E-10	4.1E-10	2.3E-13	3.1E-09	1.8E-15	3.0E-10	9.4E-09	0.0%
Cs-134	7.0E-04	7.5E-03	1.8E-04	5.8E-05	1.0E-05	2.5E-03	2.8E-09	2.4E-04	1.1E-02	7.7%
Cs-137	1.0E-04	1.1E-03	2.7E-05	8.4E-06	1.6E-05	9.9E-04	4.2E-10	5.6E-08	2.2E-03	1.5%
H-3	6.4E-05	2.1E-04	1.7E-05	3.2E-06	0.0E+00	0.0E+00	8.3E-08	0.0E+00	2.9E-04	0.2%
I-131 (Xe-131m)*	8.0E-09	2.6E-08	2.1E-09	4.0E-08	3.6E-13	1.1E-11	9.3E-14	9.9E-13	7.6E-08	0.0%
Mn-54	1.6E-07	4.2E-07	4.3E-06	9.6E-08	1.6E-10	1.4E-05	5.2E-13	1.4E-06	2.1E-05	0.0%
Ni-63	1.2E-06	3.8E-06	6.3E-07	1.2E-07	0.0E+00	0.0E+00	2.1E-12	0.0E+00	5.8E-06	0.0%
Sb-124	2.1E-07	1.1E-05	4.5E-08	8.5E-09	2.2E-09	2.6E-07	7.6E-12	2.5E-08	1.2E-05	0.0%
Sb-125 (Te-125m)*	1.1E-05	5.9E-05	3.0E-06	5.4E-06	2.3E-08	4.7E-06	4.3E-11	4.2E-07	8.4E-05	0.1%
Te-123m (Te-123)*	4.0E-06	1.3E-05	1.1E-06	2.0E-06	9.6E-11	3.5E-08	4.0E-12	3.1E-09	2.0E-05	0.0%
Total	2.9E-02	1.0E-01	7.8E-03	7.9E-04	3.0E-05	6.6E-03	8.8E-08	5.4E-04	1.4E-01	100.0%
% Contribution by Pathway	20.3%	68.8%	5.4%	0.5%	0.0%	4.5%	0.0%	0.4%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

b) Doses resulting from Gaseous Discharges from Sizewell C

Table 2-33 Annual Dose (µSv/y) to Adult Member of Farming Family from Exposure to Gaseous Discharges from Sizewell C

Radionuclide	Pathway												Total	% Contribution by radionuclide
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resus-pension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat		
Ar-41	0.0E+00	5.6E-03	1.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.7E-03	0.1%
C-14	1.1E-01	0.0E+00	1.5E-06	0.0E+00	0.0E+00	0.0E+00	3.5E-01	1.4E+00	2.2E-01	5.2E-01	9.9E-01	1.3E-01	3.8E+00	94.4%
Co-58	2.2E-06	3.8E-08	6.4E-11	1.8E-05	2.8E-07	2.7E-09	6.1E-09	2.9E-07	1.3E-07	1.9E-06	1.0E-08	3.6E-09	2.3E-05	0.0%
Co-60	1.7E-05	1.1E-07	1.3E-10	8.9E-04	1.3E-06	4.0E-08	1.4E-07	2.2E-06	1.2E-06	1.3E-05	1.1E-06	7.9E-08	9.3E-04	0.0%
Cs-134	8.5E-06	5.5E-08	3.2E-10	2.2E-04	3.2E-06	1.6E-08	1.7E-04	4.2E-04	7.2E-05	6.6E-05	1.1E-04	1.2E-04	1.2E-03	0.0%
Cs-137 (Ba-137m)*	5.3E-06	1.2E-08	3.8E-10	3.6E-04	4.9E-06	2.4E-08	1.2E-04	2.9E-04	4.7E-05	4.6E-05	7.8E-05	9.3E-05	1.0E-03	0.0%
H-3	2.1E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.0E-03	8.0E-02	5.3E-03	1.3E-02	2.4E-02	1.9E-03	1.5E-01	3.8%
I-131 (Xe-131m)*	9.9E-04	5.5E-07	1.4E-08	1.5E-04	4.8E-05	3.4E-06	9.8E-04	3.7E-02	1.4E-03	4.7E-03	1.9E-03	3.3E-04	4.8E-02	1.2%
I-133 (Xe-133m, Xe-133)*	3.9E-05	1.6E-07	7.6E-09	5.1E-06	2.8E-06	4.5E-08	1.9E-07	9.2E-05	1.1E-06	2.7E-05	3.8E-07	1.8E-09	1.7E-04	0.0%
Kr-85	0.0E+00	5.1E-05	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E-04	0.0%
Xe-131m	0.0E+00	4.6E-06	2.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.9E-06	0.0%
Xe-133	0.0E+00	4.5E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.8E-03	0.1%
Xe-135 (Cs-135)*	1.9E-12	8.4E-03	6.5E-04	0.0E+00	5.9E-13	1.1E-14	2.0E-11	4.8E-11	1.5E-11	1.6E-11	2.6E-11	1.6E-11	9.1E-03	0.2%
Total	1.3E-01	1.9E-02	1.5E-03	1.6E-03	6.0E-05	3.5E-06	3.5E-01	1.6E+00	2.2E-01	5.3E-01	1.0E+00	1.3E-01	4.0E+00	100.0%
% Contribution	3.2%	0.5%	0.0%	0.0%	0.0%	0.0%	8.9%	39.5%	5.6%	13.5%	25.5%	3.3%	100.00%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-34 Annual Dose (µSv/y) to Child Member of Farming Family from Exposure to Gaseous Discharges from Sizewell C

Radionuclide	**Pathway**												**Total**	**% Contribution by radionuclide**
	Inhalation of Plume	**Gamma from Plume**	**Beta from Plume**	**Gamma from Ground**	**Beta from Ground**	**Resus-pension**	**Cow meat**	**Cow milk**	**Fruit**	**Green vegetables**	**Root vegetables**	**Sheep meat**		
Ar-41	0.0E+00	5.0E-03	1.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.2E-03	0.2%
C-14	8.2E-02	0.0E+00	1.5E-06	0.0E+00	0.0E+00	0.0E+00	3.9E-01	2.0E+00	1.0E-01	1.3E-01	2.4E-01	7.2E-02	3.0E+00	92.3%
Co-58	1.9E-06	3.4E-08	6.4E-11	1.5E-05	2.8E-07	2.3E-09	1.1E-08	6.6E-07	1.0E-07	8.3E-07	4.3E-09	3.4E-09	1.9E-05	0.0%
Co-60	1.4E-05	9.8E-08	1.3E-10	7.6E-04	1.3E-06	3.5E-08	3.8E-07	7.0E-06	1.3E-06	7.9E-06	6.5E-07	1.0E-07	7.9E-04	0.0%
Cs-134	3.9E-06	5.0E-08	3.2E-10	1.9E-04	3.2E-06	7.5E-09	1.0E-04	3.1E-04	1.8E-05	8.9E-06	1.5E-05	3.6E-05	6.8E-04	0.0%
Cs-137 (Ba-137m)*	2.4E-06	1.1E-08	3.8E-10	3.1E-04	4.9E-06	1.1E-08	7.5E-05	2.2E-04	1.2E-05	6.6E-06	1.1E-05	2.9E-05	6.8E-04	0.0%
H-3	1.5E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.2E-03	1.0E-01	2.3E-03	3.0E-03	5.5E-03	9.6E-04	1.3E-01	4.1%
I-131 (Xe-131m)*	1.4E-03	4.9E-07	1.4E-08	1.3E-04	4.8E-05	4.7E-06	1.9E-03	8.8E-02	1.1E-03	2.0E-03	7.9E-04	3.1E-04	9.6E-02	2.9%
I-133 (Xe-133m, Xe-133)*	5.3E-05	1.5E-07	7.6E-09	4.4E-06	2.8E-06	6.2E-08	3.7E-07	2.1E-04	8.3E-07	1.1E-05	1.6E-07	1.7E-09	2.9E-04	0.0%
Kr-85	0.0E+00	4.6E-05	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E-04	0.0%
Xe-131m	0.0E+00	4.2E-06	2.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.5E-06	0.0%
Xe-133	0.0E+00	4.0E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.3E-03	0.1%
Xe-135 (Cs-135)*	9.4E-13	7.6E-03	6.5E-04	0.0E+00	5.9E-13	5.5E-15	1.4E-11	4.1E-11	4.3E-12	2.5E-12	4.0E-12	5.3E-12	8.2E-03	0.3%
Total	9.9E-02	1.7E-02	1.5E-03	1.4E-03	6.0E-05	4.8E-06	4.0E-01	2.2E+00	1.0E-01	1.4E-01	2.5E-01	7.3E-02	3.3E+00	100.0%
% Contribution by pathway	3.0%	0.5%	0.0%	0.0%	0.0%	0.0%	12.2%	66.9%	3.2%	4.2%	7.7%	2.2%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-35 Annual Dose (µSv/y) to Infant Member of Farming Family from Exposure to Gaseous Discharges from Sizewell C

Radionuclide	**Pathway**												**Total**	**% Contribution by radionuclide**
	Inhalation of Plume	**Gamma from Plume**	**Beta from Plume**	**Gamma from Ground**	**Beta from Ground**	**Resus-pension**	**Cow meat**	**Cow milk**	**Fruit**	**Green vegetables**	**Root vegetables**	**Sheep meat**		
Ar-41	0.0E+00	3.9E-03	1.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.1E-03	0.1%
C-14	5.6E-02	0.0E+00	1.5E-06	0.0E+00	0.0E+00	0.0E+00	2.1E-01	5.3E+00	5.0E-02	1.9E-01	2.6E-01	4.3E-02	6.1E+00	89.2%
Co-58	1.8E-06	2.6E-08	6.4E-11	1.0E-05	2.8E-07	2.1E-09	8.0E-09	2.3E-06	6.6E-08	1.5E-06	6.0E-09	2.6E-09	1.6E-05	0.0%
Co-60	1.1E-05	7.6E-08	1.3E-10	5.2E-04	1.3E-06	2.6E-08	2.5E-07	2.3E-05	7.8E-07	1.4E-05	8.6E-07	7.5E-08	5.7E-04	0.0%
Cs-134	1.8E-06	3.9E-08	3.2E-10	1.3E-04	3.2E-06	3.5E-09	3.1E-05	4.7E-04	5.1E-06	7.4E-06	9.2E-06	1.2E-05	6.7E-04	0.0%
Cs-137 (Ba-137m)*	1.2E-06	8.6E-09	3.8E-10	2.1E-04	4.9E-06	5.5E-09	2.4E-05	3.6E-04	3.6E-06	5.7E-06	7.0E-06	1.0E-05	6.3E-04	0.0%
H-3	1.1E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-03	2.9E-01	1.2E-03	4.5E-03	6.2E-03	6.0E-04	3.1E-01	4.5%
I-131 (Xe-131m)*	1.5E-03	3.8E-07	1.4E-08	8.7E-05	4.8E-05	5.2E-06	1.8E-03	4.1E-01	9.5E-04	5.1E-03	1.5E-03	3.3E-04	4.2E-01	6.1%
I-133 (Xe-133m, Xe-133)*	7.6E-05	1.1E-07	7.6E-09	3.0E-06	2.8E-06	8.8E-08	4.4E-07	1.3E-03	9.1E-07	3.6E-05	3.8E-07	2.2E-09	1.4E-03	0.0%
Kr-85	0.0E+00	3.6E-05	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.9E-04	0.0%
Xe-131m	0.0E+00	3.2E-06	2.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-06	0.0%
Xe-133	0.0E+00	3.1E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-03	0.1%
Xe-135 (Cs-135)*	5.2E-13	5.9E-03	6.5E-04	0.0E+00	5.9E-13	3.0E-15	5.0E-12	7.4E-11	1.4E-12	2.4E-12	2.9E-12	2.2E-12	6.5E-03	0.1%
Total	6.8E-02	1.3E-02	1.5E-03	9.6E-04	6.0E-05	5.4E-06	2.2E-01	6.0E+00	5.2E-02	2.0E-01	2.7E-01	4.4E-02	6.9E+00	100.0%
% Contribution by pathway	1.0%	0.2%	0.0%	0.0%	0.0%	0.0%	3.2%	87.4%	0.8%	2.9%	3.9%	0.6%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-36 Annual Dose (µSv/y) to Sizewell B Worker from Exposure to Gaseous Discharges from Sizewell C

Radionuclide	Pathway												Total	% Contribution by radionuclide
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resus-pension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat		
Ar-41	0.0E+00	1.2E-02	2.3E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-02	0.3%
C-14	1.7E-01	0.0E+00	2.2E-06	0.0E+00	0.0E+00	0.0E+00	3.5E-01	1.4E+00	2.2E-01	5.2E-01	9.9E-01	1.3E-01	3.8E+00	93.7%
Co-58	3.6E-06	7.7E-08	9.4E-11	3.1E-05	4.2E-07	4.4E-09	6.1E-09	2.9E-07	1.3E-07	1.9E-06	1.0E-08	3.6E-09	3.7E-05	0.0%
Co-60	2.6E-05	2.2E-07	2.0E-10	1.5E-03	2.0E-06	6.7E-08	1.4E-07	2.2E-06	1.2E-06	1.3E-05	1.1E-06	7.9E-08	1.6E-03	0.0%
Cs-134	1.4E-05	1.1E-07	4.7E-10	3.8E-04	4.8E-06	2.7E-08	1.7E-04	4.2E-04	7.2E-05	6.6E-05	1.1E-04	1.2E-04	1.4E-03	0.0%
Cs-137 (Ba-137m)*	8.5E-06	1.5E-08	5.2E-10	6.3E-04	7.5E-06	4.0E-08	1.2E-04	2.9E-04	4.7E-05	4.6E-05	7.8E-05	9.3E-05	1.3E-03	0.0%
H-3	3.3E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.0E-03	8.0E-02	5.3E-03	1.3E-02	2.4E-02	1.9E-03	1.6E-01	4.0%
I-131 (Xe-131m)*	1.6E-03	1.1E-06	2.1E-08	2.5E-04	7.2E-05	5.6E-06	9.8E-04	3.7E-02	1.4E-03	4.7E-03	1.9E-03	3.3E-04	4.8E-02	1.2%
I-133 (Xe-133m, Xe-133)*	6.2E-05	3.4E-07	1.1E-08	8.7E-06	4.2E-06	7.3E-08	1.9E-07	9.2E-05	1.1E-06	2.7E-05	3.8E-07	1.8E-09	2.0E-04	0.0%
Kr-85	0.0E+00	1.0E-04	5.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.3E-04	0.0%
Xe-131m	0.0E+00	9.1E-06	3.4E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-05	0.0%
Xe-133	0.0E+00	8.7E-03	5.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.2E-03	0.2%
Xe-135 (Cs-135)*	1.7E-12	1.7E-02	9.7E-04	0.0E+00	6.0E-13	1.0E-14	2.0E-11	4.8E-11	1.5E-11	1.6E-11	2.6E-11	1.6E-11	1.8E-02	0.4%
Total	2.0E-01	3.7E-02	2.2E-03	2.8E-03	9.1E-05	5.8E-06	3.5E-01	1.6E+00	2.2E-01	5.3E-01	1.0E+00	1.3E-01	4.1E+00	100.0%
% Contribution by pathway	5.0%	0.9%	0.1%	0.1%	0.0%	0.0%	8.7%	38.5%	5.5%	13.1%	24.9%	3.2%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

c) Doses resulting from Combined Gaseous Discharges from Sizewell B and C

Table 2-37 Annual Dose (µSv/y) to Adult Member of Farming Family from Exposure to Gaseous Discharges from Sizewell B and C

Radionuclide	Pathway												Total	% Contribution
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resus-pension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat		
Ar-41	0.0E+00	1.3E-01	3.6E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-01	2.5%
C-14	1.4E-01	0.0E+00	2.0E-06	0.0E+00	0.0E+00	0.0E+00	4.7E-01	2.0E+00	2.9E-01	7.0E-01	1.3E+00	1.8E-01	5.1E+00	91.2%
Co-58	2.2E-06	3.8E-08	6.4E-11	1.8E-05	2.8E-07	2.7E-09	6.1E-09	2.9E-07	1.3E-07	1.9E-06	1.0E-08	3.6E-09	2.3E-05	0.0%
Co-60	1.5E-04	9.6E-07	1.2E-09	7.8E-03	1.2E-05	3.6E-07	1.2E-06	1.9E-05	1.0E-05	1.2E-04	9.8E-06	6.9E-07	8.2E-03	0.1%
Cs-134	8.5E-06	5.5E-08	3.2E-10	2.2E-04	3.2E-06	1.6E-08	1.7E-04	4.2E-04	7.2E-05	6.6E-05	1.1E-04	1.2E-04	1.2E-03	0.0%
Cs-137 (Ba-137m)*	5.3E-06	1.2E-08	3.8E-10	3.6E-04	4.9E-06	2.4E-08	1.2E-04	2.9E-04	4.7E-05	4.6E-05	7.8E-05	9.3E-05	1.0E-03	0.0%
H-3	3.1E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.5E-03	1.2E-01	7.9E-03	1.9E-02	3.6E-02	2.8E-03	2.2E-01	4.0%
I-131 (Xe-131m)*	2.2E-03	1.2E-06	3.2E-08	3.4E-04	1.1E-04	7.6E-06	2.2E-03	8.4E-02	3.1E-03	1.1E-02	4.2E-03	7.5E-04	1.1E-01	1.9%
I-133 (Xe-133m, Xe-133)*	3.9E-05	1.6E-07	7.6E-09	5.1E-06	2.8E-06	4.5E-08	1.9E-07	9.2E-05	1.1E-06	2.7E-05	3.8E-07	1.8E-09	1.7E-04	0.0%
Kr-85	0.0E+00	5.1E-05	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E-04	0.0%
Xe-131m	0.0E+00	4.6E-06	2.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.9E-06	0.0%
Xe-133	0.0E+00	4.5E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.8E-03	0.1%
Xe-135 (Cs-135)*	1.9E-12	8.4E-03	6.5E-04	0.0E+00	5.9E-13	1.1E-14	2.0E-11	4.8E-11	1.5E-11	1.6E-11	2.6E-11	1.6E-11	9.1E-03	0.2%
Total	1.8E-01	1.5E-01	5.0E-03	8.8E-03	1.3E-04	8.1E-06	4.8E-01	2.2E+00	3.1E-01	7.3E-01	1.4E+00	1.8E-01	5.6E+00	100.0%
% Contribution	3.2%	2.6%	0.1%	0.2%	0.0%	0.0%	8.6%	38.9%	5.5%	13.1%	24.7%	3.2%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-38 Annual Dose (µSv/y) to Child Member of Farming Family from Exposure to Gaseous Discharges from Sizewell B and C

Radionuclide	Pathway												Total	% Contribution by radionuclide
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resus-pension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat		
Ar-41	0.0E+00	1.2E-01	3.6E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-01	2.7%
C-14	1.1E-01	0.0E+00	2.0E-06	0.0E+00	0.0E+00	0.0E+00	5.3E-01	2.7E+00	1.4E-01	1.8E-01	3.3E-01	9.7E-02	4.1E+00	87.9%
Co-58	1.9E-06	3.4E-08	6.4E-11	1.5E-05	2.8E-07	2.3E-09	1.1E-08	6.6E-07	1.0E-07	8.3E-07	4.3E-09	3.4E-09	1.9E-05	0.0%
Co-60	1.3E-04	8.6E-07	1.2E-09	6.7E-03	1.2E-05	3.1E-07	3.3E-06	6.1E-05	1.1E-05	6.9E-05	5.7E-06	9.0E-07	7.0E-03	0.2%
Cs-134	3.9E-06	5.0E-08	3.2E-10	1.9E-04	3.2E-06	7.5E-09	1.0E-04	3.1E-04	1.8E-05	8.9E-06	1.5E-05	3.6E-05	6.8E-04	0.0%
Cs-137 (Ba-137m)*	2.4E-06	1.1E-08	3.8E-10	3.1E-04	4.9E-06	1.1E-08	7.5E-05	2.2E-04	1.2E-05	6.6E-06	1.1E-05	2.9E-05	6.8E-04	0.0%
H-3	2.3E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.8E-03	1.5E-01	3.4E-03	4.5E-03	8.3E-03	1.4E-03	2.0E-01	4.3%
I-131 (Xe-131m)*	3.1E-03	1.1E-06	3.2E-08	2.9E-04	1.1E-04	1.0E-05	4.3E-03	2.0E-01	2.5E-03	4.6E-03	1.8E-03	7.1E-04	2.2E-01	4.6%
I-133 (Xe-133m, Xe-133)*	5.3E-05	1.5E-07	7.6E-09	4.4E-06	2.8E-06	6.2E-08	3.7E-07	2.1E-04	8.3E-07	1.1E-05	1.6E-07	1.7E-09	2.9E-04	0.0%
Kr-85	0.0E+00	4.6E-05	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.0E-04	0.0%
Xe-131m	0.0E+00	4.2E-06	2.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.5E-06	0.0%
Xe-133	0.0E+00	4.0E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.3E-03	0.1%
Xe-135 (Cs-135)*	9.4E-13	7.6E-03	6.5E-04	0.0E+00	5.9E-13	5.5E-15	1.4E-11	4.1E-11	4.3E-12	2.5E-12	4.0E-12	5.3E-12	8.2E-03	0.2%
Total	1.4E-01	1.3E-01	5.0E-03	7.5E-03	1.3E-04	1.1E-05	5.4E-01	3.1E+00	1.4E-01	1.9E-01	3.4E-01	1.0E-01	4.7E+00	100.0%
% Contribution by pathway	2.9%	2.8%	0.1%	0.2%	0.0%	0.0%	11.7%	65.7%	3.1%	4.0%	7.3%	2.1%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-39 Annual Dose (µSv/y) to Infant Member of Farming Family from Exposure to Gaseous Discharges from Sizewell B and C

Radionuclide	Pathway												Total	% Contribution by radionuclide
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resus-pension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat		
Ar-41	0.0E+00	9.3E-02	3.6E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.7E-02	1.0%
C-14	7.6E-02	0.0E+00	2.0E-06	0.0E+00	0.0E+00	0.0E+00	2.9E-01	7.2E+00	6.8E-02	2.6E-01	3.6E-01	5.9E-02	8.3E+00	84.6%
Co-58	1.8E-06	2.6E-08	6.4E-11	1.0E-05	2.8E-07	2.1E-09	8.0E-09	2.3E-06	6.6E-08	1.5E-06	6.0E-09	2.6E-09	1.6E-05	0.0%
Co-60	9.5E-05	6.7E-07	1.2E-09	4.6E-03	1.2E-05	2.3E-07	2.2E-06	2.0E-04	6.9E-06	1.2E-04	7.6E-06	6.6E-07	5.0E-03	0.1%
Cs-134	1.8E-06	3.9E-08	3.2E-10	1.3E-04	3.2E-06	3.5E-09	3.1E-05	4.7E-04	5.1E-06	7.4E-06	9.2E-06	1.2E-05	6.7E-04	0.0%
Cs-137 (Ba-137m)*	1.2E-06	8.6E-09	3.8E-10	2.1E-04	4.9E-06	5.5E-09	2.4E-05	3.6E-04	3.6E-06	5.7E-06	7.0E-06	1.0E-05	6.3E-04	0.0%
H-3	1.6E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.4E-03	4.3E-01	1.8E-03	6.8E-03	9.4E-03	9.0E-04	4.7E-01	4.7%
I-131 (Xe-131m)*	3.5E-03	8.6E-07	3.2E-08	2.0E-04	1.1E-04	1.2E-05	4.0E-03	9.1E-01	2.1E-03	1.2E-02	3.3E-03	7.4E-04	9.4E-01	9.5%
I-133 (Xe-133m, Xe-133)*	7.6E-05	1.1E-07	7.6E-09	3.0E-06	2.8E-06	8.8E-08	4.4E-07	1.3E-03	9.1E-07	3.6E-05	3.8E-07	2.2E-09	1.4E-03	0.0%
Kr-85	0.0E+00	3.6E-05	3.5E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.9E-04	0.0%
Xe-131m	0.0E+00	3.2E-06	2.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-06	0.0%
Xe-133	0.0E+00	3.1E-03	3.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-03	0.0%
Xe-135 (Cs-135)*	5.2E-13	5.9E-03	6.5E-04	0.0E+00	5.9E-13	3.0E-15	5.0E-12	7.4E-11	1.4E-12	2.4E-12	2.9E-12	2.2E-12	6.5E-03	0.1%
Total	9.5E-02	1.0E-01	5.0E-03	5.1E-03	1.3E-04	1.2E-05	3.0E-01	8.6E+00	7.2E-02	2.8E-01	3.7E-01	6.0E-02	9.8E+00	100.0%
% Contribution by pathway	1.0%	1.0%	0.1%	0.1%	0.0%	0.0%	3.0%	86.9%	0.7%	2.8%	3.8%	0.6%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 2-40 Annual Dose (µSv/y) to Sizewell B Worker from Exposure to Gaseous Discharges from Sizewell B and C

Radionuclide	Pathway												Total	% Contribution by radionuclide
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resus-pension	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat		
Ar-41	0.0E+00	2.8E-01	5.4E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.8E-01	4.8%
C-14	2.3E-01	0.0E+00	2.9E-06	0.0E+00	0.0E+00	0.0E+00	4.7E-01	2.0E+00	2.9E-01	7.0E-01	1.3E+00	1.8E-01	5.2E+00	88.4%
Co-58	3.6E-06	7.7E-08	9.4E-11	3.1E-05	4.2E-07	4.4E-09	6.1E-09	2.9E-07	1.3E-07	1.9E-06	1.0E-08	3.6E-09	3.7E-05	0.0%
Co-60	2.3E-04	2.0E-06	1.8E-09	1.4E-02	1.8E-05	5.9E-07	1.2E-06	1.9E-05	1.0E-05	1.2E-04	9.8E-06	6.9E-07	1.4E-02	0.2%
Cs-134	1.4E-05	1.1E-07	4.7E-10	3.8E-04	4.8E-06	2.7E-08	1.7E-04	4.2E-04	7.2E-05	6.6E-05	1.1E-04	1.2E-04	1.4E-03	0.0%
Cs-137 (Ba-137m)*	8.5E-06	1.5E-08	5.2E-10	6.3E-04	7.5E-06	4.0E-08	1.2E-04	2.9E-04	4.7E-05	4.6E-05	7.8E-05	9.3E-05	1.3E-03	0.0%
H-3	5.0E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.5E-03	1.2E-01	7.9E-03	1.9E-02	3.6E-02	2.8E-03	2.4E-01	4.2%
I-131 (Xe-131m)*	3.6E-03	2.5E-06	4.7E-08	5.7E-04	1.6E-04	1.2E-05	2.2E-03	8.4E-02	3.1E-03	1.1E-02	4.2E-03	7.5E-04	1.1E-01	1.9%
I-133 (Xe-133m, Xe-133)*	6.2E-05	3.4E-07	1.1E-08	8.7E-06	4.2E-06	7.3E-08	1.9E-07	9.2E-05	1.1E-06	2.7E-05	3.8E-07	1.8E-09	2.0E-04	0.0%
Kr-85	0.0E+00	1.0E-04	5.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.3E-04	0.0%
Xe-131m	0.0E+00	9.1E-06	3.4E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-05	0.0%
Xe-133	0.0E+00	8.7E-03	5.1E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.2E-03	0.2%
Xe-135 (Cs-135)*	1.7E-12	1.7E-02	9.7E-04	0.0E+00	6.0E-13	1.0E-14	2.0E-11	4.8E-11	1.5E-11	1.6E-11	2.6E-11	1.6E-11	1.8E-02	0.3%
Total	2.8E-01	3.0E-01	7.4E-03	1.5E-02	2.0E-04	1.3E-05	4.8E-01	2.2E+00	3.1E-01	7.3E-01	1.4E+00	1.8E-01	5.9E+00	100.0%
% Contribution by pathway	4.8%	5.1%	0.1%	0.3%	0.0%	0.0%	8.2%	37.1%	5.2%	12.5%	23.6%	3.1%	100.0%	

* Dose from progeny, stated in brackets, is included in the dose from the parent.

115. The annual dose to the adult, child and infant members of the fishing family from exposure to aqueous discharges from SZC, summed across the relevant marine pathways, was calculated to be 10, 4.9 and 1.3 µSv/y, respectively. The corresponding dose from exposure to combined aqueous discharges from SZB and SZC was calculated to be 12 µSv/y, 5.3 µSv/y and 1.4 µSv/y, respectively. The annual dose to an adult houseboat occupant and a wildfowler from exposure to aqueous discharges from SZC, and from SZB and SZC combined were less than 0.2 µSv/y. For all CRPs exposed to aqueous discharges, C-14 was the main contributor to the total dose from SZC discharges and from combined SZB and SZC discharges, mainly as a result of internal exposure from consumption of marine foodstuffs. There were minor contributions to the total dose from Co-60, Cs-134 and Cs-137.

116. The annual dose to the adult, child and infant members of the farming family from exposure to gaseous discharges from SZC, summed across the relevant terrestrial pathways, was calculated to be 4.0, 3.3 and 6.9 µSv/y, respectively. The corresponding dose from exposure to combined SZB and SZC gaseous discharges was calculated to be 5.6 µSv/y, 4.7 µSv/y and 9.8 µSv/y respectively. The doses to the SZB worker were calculated to be 4.1 µSv/y as a result of SZC discharges and 5.9 µSv/y from combined SZB and SZC discharges. C-14 was also the main contributor to total dose to CRPs exposed to gaseous discharges from Sizewell and from SZB and SZC combined. The C-14 dose was mainly as a result of consumption of terrestrial foodstuffs. There were minor contributions to the total dose from I-131, H-3 and Ar-41.

3 ANNUAL DOSE TO THE CANDIDATES FOR THE REPRESENTATIVE PERSON FROM DIRECT RADIATION

3.1 Assessment Methodology

117. The exposure of members of the public from direct radiation emanating from the SZC reactor buildings will be negligible due to the shielding incorporated into the design of the reactor buildings (for instance as demonstrated by SZB). Direct radiation from SZC is therefore largely attributable to the HHK and HHI on site. Dose from skyshine as a result of radiation escaping from the roofs of the storage facilities and being reflected by the atmosphere has also been considered.

118. Direct radiation doses from licensed nuclear sites across the UK are measured and reported in the annual RIFE Reports compiled by CEFAS on behalf of UK regulators (e.g. RIFE 23) [Ref 25]. The annual direct radiation dose to a local adult inhabitant close (<0.25 km) to the proposed SZC is reported to be <20 µSv/y [Ref 25]. This value is attributed to SZB (the contribution from SZA for 2013 is stated as at background rates). This <20 µSv/y value appears to be generic and is reported for a number of other reactor sites. The Environment Agency 2006 [Ref 45] periodic radiological review of reactor operations at Sizewell reports a direct radiation annual dose of 10 µSv/y. This specific value has been used here in preference to the generic less than value given in RIFE 23.

119. The design of the SZC spent fuel and radioactive waste stores is yet to be finalised and specific details regarding shielding and spent fuel and radioactive waste inventories are not yet available. Thus, the source term used to assess the potential exposure of members of the public to direct radiation from SZC infrastructure has been based on the consideration that the outside of any building is an undesignated area and is therefore subject to the annual dose limit of 1,000 µSv/y for non-radiation workers under IRR99, consistent with the approach used for the HPC RIA [Ref 26].

120. A dose rate of 0.5 µSv/h on the external surface of the building is taken as the source term for the purpose of assessing the annual dose from exposure to direct radiation. This value is derived from the pessimistic assumption that exposure at the annual limit (1,000 µSv/y) occurs during a normal working year of 2,000 hours [Ref 26]. For simplicity, this dose rate is assumed to be at a distance of 1 m from the outer wall of the HHK and HHI. In practice, the principle of As Low As Reasonably Practicable must be demonstrated in accordance with regulatory requirements and the dose rate is likely to be much below the annual limits.

121. The relationship between the source dose rate and the direct dose rate at a receptor point depends on the proximity of the receptor to the source. When the receptor is in close proximity to the source, dose rate at the receptor point is estimated by scaling the source term using a 1/r relationship (where r = distance from the outer wall of the HHK and HHI). This is applicable for receptors within a distance equivalent to around three times the width of the building and has been pessimistically used for a person walking along the site perimeter and a SZB worker. This relationship becomes a $1/r^2$ (inverse-square law) for receptors located at farther distances; i.e. anyone located greater than 606 m away from the HHK or 411 m away from the HHI [Ref 26].

122. A simple model developed to calculated skyshine from a waste store [Ref 47] based on National Council on Radiation Protection and Measurements (NCRP) report 151 [Ref 48] has been adapted to provide a simple estimate of skyshine from the SZC stores. The model adopted from reference [Ref 47] is based on the situation shown in Figure 3-1. The dose rate at point d_s from the centre of the store according to this model is given by Equation 1. However, in this case, a store full of containers is taken to be the source, which changes some of the parameters compared to those used in [Ref 47], as discussed below.

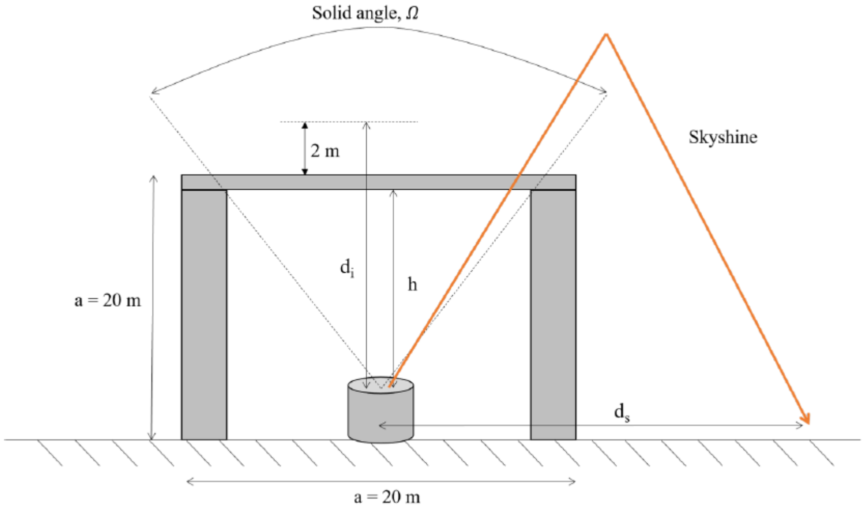

Figure 3-1 Schematic of the original model reproduced from [Ref 47]

Equation 1

$$D_s = \frac{2.5\text{x}10^{-2} D_0 B_{xs} \Omega^{1.3}}{(d_i d_s)^2}$$

123. Where:

D_s is the dose at point d_s (µSv/h). This is equal to the distance from the store to the CRP, denoted by r.

D_0 is the absorbed dose rate (µGy/h) 1 m above the source (and therefore the store roof). In this case, this is equivalent to the effective dose rate (µSv/h), as the effective dose rate is derived from the limit on whole body radiation, and skyshine is gamma radiation, so tissue and radiation weighting factors are both 1.

B_{xs} is a shielding factor for the roof, but is set to 1 here as the store is taken to be the source so there is no roof above the 'source', this is a conservative assumption.

Ω is a restricting aperture and was based on a square aperture in reference [Ref 47]. However, in this case, the whole store is treated as the radiation source, with a known dose rate 1 m above the source. As such, there is no aperture restricting the radiation beam, so Ω is equal to 2π. This is a conservative approach.

d_i is the distance from the source to 2 m above the roof, so in this case is 2 m.

124. This is a simple model, and it was demonstrated in reference [Ref 47] that doses calculated using Monte Carlo N-Particle (MCNP) software, MCNPX, are larger by up to two orders of magnitude. A sensitivity analysis was carried out to determine whether, if doses are increased by two orders of magnitude, the doses from skyshine are more significant than the direct doses.

3.2 CRPs and Exposure Pathways

125. Three individuals whom, on account of their habits, are considered to be the most exposed members of the public to direct radiation were identified from reviews of the 2010 CEFAS survey [Ref 38][17] and geographical information published in the MAGIC interactive mapping tool hosted by the Department for Environment, Food and Rural Affairs (DEFRA) [Ref 49]. These CRPs are a local resident living close to the site, a dog walker using a nearby footpath and a worker at the neighbouring SZB station who spends a large proportion (50%) of their working hours outdoors.

a) Dog Walker

126. The current site plan for SZC [1] indicates an option for a public footpath around the north of the site which joins the coastal path to the east of the site. It is assumed that the dog walker uses the proposed public footpath and coastal path once per day. This corresponds to a distance of approximately 2.9 km. The average pace of the dog walker is assumed to be 5 km/h. The distance of the path from the SZC site varies, so dose rates were calculated at a number of points along the path in order to calculate dose to the dog walker as they walk the full length.

127. The current site plan for SZC [1] indicates that the HHK and HHI are situated close to the western boundary. The HHK is completely shielded from the coastal area by intervening buildings and infrastructure so the direct dose to a dog walker from the HHK along the coastal section of the footpath (and other persons using the beach) is therefore considered to be insignificant. There are fewer buildings between the HHI and the coastal path, so this section of path was cautiously included in the dose assessment from the HHI. It is cautiously assumed that skyshine is not reduced by surrounding buildings for either facility.

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[17] Individuals with the same habits were also identified in the 2015 CEFAS survey [Ref 10].

128. The annual dose to a dog walker from exposure to direct radiation emanating from the SZC HHK and HHI is calculated using the following relationship:

Equation 2

$$\text{Annual Dose} = \sum_n \frac{365.25\, D\, l_n}{j_n v}$$

129. Where:

j_n (m): If the distance from the store to the CRP (rn, a variable distance) is less than three times the width of the store, j_n = rn. If r is more than three times the width of the store, $j_n = rn^2$.

D = dose rate at 1 m from external surface of building (0.5 µSv/h)

v = walking speed (5 km/h)

l_n = length of path walked at distance rn from the waste store (km)

130. The dose to the dog walker from skyshine is calculated using the following relationship:

Equation 3

$$\text{Annual Dose} = \sum_n \frac{365.25\, D_{s,n}\, l_n}{v}$$

131. Where:

$D_{s,n}$ is the dose rate from skyshine calculated using Equation 1 at point n

v = walking speed (5 km/h)

l_n = length of path walked at distance rn from the waste store (km)

b) Local Resident

132. The dose to a local resident is calculated on the assumption that the local resident occupies a dwelling situated approximately 900 m from the HHK and 1100 m from the HHI in the direct line of sight of the facilities. This CRP is assumed to occupy the dwelling for 8,620 h/y. Adults are assumed to spend 75% of their time indoors, children 80% of their time indoors and infants 90% of their time indoors, consistent with the individual dose assessment, see Table 2-20.

133. The cumulative annual dose to the local resident from exposure to direct radiation emanating from the SZC HHK and HHI, for combined indoor and outdoor occupancy is calculated using the following relationship:

Equation 4

$$\text{Annual Dose} = \frac{D(LF_i O_i + LF_o O_o)}{r^2}$$

Where:

r = distance from the waste store to dwelling (900 m for the HHK, 1107 m for the HHI)

D = dose rate at 1 m from external surface of building (0.5 µSv/h)

LF_i = indoor location factor (0.1)

LF_o = outdoor location factor (1)

O_i = indoor occupancy rate (e.g. for adult 8,620 h/y x 0.75 = 6,465 h/y)

O_o = outdoor occupancy rate (e.g. for adult 8,620 h/y x 0.25 = 2,155 h/y)

134. The cumulative annual dose to the resident family from skyshine is calculated using the following relationship:

Equation 5

$$\text{Annual Dose} = D_s(LF_i O_i + LF_o O_o)$$

135. here all parameters are as defined in Equation 4 and D_s is the skyshine dose rate at the residence location calculated using Equation 1.

c) Sizewell B Worker

136. The dose to the SZB worker is calculated using a similar approach as described for the local resident, but using the relationship given in Equation 6. The SZB worker is assumed to occupy a location on the SZB station situated approximately 150 m from the HHK and 477 m from the HHI at SZC for 2,000 h/y. It is assumed that 50% of this time is spent outdoors. For the time not at work it is assumed they reside at a location unaffected by external dose and therefore the calculated dose does not include the contribution the SZB worker may receive from their own premises.

137. The cumulative annual dose to the SZB worker from exposure to direct radiation emanating from the SZC HHK or HHI, for combined indoor and outdoor occupancy is calculated using the following relationship:

Equation 6

$$\text{Annual Dose} = \frac{D(LF_i O_i + LF_o O_o)}{j}$$

138. Where:

j: The SZB worker is taken to be 150 m from the HHK, which is less than three times the width of the store, so j = 150 m in this case. The worker is taken to be 477 m from the HHI, which is more than three times the width of the store, so j = (477 m)^2 in this case.

D = dose rate at 1 m from external surface of building (0.5 µSv/h)

LF_i = indoor location factor (0.1)

LF_o = outdoor location factor (1)

O_i = indoor occupancy rate (2,000 h/y x 0.5 = 1,000 h/y)

O_o = outdoor occupancy rate (2,000 h/y x 0.5 = 1,000 h/y)

139. The cumulative annual dose to the SZB worker from exposure to skyshine emanating from the SZC HHK and HHI, for combined indoor and outdoor occupancy is calculated using the relationship shown in Equation 5, where all parameters are as defined in Equation 6 and Ds is the skyshine dose rate at the worker's location calculated using Equation 1.

140. For all CRPs, dose from each store is calculated separately using the appropriate equation above. The total dose to each CRP can be calculated by summing the dose from each store.

3.3 Results and Discussion

a) Direct dose

141. The annual dose to a dog walker from exposure to direct radiation from SZC, using the assumptions described in the preceding sections, is calculated to be 0.020 µSv/y from the HHI and 0.0021 µSv/y from the HHK. The dose from the HHI is higher as there is a section of the path to the north and west of the site, and the HHI is at the north-west corner of the proposed SZC site [Ref 1].

142. The annual dose to the local resident from exposure to direct radiation from SZC is calculated to be 0.0011 µSv/y from the HHI and 0.0017 µSv/y from the HHK. If a 50% outdoor occupancy is assumed, the dose to this CRP becomes 0.0019 µSv/y and 0.0029 µSv/y respectively. The doses to a child and an infant living at the same location, assuming NRPB-W41 indoor occupancy factors of 0.8 and 0.9 [Ref 35], is calculated to be 0.00099 µSv/y and 0.00067 µSv/y respectively from the HHI and 0.0015 µSv/y and 0.0010 µSv/y respectively for the HHK.

143. The annual dose to the SZB worker from exposure to direct radiation from SZC, assuming 2000 h/y at the SZB station and 50% outdoor occupancy is calculated to be 0.0024 µSv/y from the HHI and 3.7 µSv/y from the HHK. The dose from the HHK is much higher than from the HHI as the HHK is next to the boundary between the SZB and C sites, whereas the HHI is on the opposite side of the SZC site. As noted in Section 3.1, the observed direct radiation dose to a member of the public who resides near to SZB is 10 µSv/y and this is likely to be similar for a SZB worker.

b) Skyshine dose

144. For all CRPs considered, the dose from skyshine was at least one order of magnitude smaller than the direct dose. Table 3-1 presents the direct doses and the skyshine doses, along with the total dose from both pathways.

Table 3-1 Combined doses from direct radiation and skyshine

		CRP				
		Dog Walker (adult)	**Sizewell B worker (adult)**	**Adult local resident**	**Child local resident**	**Infant local resident**
Dose from HHI (µSv/y)	Direct dose	2.0E-02	2.4E-03	1.1E-03	9.9E-04	6.7E-04
	Skyshine dose	1.7E-05	1.6E-04	7.8E-05	6.7E-05	4.6E-05
	Total dose	**2.0E-02**	**2.6E-03**	**1.2E-03**	**1.1E-03**	**7.1E-04**
Dose from HHK (µSv/y)	Direct dose	2.1E-03	3.7E+00	1.7E-03	1.5E-03	1.0E-03
	Skyshine dose	1.5E-05	1.7E-03	1.2E-04	1.0E-04	6.9E-05
	Total dose	**2.1E-03**	**3.7E+00**	**1.8E-03**	**1.6E-03**	**1.1E-03**

145. Jones et al [Ref 47] compared doses calculated via the approach used here with skyshine doses calculated using MCNP simulation, and found that the MCNP simulations gave doses that were approximately two orders of magnitude larger. As such, the estimate of skyshine doses in this assessment may be underestimated by up to two orders of magnitude. Table 3-2 presents the skyshine doses increased by two orders of magnitude and total dose when combined with direct radiation doses. If the calculated skyshine doses are increased by two orders of magnitude, the skyshine doses become comparable to or larger than the direct doses.

Table 3-2 Combined doses from direct radiation and skyshine when skyshine is increased by two orders of magnitude

		CRP				
		Dog Walker (adult)	**Sizewell B worker (adult)**	**Adult local resident**	**Child local resident**	**Infant local resident**
Dose from HHI (µSv/y)	Direct dose	2.0E-02	2.4E-03	1.1E-03	9.9E-04	6.7E-04
	Skyshine dose	1.7E-03	1.6E-02	7.8E-03	6.7E-03	4.6E-03
	Total dose	**2.2E-02**	**1.9E-02**	**8.9E-03**	**7.7E-03**	**5.2E-03**
Dose from HHK (µSv/y)	Direct dose	2.1E-03	3.7E+00	1.7E-03	1.5E-03	1.0E-03
	Skyshine dose	1.5E-03	1.7E-01	1.2E-02	1.0E-02	6.9E-03
	Total dose	**3.6E-03**	**3.8E+00**	**1.4E-02**	**1.2E-02**	**7.9E-03**

146. When the skyshine dose is increased by two orders of magnitude, the direct dose remains dominant in the case of the dog walker CRP for both stores. The direct dose from the HHK is also larger than the increased skyshine dose for the SZB worker, whereas the increased skyshine dose dominates from the HHI. For all local resident CRPs, the increased skyshine dose is larger than the direct dose from both stores but by less than one order of magnitude.

147. The calculated doses to the CRPs for exposure to direct radiation and skyshine emanating from SZC are generally very small when compared to the reported direct radiation dose of around 10 µSv/y for the Sizewell area (e.g. from SZB). Even when the skyshine dose is increased by two orders of magnitude, the largest dose, to the SZB worker from the neighbouring HHK, is just over one third of the reported direct dose from the current Sizewell site [Ref 45]. All other doses are more than two orders of magnitude smaller than this.

4 ANNUAL DOSE TO THE REPRESENTATIVE PERSON

4.1 Assessment Methodology

148. The representative person refers to the individual receiving a dose that is representative of the more highly exposed individuals in the population [Ref 4]. The dose to the representative person is calculated by aggregating the doses

from all of the relevant exposure pathways associated with both aqueous and gaseous discharge, as well as the exposure due to direct radiation from SZC. This dose is subject to the source dose constraint of 300 µSv/y. The dose to the representative person due to the combined discharges of aqueous and gaseous effluent (but excluding direct radiation) from SZB and SZC can be compared to the site dose constraint of 500 µSv/y.

149. In order to determine the dose to the representative person, two scenarios are considered (no further assessment of dose to a SZB worker was undertaken as this was assumed to be the same as for a resident local to the site):

- The CRP for aqueous discharges (the fishing family) also consuming locally sourced terrestrial foods at mean rates, living in close proximity to the site and walking along a public footpath close to the site daily.
- The CRP for gaseous discharges (the farming family) also consuming locally sourced seafood at mean rates, walking along a public footpath close to the site daily and spending recreational time on a local beach.

150. The annual dose to the CRPs exposed to both aqueous and gaseous discharges have been calculated using all six modules (DORIS, PLUME, FARMLAND, GRANIS, RESUS and ASSESSOR) of PC-CREAM 08. Details of the source term and dispersion parameters used are described in Section 2.1. The assessment was carried out for unit discharge rates and the results scaled to the proposed annual discharge limits shown in Table 2-1 and Table 2-2 using an Excel spreadsheet which was carefully verified to ensure that it was free from errors.

4.2 Candidates for the Representative Person and Exposure Pathways

a) Fishing Family Exposed to both Aqueous and Gaseous Discharges

151. These CRPs comprise the adult, child and infant members of a fishing family with the same habits as described in Section 2.3. In addition, members of this family are assumed to live in close proximity to SZB and SZC at a residence analogous to that of the farming family, and to ingest terrestrial food at mean rates. Doses from direct radiation (including skyshine) when walking along the footpath near the site are added in section 4.4.

152. These CRPs are considered to be exposed via the following pathways:

- Marine pathways
  - Internal exposure from the ingestion of locally caught seafood (fish, crustaceans, molluscs and sea plants) incorporating radionuclides discharged into the marine environment.
  - Internal exposure from inhalation of radionuclides entrained in sea spray (including skin absorption of tritium).
  - External irradiation from beta/ gamma radionuclides incorporated into beach sediment.
  - External irradiation from handling fishing equipment contaminated with radionuclides.
- Terrestrial pathways
  - Internal exposure from inhalation of radionuclides in the gaseous plume (including skin absorption of tritium) and from resuspension of ground deposited radionuclides from discharges to atmosphere.
  - Internal exposure from the ingestion of radionuclides incorporated into locally produced terrestrial foods following deposition from the atmosphere.
  - External irradiation from exposure to beta/ gamma radionuclides in the gaseous plume and from material deposited on the ground.

153. The exposure from deposition of gaseous radionuclides along the sea washed beach has not been considered as these will be dispersed in the marine environment and their contribution will be negligible compared to direct discharges to the marine environment. Dose from the plume itself (via inhalation and external radiation) whilst on the beach has been considered.

b) Farming Family Exposed to both Aqueous and Gaseous Discharges

154. These CRPs comprise the adult, child and infant members of a farming family with similar habits to the farming family described in Section 2.4, but assuming that time is spent on the local beach and that they ingest seafood at mean rates. The exposure pathways are the same as for the fishing family exposed to both aqueous and gaseous discharges. Direct radiation dose (including skyshine) when walking along the local footpath is added in Section 4.4.

155. Sea to land transfer of radioactivity was independently assessed for the HPC site on behalf of the Environment Agency [Ref 50]. This showed that the dose from inhalation of sea spray was at least an order of magnitude lower than any other pathway and in most instances was several orders of magnitude lower. This has been assessed for SZC and is presented in Appendix A.4. Other mechanisms of sea spray driven transfer to land, such as ground deposition and uptake into foodstuffs will produce a lower dose and hence have not been considered further.

4.3 Habits Data

a) Food Intake

156. Table 4-1 and Table 4-2 below present the food ingestion rates of the fishing family and the farming family exposed to both aqueous and gaseous discharges from SZC.

Table 4-1 Food Intake Data for Fishing Family Exposed to both Aqueous and Gaseous Discharges

Parameter	Adult	Child	Infant
Marine Pathways	***Refer to Table 2-10***		
Terrestrial Pathways			
Fraction of food produced locally	1	1	1
Cow milk (mean ingestion rates) (kg/y)	95	110	130
Green vegetables (mean ingestion rates) (kg/y)	88.3	16.3	11.8
Cow meat (mean ingestion rates) (kg/y)	19.2	12.8	4.3
Sheep meat (mean ingestion rates) (kg/y)	7.2	2.9	0.86
Root vegetables (mean ingestion rates) (kg/y)	128.4	30.2	12.8
Fruit (mean ingestion rates) (kg/y)	36.9	12.5	3.1

157. Ingestion rates for milk are mean values taken from RIFE 23 [Ref 25], as no consumption of milk was identified in the 2015 CEFAS survey for any age group. The food ingestion data for green vegetables in Table 4-1 is a sum of the ingestion rates for ‘green vegetables’ and ‘other vegetables’ taken from the 2015 CEFAS survey; similarly, the ingestion data for root vegetables is a sum of rates for ‘root vegetables’ and ‘potatoes’ taken from the 2015 CEFAS survey [Ref 10]. Child and infant ingestion rates for cow milk and cow meat, and the infant ingestion rates for sheep meat were not provided in the 2015 CEFAS survey. These data have been extrapolated from adult ingestion rates using CEFAS scaling factors. All ingestion rates taken from CEFAS 2015 for terrestrial pathways are the mean values for the high-rate group.

Table 4-2 Food Intake Data for Farming Family Exposed to both Aqueous and Gaseous Discharges

Parameter	Adult	Child	Infant
Terrestrial Pathways	***Refer to Table 2-19***		
Marine Pathways			
Fraction of seafood caught in the local compartment	1	1	1
Fraction of seafood caught in the regional compartment	0	0	0
Fish ingestion rates (kg/y) (mean ingestion rates)	23.46	14	7.4
Crustaceans ingestion rates (kg/y) (mean ingestion rates)	10.4	1.4	0.52
Molluscs ingestion rates (kg/y) (mean ingestion rates)	3.2	0.8	0.16
Sea plants ingestion rates (kg/y) (mean ingestion rates)	0.6	0.0	0.0

158. No consumption of sea plants by children or infants was recorded in the 2015 CEFAS survey [Ref 10] and there is no conversion factor provided to convert the adult consumption rate. There is also no consumption rate provided in RIFE, so the ingestion rates were set to zero. No consumption of mollusc or crustaceans was recorded for infants, so the adult values were scaled to derive a rate for infants using the factors provided in the CEFAS 2015 report. All ingestion rates taken from CEFAS 2015 for marine pathways are the mean values for the high-rate group.

b) Occupancy Habits

159. Table 4-3 and Table 4-4 below present the occupancy habits of the fishing family and farming family used to assess the exposure to aqueous and gaseous discharges from SZC.

Table 4-3 Occupancy Data for Fishing Family Exposed to Aqueous and Gaseous Discharges

Parameter	Adult	Child	Infant
Marine Pathways	***Refer to Table 2-12***		
Terrestrial Pathways			
Time at home (h/y)	5660	8289	8526
Fraction of time spent indoors	0.75	0.8	0.9
Cloud gamma location factor	0.2	0.2	0.2
Deposited gamma location factor	0.1	0.1	0.1
Cloud beta location factor	1.0	1.0	1.0
Deposited beta location factor	1.0	1.0	1.0
Inhalation location factor	1.0	1.0	1.0
Inhalation rates at home (m^3/h)	0.9	0.63	0.21

160. The time at location is derived by subtracting the values for occupancy on the beach (Table 2-12) from the maximum occupancy rates for direct radiation (8,620 h/y) taken from the 2015 CEFAS survey [Ref 10]. The fraction of time spent indoors for an adult is based on the maximum occupancy rate for direct radiation taken from the 2015 CEFAS survey. The fraction of time spent indoors for child and infant are taken from NRPB-W41 [Ref 35]. Gamma and beta location factors are based on default PC-CREAM 08 values. Inhalation rates are based on the generalised values in NRPB-W41.

Table 4-4 Occupancy Data for Farming Family Exposed to Aqueous and Gaseous Discharges

Parameter	Adult	Child	Infant
Terrestrial Pathways			
Time spent at home (h/y)	7919	8453	8620
Fraction of time spent indoors	0.75	0.8	0.9
Inhalation rates at home	1.07	0.63	0.21
Marine Pathways			
Occupancy on beach (h/y) (97.5th percentile rates) for recreational activities	847	313	76
Time spent near the sea (h/y) for sea spray inhalation and external exposure	847	313	76
Handling of fishing equipment (h/y)	0	0	0
Fraction of time spent in local compartment	1	1	1
Fraction of time spent in regional compartment	0	0	0
Inhalation rates on the beach (m^3/h)	1.5	1.12	0.35

161. Beach occupancies are taken from the 2015 CEFAS survey [Ref 10]. As the sum of the beach occupancy and the time spent at home for the adult and for the child are greater than one year, the time spent at home was calculated by subtracting the time on the beach from the number of hours in a year. Inhalation rates for adult, child and infant are based on generalised inhalation taken from NRPB-W41 [Ref 35].

162. The inhalation rates for sea spray assume that the family does the equivalent of light work whilst they are on the beach.

163. For both families, it is assumed that the family walks along the coastal path once per day, as described in Section 3.2.

4.4 Results and Discussion

a) Annual Dose from Exposure to Fishing Family Exposed to both Aqueous and Gaseous Discharges

164. The annual dose to the adult, child and infant members of the fishing family exposed to both aqueous and gaseous discharges from SZC, summed across the relevant marine and terrestrial pathways are calculated to be 13 µSv/y, 7.0 µSv/y and 4.6 µSv/y respectively. Table 4-5 below presents a summary of the assessed doses to the fishing family from all relevant pathways (excluding direct radiation, as this is not a result of discharges).

Table 4-5 Annual Dose (µSv/y) to Fishing Family from Exposure to both Aqueous and Gaseous Discharges from SZC

	Marine Pathways	Terrestrial Pathways	Total
Adult	10	3.1	**13**
Child	4.9	2.1	**7.0**
Infant	1.3	3.3	**4.6**

165. The dominant pathway for adult and child is the ingestion of fish, which accounts for 51% and 61% respectively of the assessed dose to these age groups from all pathways. The dominant pathway for infant is the consumption of milk, accounting for 53% of the dose from all pathways.

166. C-14 is the dominant radionuclide, contributing between 92% and 96% of the assessed dose from all pathways. Other important radionuclides are Co-60, which contributes 4.3% of the dose to adult (largely from beach occupancy), and I-131 and H-3 which contribute 3.8% and 3.1% of the dose to infant (largely from milk ingestion).

167. The corresponding annual doses from the combined aqueous and gaseous discharges from SZB and SZC are calculated as 17 µSv/y, 8.3 µSv/y and 6.1 µSv/y for adult, child and infant members of the fishing family exposed to aqueous and gaseous radionuclides. Table 4-6 below provides a summary of the assessed dose, aggregated by pathways.

Table 4-6 Annual Dose (µSv/y) to Fishing Family from Exposure to both Aqueous and Gaseous Discharges from Sizewell B and C

	Marine Pathways	Terrestrial Pathways	Total
Adult	12	5.0	**17**
Child	5.3	3.0	**8.3**
Infant	1.4	4.7	**6.1**

168. Again, the dominant pathway for adult and child is the ingestion of fish accounting for 45% and 54% respectively of the assessed dose, whilst the ingestion of milk accounts for 57% of the dose to infant. C-14 accounts for 79%, 89% and 86% of the dose to adult, child and infant respectively. Other important radionuclides include Cs-134 (used as a surrogate for ‘other radionuclides’ in the permitted aqueous discharges from SZB) which contributes 9.3% and 3.9% of the dose to adult and child, and I-131 and H-3 which accounts for 6.5% and 3.5% respectively of the dose to infant.

b) Annual Dose from Exposure to Farming Family Exposed to both Aqueous and Gaseous Discharges

169. The annual dose to the adult, child and infant members of the farming family exposed to both aqueous and gaseous discharges from SZC, summed across the relevant terrestrial and marine pathways, is calculated to be 11 µSv/y, 7.3 µSv/y and 11 µSv/y respectively. Table 4-7 below presents a summary of the assessed doses to the fishing family from all relevant pathways (excluding direct radiation, as this is not a result of discharges).

Table 4-7 Annual Dose (µSv/y) to Farming Family from Exposure to both Aqueous and Gaseous Discharges from Sizewell C

	Terrestrial Pathways	Marine Pathways	Total
Adult	4.1	6.7	**11**
Child	3.3	4.0	**7.3**
Infant	6.9	3.9	**11**

170. The dominant pathway for adult and child is the ingestion of fish, which accounts for 38% and 46% respectively of the assessed dose to these age groups from all pathways. The dominant pathway for infant is the consumption of milk, accounting for 56% of the dose from all pathways.

171. C-14 is the dominant radionuclide, contributing between 93% and 95% of the assessed dose from all pathways. Other important radionuclides include H-3, which contributes 1.6%, 2.0% and 2.9% of the dose to adult, child and infant respectively, and I-131 which contributes 3.9% of the dose to infant (largely from milk ingestion).

172. The corresponding annual dose from the combined aqueous and gaseous discharges from SZB and SZC is calculated as 13 µSv/y, 9.1 µSv/y and 14 µSv/y for adult, child and infant members of the farming family exposed to aqueous and gaseous radionuclides. Table 4-8 below provides a summary of the assessed dose, aggregated by pathways.

Table 4-8 Annual Dose (µSv/y) to Farming Family from Exposure to both Aqueous and Gaseous Discharges from Sizewell B and C

	Terrestrial Pathways	Marine Pathways	Total
Adult	5.9	7.6	**13**
Child	4.8	4.3	**9.1**
Infant	9.9	4.1	**14**

173. Again, the dominant pathway for adult and child is the ingestion of fish accounting for 34% and 40% respectively of the assessed dose, whilst the ingestion of milk accounts for 61% of the dose to infant. Ingestion of milk also contributes significantly to the child dose, accounting for 34% of the total dose. C-14 accounts for 87%, 88% and 88% of the dose to adult child and infant, respectively. Other important radionuclides include Cs-134 (used as a surrogate for 'other radionuclides' in the permitted aqueous discharges from SZB) contribute 5.4% and 3% of the dose to adult and child, and I-131 and H-3 which accounts for 6.7% and 3.4% respectively of the dose to infant.

c) Annual Dose to the Representative Person

Dose assessed against the Source Constraint

174. All reasonably foreseeable and relevant future exposure pathways should be included in the assessment of doses for comparison with the source constraint (i.e. doses arising from the future discharges of radioactive waste from SZC and future direct radiation exposure from SZC). Doses arising from exposure to radionuclides in the environment from historical discharges are not included in the comparison with the source constraint [Ref 4].

175. The highest dose from exposure to aqueous and gaseous discharges and from exposure to direct radiation from SZC is 13 µSv/y to an adult member of the fisherman family. This assumes they are also a local resident and dog walker for the purpose of direct radiation calculations, and doses from both stores are included. This individual is therefore considered to be the representative person. This dose is significantly less than both the current source dose constraint of 300 µSv/y, and the dose constraint of 150 µSv/y proposed in 2009 by PHE for new nuclear facilities[18] [Ref 14]. Results are summarised in Table 4-9.

Table 4-9 Annual Dose Summary (µSv/y) to the Representative Person (Adult Member of Fishing Family) from Sizewell C against the Source Constraint

	Historical exposures	Future exposures			Total	% of relevant constraint/limit
		Terrestrial Pathways	Marine Pathways	Direct Radiation		
Dose (source constraint)	n/a	10	3.1	0.025	**13**	4.4%

Dose assessed against the Site Constraint

176. The doses arising from future discharges of radioactive waste from the Sizewell site, i.e. inclusive of discharges from SZB and C (but not direct radiation) should be assessed for comparison with the site constraint. Doses arising from exposure to radionuclides in the environment from historical discharges are not included in the comparison with the site constraint [Ref 4].

177. The dose to the representative person from the combined discharges of aqueous and gaseous effluents from SZB and C (excluding direct radiation pathways) is 17 µSv/y. This is significantly less than the site dose constraint of 500 µSv/y for facilities with a contiguous boundary. Results are summarised in Table 4-10.

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[18] This proposal is not a statutory requirement.

Table 4-10 Annual Dose Summary (µSv/y) to the Representative Person (Adult Member of Fishing Family) against the Site Constraint

	Historical exposures	Future exposures			Total	% of relevant constraint/limit
		Terrestrial Pathways	Marine Pathways	Direct Radiation		
Dose (site constraint)	n/a	12	5.0	n/a	**17**	3.4%

Dose assessed against the Public Dose Limit

178. Regulatory guidance [Ref 4] states that additional doses to the representative person from historical discharges from the source being considered and doses from historical and future discharges and direct radiation from other relevant sources subject to control should be assessed and the total dose compared with the dose limit of 1 mSv/y.

179. The total dose to the representative person has been calculated by aggregating exposures arising from historical discharges from SZA, SZB and other sources (including Chernobyl deposition and the long range contributions from Sellafield and other permitted discharges), future discharges from SZB and SZC and future direct radiation from SZB and SZC. The Principles Document [Ref 4] advises that the dose from historical discharges may be taken from the results of retrospective assessments such as those published in the annual RIFE reports. The RIFE reports contain the published results of retrospective dose assessments to the representative person for key nuclear licensed sites across the UK. The dose to the representative person for Sizewell, reported in the last four RIFE reports available at the time of writing (RIFE 20, 21, 22 and 23), ranged from <5 to 6 µSv/y for terrestrial pathways (excluding direct radiation), <5 to 10 µSv/y for marine pathways (resulting from houseboat occupancy or fish consumption) and was 20 µSv/y for direct radiation [Ref 51] [Ref23] [Ref24] [Ref25]. To ensure that the assessment is pessimistic, the highest values of 6 µSv/y for terrestrial pathways and 10 µSv/y for marine pathways have been taken as the component of the total dose to the representative person for SZC arising from historic discharges. The total dose from historical discharges via marine and terrestrial pathways is therefore taken to be 16 µSv/y. It is assumed that the total direct dose from SZB and SZC combined can be estimated as the current observed dose from the Sizewell site (20 µSv/y) [Ref 51] [Ref23] [Ref 24] [Ref 25], as this value is much larger than the calculated direct doses (including the skyshine component) from SZC, presented in Section 3.3.

180. The total dose to the representative person (adult member of a fishing family) includes 16 µSv/y for historical discharges via marine and terrestrial pathways; 17 µSv/y from the combined discharges of aqueous and gaseous effluents from SZB and C and 20 µSv/y for direct radiation from SZB and SZC. Results are summarised in Table 4-11.

Table 4-11 Summary of Annual Doses (µSv/y) to the Representative Person (Adult Member of Fishing Family)

	Historical discharges	Future exposures			Total	% of relevant constraint/limit
		Terrestrial Pathways	Marine Pathways	Direct Radiation		
Total Dose*	16	12	5.0	20	**53**	5.3%

*Total dose includes the contribution from exposure from historical discharges; the contribution from future aqueous and gaseous discharges from combined operations at Sizewell; and the direct radiation from future combined operations at Sizewell.

181. Table 4-12 and Table 4-13 below provide a breakdown of dose to the representative person by radionuclides and pathways. Dose from ingestion dominates for both gaseous and aqueous discharges. Dose from aqueous discharges dominates overall, contributing 76% of the dose from SZC discharges and 71% of the dose from SZB and SZC discharges.

Table 4-12 Dose (µSv/y) to the Representative Person from Exposure to both Aqueous and Gaseous Discharges from Sizewell C^

Radionuclide	Doses from Gaseous Discharges				Doses from Aqueous discharges				Total	% contribution
	Inhalation & resuspension	External	Ingestion	Total	Inhalation	External	Ingestion	Total		
Ar-41	0.0E+00	3.0E-02	0.0E+00	3.0E-02	N/A	N/A	N/A	N/A	3.0E-02	0.2%
C-14	3.3E-01	3.5E-06	2.5E+00	2.9E+00	6.0E-07	2.8E-03	9.5E+00	9.5E+00	1.2E+01	92.8%
Co-58	7.1E-06	1.2E-05	2.2E-06	2.1E-05	8.0E-09	6.4E-03	2.3E-03	8.7E-03	8.7E-03	0.1%
Co-60	5.2E-05	5.8E-04	1.6E-05	6.5E-04	8.4E-08	5.5E-01	1.8E-02	5.7E-01	5.7E-01	4.3%
Cs-134	2.7E-05	1.5E-04	6.8E-04	8.5E-04	1.1E-08	6.7E-03	6.5E-03	1.3E-02	1.4E-02	0.1%
Cs-137 (Ba-137m, gaseous only)*	1.7E-05	2.4E-04	4.8E-04	7.4E-04	1.4E-08	2.3E-02	8.0E-03	3.1E-02	3.2E-02	0.2%
H-3	6.6E-02	0.0E+00	7.5E-02	1.4E-01	2.1E-05	0.0E+00	1.8E-02	1.8E-02	1.6E-01	1.2%
I-131 (Xe-131m)*	3.2E-03	1.3E-04	2.4E-02	2.7E-02	5.3E-10	5.1E-08	1.0E-04	1.0E-04	2.7E-02	0.2%
I-133 (Xe-133m, Xe-133)*	1.2E-04	6.1E-06	6.4E-05	2.0E-04	N/A	N/A	N/A	N/A	2.0E-04	0.0%
Kr-85	0.0E+00	1.1E-03	0.0E+00	1.1E-03	N/A	N/A	N/A	N/A	1.1E-03	0.0%
Xe-131m	0.0E+00	3.1E-05	0.0E+00	3.1E-05	N/A	N/A	N/A	N/A	3.1E-05	0.0%
Xe-133	0.0E+00	2.4E-02	0.0E+00	2.4E-02	N/A	N/A	N/A	N/A	2.4E-02	0.2%
Xe-135 (Cs-135)*	3.2E-12	4.6E-02	1.0E-10	4.6E-02	N/A	N/A	N/A	N/A	4.6E-02	0.3%
Ag-110m	N/A	N/A	N/A	N/A	1.3E-08	1.8E-03	2.9E-02	3.1E-02	3.1E-02	0.2%
Cr-51	N/A	N/A	N/A	N/A	4.6E-12	1.8E-06	9.9E-07	2.8E-06	2.8E-06	0.0%
Mn-54	N/A	N/A	N/A	N/A	1.1E-09	3.3E-03	3.2E-04	3.6E-03	3.6E-03	0.0%
Ni-63	N/A	N/A	N/A	N/A	1.4E-09	0.0E+00	1.6E-04	1.6E-04	1.6E-04	0.0%
Sb-124	N/A	N/A	N/A	N/A	8.2E-09	2.3E-04	2.8E-03	3.0E-03	3.0E-03	0.0%
Sb-125 (Te-125m)*	N/A	N/A	N/A	N/A	1.3E-08	1.6E-03	3.3E-03	4.9E-03	4.9E-03	0.0%
Te-123m (Te-123)*	N/A	N/A	N/A	N/A	2.9E-09	2.1E-05	3.4E-03	3.4E-03	3.4E-03	0.0%
Total	4.0E-01	1.0E-01	2.6E+00	3.1E+00	2.2E-05	5.9E-01	9.6E+00	1.0E+01	1.3E+01	100.0%
% contribution from pathway	3.0%	0.8%	19.8%	23.6%	0.0%	4.5%	71.9%	76.4%	100.0%	

^ Total dose from direct radiation and skyshine is not included in this table. The total dose from these pathways was 0.025 µSv/y.

* Dose from progeny, stated in brackets, is included in the dose from the parent.

Table 4-13 Dose (µSv/y) to the Representative Person from Exposure to both Aqueous and Gaseous Discharges from Sizewell B and C

Radionuclide	Doses from Gaseous Discharges				Doses from Aqueous discharges				Total	% contribution
	Inhalation & resuspension	External	Ingestion	Total	Inhalation	External	Ingestion	Total		
Ar-41	0.0E+00	7.3E-01	0.0E+00	7.3E-01	N/A	N/A	N/A	N/A	7.3E-01	4.3%
C-14	4.5E-01	4.8E-06	3.4E+00	3.9E+00	6.0E-07	2.8E-03	9.5E+00	9.5E+00	1.3E+01	78.5%
Co-58	7.1E-06	1.2E-05	2.2E-06	2.1E-05	8.0E-09	6.4E-03	2.3E-03	8.7E-03	8.7E-03	0.1%
Co-60	4.6E-04	5.1E-03	1.4E-04	5.8E-03	8.4E-08	5.5E-01	1.8E-02	5.7E-01	5.7E-01	3.4%
Cs-134	2.7E-05	1.5E-04	6.8E-04	8.5E-04	1.3E-06	8.0E-01	7.8E-01	1.6E+00	1.6E+00	9.3%
Cs-137 (Ba-137m, gaseous only)*	1.7E-05	2.4E-04	4.8E-04	7.4E-04	1.6E-07	2.7E-01	9.2E-02	3.6E-01	3.6E-01	2.1%
H-3	9.9E-02	0.0E+00	1.1E-01	2.1E-01	3.0E-05	0.0E+00	2.5E-02	2.5E-02	2.4E-01	1.4%
I-131 (Xe-131m)*	7.2E-03	3.0E-04	5.3E-02	6.1E-02	5.3E-10	5.1E-08	1.0E-04	1.0E-04	6.1E-02	0.4%
I-133 (Xe-133m, Xe-133)*	1.2E-04	6.1E-06	6.4E-05	2.0E-04	N/A	N/A	N/A	N/A	2.0E-04	0.0%
Kr-85	0.0E+00	1.1E-03	0.0E+00	1.1E-03	N/A	N/A	N/A	N/A	1.1E-03	0.0%
Xe-131m	0.0E+00	3.1E-05	0.0E+00	3.1E-05	N/A	N/A	N/A	N/A	3.1E-05	0.0%
Xe-133	0.0E+00	2.4E-02	0.0E+00	2.4E-02	N/A	N/A	N/A	N/A	2.4E-02	0.1%
Xe-135 (Cs-135)*	3.2E-12	4.6E-02	1.0E-10	4.6E-02	N/A	N/A	N/A	N/A	4.6E-02	0.3%
Ag-110m	N/A	N/A	N/A	N/A	1.3E-08	1.8E-03	2.9E-02	3.1E-02	3.1E-02	0.2%
Cr-51	N/A	N/A	N/A	N/A	4.6E-12	1.8E-06	9.9E-07	2.8E-06	2.8E-06	0.0%
Mn-54	N/A	N/A	N/A	N/A	1.1E-09	3.3E-03	3.2E-04	3.6E-03	3.6E-03	0.0%
Ni-63	N/A	N/A	N/A	N/A	1.4E-09	0.0E+00	1.6E-04	1.6E-04	1.6E-04	0.0%
Sb-124	N/A	N/A	N/A	N/A	8.2E-09	2.3E-04	2.8E-03	3.0E-03	3.0E-03	0.0%
Sb-125 (Te-125m)*	N/A	N/A	N/A	N/A	1.3E-08	1.6E-03	3.3E-03	4.9E-03	4.9E-03	0.0%
Te-123m (Te-123)*	N/A	N/A	N/A	N/A	2.9E-09	2.1E-05	3.4E-03	3.4E-03	3.4E-03	0.0%
Total	5.6E-01	8.0E-01	3.6E+00	5.0E+00	3.2E-05	1.6E+00	1.0E+01	1.2E+01	1.7E+01	100.0%
% contribution from pathway	3.3%	4.7%	21.2%	29.2%	0.0%	9.6%	61.3%	70.8%	100.0%	

5 SHORT-TERM DOSE ASSESSMENT

5.1 Assessment Methodology

182. This section calculates the dose from short-term gaseous releases under a maximum anticipated short-term discharge scenario.

183. Short-term doses are required to be assessed explicitly, in addition to the doses from continuous releases, as part of the radiological assessments submitted in support of applications for environmental permits for nuclear facilities. This is because short-term discharges may involve the release of elevated levels of radionuclides over short periods of time[19] and the discharged radionuclides may not reach equilibrium in the environment. The PC-CREAM 08 suite of models were developed for assessing the impact of routine, continuous radioactive discharges over a minimum period of one year and are not appropriate for assessing the impacts of short-term discharges [Ref 29]. Thus, an approach based on NDAWG Guidance Note 6 [Ref 52] and NRPB-W54 [Ref 53] has been adopted to assess doses from short-term discharges from SZC. This approach broadly follows the methodology used for the HPC assessment [Ref 26], but uses pessimistic NDAWG food concentration factors (CF) [Ref 54] rather than dynamic chain modelling. This is consistent with the approach used by the Environment Agency in their determination of the HPC application [Ref 26].

184. Only short-term doses arising from gaseous discharges to the atmosphere were assessed. Aqueous discharges to sea are normally considered as part of continuous discharge assessments on account of the practice of accumulating operational aqueous effluents in tanks for short periods of time prior to discharge, resulting in a semi-continuous discharge pattern [Ref 4]. Furthermore, NDAWG considers that given the low and predictable variability in the frequency of tidal currents, which drive dispersion in coastal environments, and on account of the high mobility of fish (the dominant pathway for exposure to aqueous discharges to the marine environment), the assessment of dose from short-term aqueous discharges to coastal or estuarine environments is unlikely to be needed [Ref 52].

185. The assessment of doses arising from uncontrolled short-term releases as a result of incidents or accidents is beyond the scope of this report and permitting regulations; it falls under the regulatory remit of the ONR.

186. Environmental conditions (e.g. wind direction) are not likely to be the same during every short-term release and a scenario comprising multiple short-term releases is not envisaged. Similarly, the averaging assumptions used for assessing the annual dose due to routine, continuous discharges (integration over 60 years) will cover multiple short-term releases that occur beyond one-year [Ref 4].

187. The sections below describe the methodologies applied and present the results of the short-term dose assessment undertaken for SZC.

a) Source Term

188. Table 5-1 below presents the proposed short-term discharge rates for SZC. These data represent maximum anticipated short-term discharge values. They are derived assuming that 1/12th of the proposed yearly discharge limit is released within a 24-hour period. The values are expressed as 24 hr total release and associated emission rate. This approach is considered to bound contingencies such as start-up and shut downs. It is assumed that short term discharges would not occur at the same time for both EPR^{TM} units.

189. The releases are assumed to be made over a period of 24-hours from a 70 m high stack [Ref 20]. The wake-effects of nearby buildings were accounted for in the atmospheric dispersion model as described in the following sections.

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[19] Short-term releases are defined as where 2% or more of a predicted 12-monthly discharges occurs over a relatively short period (typically ≤1 day).

Table 5-1 Predicted Short-Term Discharges

Radionuclide	Total Release in 24h (Bq)	Emission Rate over 24 hours (Bq/s)
Ar-41	1.09E+11	1.26E+06
C-14	1.17E+11	1.35E+06
Co-58	9.08E+05	1.05E+01
Co-60	1.07E+06	1.23E+01
Cs-134	8.32E+05	9.63E+00
Cs-137	7.46E+05	8.63E+00
H-3	5.00E+11	5.79E+06
I-131	3.33E+07	3.86E+02
I-133	6.45E+06	7.47E+01
Kr-85	5.22E+11	6.04E+06
Xe-131m	1.13E+10	1.30E+05
Xe-133	2.37E+12	2.74E+07
Xe-135	7.43E+11	8.60E+06

b) Dispersion Modelling

190. The atmospheric dispersion code (ADMS, version 5) [Ref 55] was used to predict air concentrations and deposition rates at local habitations for a 24-hour short-term gaseous discharge from SZC, using site-specific Met data. The NRPB (now PHE) considers this model to be suitable for modelling atmospheric dispersion from short-term releases [Ref 30].

191. Table 5-2 below presents the key parameters used as input into the ADMS model. These data were taken from the HPC RIA [Ref 26].

192. Site specific hourly sequential Met data for SZC covering the 10-year period from 2003-2012, based on the numerical weather prediction (NWP) model and procured from the Met Office, was used as input into the ADMS code. A subset of this data for the period from 1st June – 31st August for each of the 10 years was used to calculate the 95th percentile of the 24-hour rolling mean atmospheric concentrations and the average deposition rates over these periods.

Table 5-2 Atmospheric Dispersion Model Input Parameters

Parameter	Value
Physical stack height (m)	70
Stack diameter (m)	3
Stack exit velocity (m/s)	9.6
Discharge gas	Air
Ambient temp. of discharge gases (°C)	15
Averaging period (h)	24
Surface roughness length (m)	0.3
Deposition velocity (m/s)	• 5.00E-03 (tritium) • 0 (noble gases and C-14) • 1.00E-02 (iodine as I-131) • 1.00E-03 (aerosols as Cs-137)
Washout coefficient (1/s)*	• AR^B (tritium) • 0 (noble gases and C-14) • AR^B (iodine) • AR^B (aerosol as Cs-137)
Meteorological Data	NWP site-specific met data for Sizewell C for 2003-2012

*AR^B: A= 1.00E-4, B=0.64 & R=rainfall (mm/h). It is pessimistically assumed that radionuclides that are washed out of the air and deposit to the ground remain there and do not get washed into watercourses and then to the sea.

193. The volumetric flow rate used is liable to change every time the heating, ventilation and air conditioning system is tuned. The value used in the dose assessment is the initial GDA flow rate, which is considered to be a lower estimate thus providing a pessimistic bounding value.

194. The period of 1st June – 31st August was selected because it represents the peak-growing season for most terrestrial foodstuffs and animal feed (pasture and hay) in the UK. Livestock also normally graze on fresh pastures in the field during this time. This period also corresponds to the summer period which is generally associated with higher outdoor occupancy in the UK. It is therefore considered to represent a cautious, but realistic approach, for short-term dose assessments. The release is assumed to occur on 1st July [Ref 53].

195. Discharges from the two gaseous emission stacks at SZC were modelled separately using unit release rates (1 Bq/s). It is considered unlikely that both reactors would make short-term discharge at the same time; thus the worst results of the two stacks (the south stack) was scaled to the predicted short-term discharge rates and used for the assessment.

196. For the purpose of assessing short-term doses, the same local residence location and the same farming area were used as for the assessment of annual individual dose due to continuous discharges.

c) Food Concentration Calculations

197. The approach for modelling radionuclide concentration in food was based on the methodology articulated in the NDAWG publication ‘Short-term Releases to the Atmosphere’ [Ref 54]. This is consistent with the approach used by the Environment Agency in their assessment of potential doses due to predicted short-term releases from HPC [Ref 50].

198. The NDAWG publication comprises food CFs which provide the concentration of selected depositing radionuclides in major terrestrial foodstuffs for unit short-term releases [Ref 54]. These CF values, with the exception of those for

C-14, were derived on the basis of the FARMLAND methodology developed by the NRPB [Ref 56]. The food CFs for C-14 were based on the FSA SPADE model [Ref 57]. The food CFs assume that the deposition occurs in the summer and therefore they will overestimate the concentrations in foodstuffs if the release occurs at a different time of year.

199. The NDAWG food CFs, reproduced in Table 5-3 below, were combined with the modelled radionuclide deposition rates (atmospheric concentration values in the case of C-14) and food intake rates and ingestion dose coefficients to calculate short-term doses via food ingestion pathways. Food CFs are not available for Co-58, Cs-134 and I-133; thus, the CFs for Co-60, Cs-137 and I-131, which are isotopes of the same elements, were used as analogues for these radionuclides, respectively. The use of the selected analogues represents a pessimistic approach given their significantly longer half-lives compared to the radionuclides for which data were not available. This will ultimately result in an overestimate of the integrated concentrations in food for Co-58, Cs-134 and I-133 since the concentrations in the foodstuffs would decay at a faster rate.

Table 5-3 Activity Concentrations in Foods for Cautious Short-Term Assessment Integrated to 1 year (Bq y/kg per Bq/m2 or Bq y kg per Bq d/m3 for C-14)

Radionuclide	Green Vegetables	Root Vegetables	Fruit	Cow Milk	Cow Meat	Sheep Meat
C-14	2.63E+00	6.59E+00	6.33E+00	3.30E+00	1.57E+01	2.01E+01
Co-58	3.17E-03	4.05E-05	1.87E-03	4.23E-03	1.12E-03	9.66E-04
Co-60	3.17E-03	4.05E-05	1.87E-03	4.23E-03	1.12E-03	9.66E-04
Cs-134	3.73E-03	9.53E-03	3.72E-02	1.10E-02	5.49E-02	4.60E-02
Cs-137	3.73E-03	9.53E-03	3.72E-02	1.10E-02	5.49E-02	4.60E-02
H-3	1.95E-03	1.95E-03	1.95E-03	9.06E-04	7.83E-04	1.19E-03
I-131	1.25E-03	2.73E-04	2.99E-03	1.84E-03	7.84E-04	1.01E-03
I-133	1.25E-03	2.73E-04	2.99E-03	1.84E-03	7.84E-04	1.01E-03

d) Representative Members of the Public

200. The representative members of the public exposed to short-term discharges to the atmosphere are assumed to be the farming family identified as the CRPs for continuous gaseous discharges in Section 2.4. These persons are exposed via the following pathways (as identified in Section 2.4):

- Internal exposure from inhalation of radionuclides in gaseous plume and from resuspension of ground deposited radionuclides from discharges to atmosphere.
- Skin absorption of tritium[20].
- Internal exposure from the ingestion of radionuclides incorporated into locally produced terrestrial foods following deposition of radionuclides discharged to atmosphere.
- External irradiation from exposure to beta / gamma radionuclides in the gaseous plume and from material deposited on the ground following discharge to atmosphere.

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[20] This was not assessed separately but included as part of the inhalation pathways (the dose coefficient for inhalation of tritium includes a multiplier for the skin absorption pathway).

e) Habits Data

Food Intake

201. A top two assessment identified that for the adult, consumption of milk and root vegetables led to the highest doses when 97.5th percentile consumption rates were used. For the child and infant age groups, consumption of milk and cow meat led to the highest doses. Consumption rates for these categories were kept at 97.5th percentile rates, and for all other categories mean consumption rates were used, in accordance with the top two approach.

Table 5-4 Food Intake Data for Short-Term Dose Assessment

Parameter	**Adult**	**Child**	**Infant**
Faction of food produced locally	1	1	1
Cow milk (kg/y)	240*	240*	320*
Green vegetables (kg/y)	88.3	16.3	11.8
Cow meat (kg/y)	19.2	15.7*	5.2*
Sheep meat (kg/y)	7.2	2.88	0.86
Root vegetables (kg/y)	167.7*	30.2	12.8
Fruit (kg/y)	36.9	12.5	3.1

*The 97.5th consumption rate was used for data marked. All remaining consumption rates were mean rates.

202. The food ingestion data for green vegetables in Table 5-4 is a sum of the ingestion rates for green vegetables and other vegetables taken from the 2015 CEFAS survey; similarly, the ingestion data for root vegetables is a sum of rates for root vegetables and potatoes taken from the 2015 CEFAS survey. Child and infant ingestion rates for sheep meat and cow meat were not provided in the 2015 CEFAS survey, so values were extrapolated from adult ingestion rates using CEFAS scaling factors [Ref 10]. Ingestion rates for milk are taken from RIFE 23 [Ref 25], as no consumption of milk was identified in the 2015 CEFAS survey for any age group.

203. A factor of 0.2 was applied to green vegetables to account for food preparation loss and no food preparation loss was assumed for the remaining food categories, in line with the default values in PC-CREAM 08.

Occupancy Habits

204. The farming family are assumed to inhabit a residential location 1,036 m from the emission stack and to source their milk and meat products from livestock grazing on a marshland 550 m from the emission stack as described in Section 2.4. It is cautiously assumed that short-term gaseous releases occur during daylight in summer months [Ref 53], that the adult, child and infant members of the family are at home for the whole of the 24 h release period and are outdoors for a proportion of this time.

Table 5-5 Occupancy Data for Short-Term Dose Assessment

Parameter	Adult	Child	Infant
Home location - distance (m)	~ 1km		
Farm location - distance (m)	550m		
Time at location (h/y)	8620	8620	8620
Fraction of time spent indoors	0.75	0.8	0.9
Cloud gamma location factor	0.2	0.2	0.2
Deposited gamma location factor	0.1	0.1	0.1
Cloud beta location factor	1.0	1.0	1.0
Deposited beta location factor	1.0	1.0	1.0
Indoor reduction factor for inhalation pathways	0.5	0.5	0.5
Indoor inhalation rates (m^3/h)	0.9	0.58	0.21
Outdoor inhalation rates (m^3/h)	1.75	0.87	0.31

205. The fraction of time spent indoors for the adult was based on the maximum occupancy rates for direct radiation taken from the 2015 CEFAS survey [Ref 10] for the area >0.5 to 1 km from Sizewell. The fraction of time spent indoors for the child and infant are taken from NRPB-W41 [Ref 35]. Gamma and beta location factors are based on default PC-CREAM 08 values.

206. It is assumed that the air concentration in the house is in equilibrium with the outside air concentration. Different inhalation rates have been applied for indoor and outdoor occupancy, consistent with the approach used for the HPC assessment [Ref 26]. The indoor and outdoor inhalation rates were derived as follows:

- An adult is assumed to spend 6 hours per day (h/day) outdoors based on the fraction of time spent indoors (0.75). It is assumed the adult breaths at the heavy work inhalation rate of 3 m^3/h for 1 h and at the light work inhalation rate of 1.5 m^3/h for the remaining 5 h spent outdoors. The average outdoors inhalation rate is therefore 1.75 m^3/h.
- An adult spends 18 h/day indoors. It is assumed that the adult breathes at the resting inhalation rate of 0.54 m^3/h for 4 h, at the light work rate for 5 h, at the heavy work rate for 1 h and at the sleeping inhalation rate of 0.45 m^3/h for the remaining 8 h spent indoors. The average indoors inhalation rate is therefore calculated to be 0.9 m^3/h. The above inhalation rates have been taken from ICRP Publication 66 [Ref 39].
- An indoor occupancy factor of 0.8 (corresponding to 4.8 h/day outdoors) is assumed for child. The child is assumed to breathe at the light work rate of 1.12 m^3/h for 3.2 h and at the resting rate of 0.38 m^3/h for 1.6 h during this time. The child is assumed to spend 19.2 h/day indoors, during which they breathe at the light inhalation rate for 6.1 h, at the resting rate for 3.1 h, and at the sleeping inhalation rate of 0.31 m^3/h for the remaining 10 h. The average indoors inhalation rate for child is therefore is 0.58 m^3/h. The inhalation rates were taken from ICRP Publication 66 [Ref 39].
- The infant is assumed to spend 2.4 h/day outdoors based on an indoor occupancy fraction of 0.9. The infant is assumed to breathe at the light work rate of 0.35 m^3/h for 1.6 h and at the resting rate of 0.22 m^3/h for 0.8 h during this time. The infant spends 21.6 h/day indoors and breathes at the light inhalation rate for 2.5 h, at the resting rate for 5.1 h, and at the sleeping infant inhalation rate of 0.15 m^3/h for the remaining 14 h. The average indoors infant inhalation rate is therefore 0.21 m^3/h. The inhalation rates were taken from ICRP Publication 66 [Ref 39].

f) Dose calculation

207. Short-term doses were calculated by combining the ADMS modelled environmental concentration data with habits data and the appropriate dose coefficients, using the relationships described in NRPB-W54 [Ref 53].

208. Dose coefficients for inhalation and ingestion of food were taken from the PC-CREAM 08 User Guide [Ref 28]. External dose coefficients (for immersion in plume and from deposited material, and skin dose) were taken from FGR12 [Ref 42] and corrected using radiation weighting factors from ICRP Publication 60 within the Radiological Toolbox software (Version 3.0.0) [Ref 43].

209. External dose from radionuclides deposited on the ground and inhalation dose from resuspended radionuclides continues to occur after the plume has passed. Total dose over a year was therefore calculated for these pathways. Radioactive decay of radionuclides over the year was accounted for in the external dose from ground calculation. As the concentration of resuspended material in air varies with time, the integrated resuspended activity concentration over the year was calculated according to the method set out in NRPB-W54 [Ref 53] and divided by the number of days in a year to determine the average air concentration from resuspended material for the year.

5.2 Results and Discussion

a) ADMS Environmental Concentration Data

210. It is considered unlikely that both reactors would make short-term releases at the same time; thus separate assessments were performed for each of the two EPR^{TM} stacks at SZC at unit release rates and the more restrictive set of results were used for the short-term dose assessment. The modelled concentration data were then scaled to the short-term release rates (Table 5-1) using an Excel spreadsheet to derive the air concentration and deposition rates presented in Table 5-6 below, which were used for the short-term dose assessment.

Table 5-6 ADMS Output for the more Restrictive Emission Stack[21]

	Farm Residence Location		Farm (Grazing) Location	
Nuclide	Air Concentration (Bq/m^3)	Deposition Rates ($Bq/m^2/s$)	Air Concentration (Bq/m^3)	Deposition Rates ($Bq/m^2/s$)
Ar-41	1.39E+00		3.30E+00	
C-14	1.49E+00		3.52E+00	
Co-58	1.15E-05	4.10E-09	2.72E-05	1.03E-08
Co-60	1.35E-05	4.81E-09	3.20E-05	1.21E-08
Cs-134	1.05E-05	3.75E-09	2.49E-05	9.45E-09
Cs-137	9.41E-06	3.37E-09	2.24E-05	8.48E-09
H-3	6.08E+00	7.06E-03	1.45E+01	1.63E-02
I-131	3.90E-04	8.33E-07	9.34E-04	1.92E-06
I-133	7.54E-05	1.61E-07	1.81E-04	3.71E-07
Kr-85	6.64E+00		1.58E+01	
Xe-131m	1.43E-01		3.40E-01	
Xe-133	3.01E+01		7.15E+01	
Xe-135	9.46E+00		2.25E+01	

b) Doses from Exposure to Short-Term Discharges

211. The dose to the adult, child and infant members of the farming family from exposure to short-term discharges of gaseous radionuclides from SZC, summed across the relevant terrestrial pathways, is calculated to be 3.8 µSv/y, 3.5 µSv/y and 6.9 µSv/y respectively.

212. Table 5-7 below presents a summary of the assessed short-term doses.

Table 5-7 Summary of Assessed Short-Term Dose (µSv/y) to Farming Family from Sizewell C

Age Group	Inhalation pathways	External pathways	Ingestion Pathways	Total
Adult	5.7E-02	2.0E-02	3.7E+00	**3.8E+00**
Child	4.2E-02	2.0E-02	3.4E+00	**3.5E+00**
Infant	3.0E-02	2.0E-02	6.8E+00	**6.9E+00**

213. The dominant pathway is the ingestion of cow milk which contributes around 43%, 64% and 87% of the short-term dose to adult, child and infant age groups respectively. Ingestion pathways account for around 98-99% of the calculated short-term doses. C-14 is the dominant radionuclide, accounting for 99% of the assessed dose to the farming family.

214. If the remainder of the discharge limits were discharged continuously over a one-year period, the total dose as a result of the combined short-term and continuous discharges would be 7.5 µSv/y, 6.5 µSv/y and 13 µSv/y for the adult, child and infant members of the farming family respectively. These doses are well below the source constraint of 300 µSv/y and the public dose limit of 1 mSv/y.

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[21] As discussed in Section 2.4, farm residence location relates to crop production including fruit and vegetables and farm grazing relates to animal product location including milk and meat products.

Table 5-8 Combined Short-Term and Continuous Discharge Dose (µSv/y) to Farming Family from Sizewell C

Age Group	Inhalation pathways	External pathways	Ingestion Pathways	Total
Adult	1.7E-01	4.0E-02	7.2E+00	**7.5E+00**
Child	1.3E-01	3.8E-02	6.3E+00	**6.5E+00**
Infant	9.2E-02	3.4E-02	1.3E+01	**1.3E+01**

215. Effective dose as a result of skin exposure to beta emitting radionuclides was assessed to be of the order of 0.06 µSv/y. This includes a skin weighting factor of 0.01 which gives an equivalent skin dose of 6µSv/y. This is insignificant when compared to the annual skin dose limit of 50,000 µSv/y/cm^2 under the IRR17.

216. If the entire proposed annual limit was discharged within 24 h, the doses would be 46 µSv, 42 µSv and 82 µSv after one year. These values are less than both the source constraint and the public dose limit.

217. A breakdown of doses by radionuclide and exposure pathway from a short-term release (excluding any remaining continuous release) is presented in Table 5-9 to Table 5-11.

Table 5-9 Dose (µSv) to Adult from Sizewell C over one year from a short-term release

Radionuclide	Inhalation Dose	Effective Cloud Dose	Effective Ground Dose	Resuspension Dose (inhalation)	Green vegetables	Root vegetables	Fruit	Milk	Cow meat	Sheep Meat	Total dose (Sv)	% contribution
Ar-41	0.0E+00	7.4E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.4E-03	0.2%
C-14	5.5E-02	3.3E-07	0.0E+00	0.0E+00	4.0E-02	9.5E-01	2.0E-01	1.6E+00	6.2E-01	3.0E-01	3.8E+00	99.1%
Co-58	3.4E-07	4.4E-08	9.1E-07	6.0E-11	1.5E-08	1.8E-09	1.8E-08	6.7E-07	1.4E-08	4.6E-09	2.0E-06	<0.1%
Co-60	2.5E-06	1.4E-07	9.2E-06	6.2E-10	7.9E-08	9.6E-09	9.8E-08	3.6E-06	7.7E-08	2.5E-08	1.6E-05	<0.1%
Cs-134	1.3E-06	6.4E-08	4.2E-06	3.2E-10	4.1E-07	9.8E-06	8.5E-06	4.1E-05	1.6E-05	5.1E-06	8.7E-05	<0.1%
Cs-137	8.1E-07	7.5E-11	8.8E-09	2.0E-10	2.5E-07	6.0E-06	5.2E-06	2.5E-05	1.0E-05	3.2E-06	5.1E-05	<0.1%
H-3	2.0E-03	0.0E+00	0.0E+00	1.6E-06	3.8E-04	3.6E-03	7.9E-04	5.5E-03	3.8E-04	2.2E-04	1.3E-02	0.3%
I-131	5.4E-05	5.7E-07	8.5E-06	3.4E-08	3.5E-05	7.3E-05	1.7E-04	1.6E-03	5.5E-05	2.7E-05	2.0E-03	0.1%
I-133	2.1E-06	1.8E-07	3.0E-07	3.1E-10	1.3E-06	2.7E-06	6.6E-06	6.1E-05	2.1E-06	1.0E-06	7.7E-05	<0.1%
Kr-85	0.0E+00	1.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-04	<0.1%
Xe-131m	0.0E+00	1.7E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E-06	<0.1%
Xe-133	0.0E+00	3.5E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-03	0.1%
Xe-135	0.0E+00	9.0E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.0E-03	0.2%
Total	5.7E-02	2.0E-02	2.3E-05	1.7E-06	4.0E-02	9.6E-01	2.0E-01	1.6E+00	6.2E-01	3.0E-01	3.8E+00	100.0%
% contribution	1.5%	0.5%	<0.1%	<0.1%	1.1%	25.1%	5.3%	42.6%	16.2%	7.8%	100.0%	

Table 5-10 Dose (µSv) to Child from Sizewell C over one year from a short-term release

Radionuclide	Inhalation Dose	Effective Cloud Dose	Effective Ground Dose	Resuspension Dose (inhalation)	Green vegetables	Root vegetables	Fruit	Milk	Cow meat	Sheep Meat	Total dose (Sv)	% contribution
Ar-41	0.0E+00	7.4E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.4E-03	0.2%
C-14	4.1E-02	3.3E-07	0.0E+00	0.0E+00	1.0E-02	2.4E-01	9.4E-02	2.2E+00	7.0E-01	1.6E-01	3.5E+00	99.0%
Co-58	2.7E-07	4.4E-08	7.9E-07	4.7E-11	6.2E-09	7.4E-10	1.4E-08	1.5E-06	2.7E-08	4.2E-09	2.7E-06	<0.1%
Co-60	2.0E-06	1.4E-07	7.9E-06	4.9E-10	4.7E-08	5.6E-09	1.1E-07	1.2E-05	2.0E-07	3.2E-08	2.2E-05	<0.1%
Cs-134	5.4E-07	6.4E-08	3.6E-06	1.3E-10	5.5E-08	1.3E-06	2.1E-06	3.0E-05	9.9E-06	1.5E-06	4.9E-05	<0.1%
Cs-137	3.4E-07	7.5E-11	7.6E-09	8.4E-11	3.5E-08	8.4E-07	1.4E-06	1.9E-05	6.3E-06	9.7E-07	2.9E-05	<0.1%
H-3	1.4E-03	0.0E+00	0.0E+00	1.1E-06	8.9E-05	8.3E-04	3.4E-04	7.1E-03	4.0E-04	1.1E-04	1.0E-02	0.3%
I-131	7.2E-05	5.7E-07	7.4E-06	4.6E-08	1.5E-05	3.1E-05	1.4E-04	3.8E-03	1.1E-04	2.5E-05	4.2E-03	0.1%
I-133	2.8E-06	1.8E-07	2.6E-07	4.1E-10	5.7E-07	1.1E-06	5.2E-06	1.4E-04	4.0E-06	9.3E-07	1.6E-04	<0.1%
Kr-85	0.0E+00	1.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-04	<0.1%
Xe-131m	0.0E+00	1.6E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.6E-06	<0.1%
Xe-133	0.0E+00	3.5E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-03	0.1%
Xe-135	0.0E+00	9.0E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.0E-03	0.3%
Total	4.2E-02	2.0E-02	2.0E-05	1.1E-06	1.0E-02	2.4E-01	9.5E-02	2.2E+00	7.0E-01	1.6E-01	3.5E+00	100.0%
% contribution	1.2%	0.6%	<0.1%	<0.1%	0.3%	6.8%	2.7%	64.0%	19.9%	4.7%	100.0%	

Table 5-11 Dose (µSv) to Infant from Sizewell C over one year from a short-term release

Radionuclide	Inhalation Dose	Effective Cloud Dose	Effective Ground Dose	Resuspension Dose (inhalation)	Green vegetables	Root vegetables	Fruit	Milk	Cow meat	Sheep Meat	Total dose (Sv)	% contribution
Ar-41	0.0E+00	7.4E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.4E-03	0.1%
C-14	2.9E-02	3.3E-07	0.0E+00	0.0E+00	1.5E-02	2.0E-01	4.7E-02	6.0E+00	4.6E-01	9.8E-02	6.8E+00	99.1%
Co-58	2.2E-07	4.4E-08	5.3E-07	3.9E-11	1.2E-08	8.1E-10	9.0E-09	5.3E-06	2.3E-08	3.3E-09	6.2E-06	<0.1%
Co-60	1.4E-06	1.4E-07	5.4E-06	3.3E-10	8.4E-08	5.8E-09	6.5E-08	3.8E-05	1.7E-07	2.4E-08	4.5E-05	<0.1%
Cs-134	2.3E-07	6.4E-08	2.4E-06	5.6E-11	4.6E-08	6.3E-07	6.0E-07	4.6E-05	3.8E-06	5.2E-07	5.4E-05	<0.1%
Cs-137	1.5E-07	7.5E-11	5.2E-09	3.7E-11	3.1E-08	4.3E-07	4.0E-07	3.1E-05	2.5E-06	3.5E-07	3.5E-05	<0.1%
H-3	8.6E-04	0.0E+00	0.0E+00	6.9E-07	1.3E-04	7.3E-04	1.8E-04	2.0E-02	2.8E-04	7.0E-05	2.2E-02	0.3%
I-131	8.3E-05	5.7E-07	5.0E-06	5.2E-08	3.8E-05	4.5E-05	1.2E-04	1.8E-02	1.2E-04	2.6E-05	1.8E-02	0.3%
I-133	4.0E-06	1.8E-07	1.8E-07	5.9E-10	1.8E-06	2.1E-06	5.7E-06	8.3E-04	5.8E-06	1.2E-06	8.5E-04	<0.1%
Kr-85	0.0E+00	1.4E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-04	<0.1%
Xe-131m	0.0E+00	1.2E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-06	<0.1%
Xe-133	0.0E+00	3.5E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-03	0.1%
Xe-135	0.0E+00	9.0E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.0E-03	0.1%
Total	3.0E-02	2.0E-02	1.4E-05	7.4E-07	1.5E-02	2.0E-01	4.7E-02	6.0E+00	4.6E-01	9.8E-02	6.9E+00	100.0%
% contribution	0.4%	0.3%	<0.1%	<0.1%	0.2%	2.9%	0.7%	87.3%	6.8%	1.4%	100.0%	

6 COLLECTIVE DOSE TO UK, EU AND WORLD POPULATIONS

218. The collective dose is used as an indicator of societal risk by considering the dose impact to a population rather than looking at individual impacts. It is the time-integrated dose to a population from a single year of discharge. It provides a measure of the radiation exposure in a population from all significant exposure pathways from a given source, and represents an aggregation of small individual effective doses within an exposed population over a specified period.

219. The Environment Agency Principles Document recommends that "for permitting or authorisation purposes, collective doses to the populations of UK, Europe and the World, truncated at 500 years, should be estimated" [Ref 4]. Truncation of collective doses at 500 years is to allow for the long-term dose impact of long-lived radionuclides such as C-14, which remain in circulation long after their discharge has stopped.

220. The use of per caput dose (dose per unit head of a population) is considered to provide a more useful measure in term of the distribution of the collective across individuals within a population [Ref 4]. The per caput dose has been determined by dividing the collective doses for UK, EU and World populations by the number of individuals within each population group [Ref 58].

6.1 Assessment Methodology

221. The ASSESSOR module in PC-CREAM 08 has been used to calculate the collective doses to UK, EU and World populations truncated at 500 years from one year of routine, continuous discharges of aqueous and gaseous radionuclides from SZC. Collective dose to the World population is calculated only for globally circulating radionuclides (H-3, C-14, Kr-85 and I-129) [Ref 29].

222. The dispersion and concentration of unit discharges of aqueous and gaseous radionuclides in food and the environment (as well as external and inhalation dose rates) were modelled using the PC-CREAM 08 supporting models (DORIS for aqueous discharges to the marine environment; PLUME, GRANIS, FARMLAND and RESUS for gaseous discharges to atmosphere). The results of these models were input into the ASSESSOR module and combined with the in-built database of population grids and the associated food production data to calculate the collective dose.

223. ASSESSOR considers 'first pass' and 'global circulation' of radionuclides. The first pass component refers to the contribution to collective dose that arises as a result of the initial aqueous and gaseous discharges and the build-up of radionuclides in the environment; this component is particularly important for the UK population. The global circulation component applies to certain long-lived radionuclides which are globally dispersed in the biosphere and continue to contribute to the collective dose over long periods [Ref 29]. For gaseous discharges, the collective dose to the World population is only calculated for the global circulation component.

224. The source term for aqueous and gaseous discharges described in Section 2 for the assessment of dose to individual CRPs was used for the assessment of collective dose. Collective dose assessment is not sensitive to the specific location of discharge points on a site; consequently, gaseous discharges are assumed to be made via a single emission stack.

225. Two groups of EU populations were used in the assessment:

- EU12 for aqueous discharges to the marine environment, corresponding to EU member states with coastal boundaries (Belgium, Luxembourg, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain and the UK).
- 'Sizewell Population EU', a default population within PC-CREAM centred on Sizewell, covering Europe and part of countries beyond including areas of northern Africa, Turkey and Russia [Ref 59].

6.2 Input Data

226. The population groups for collective dose assessment as defined in PC-CREAM 08 are assumed to be made up of adults only and do not vary with time [Ref 29]. For doses from ingestion, it is assumed that all food produced in an area is eaten in that area, i.e. it is assumed that no import or export of food occurs. Default parameter values embedded in the PC-CREAM 08 code were used. The non-default parameters used were the radionuclide discharge inventory (see Table 2-1 and Table 2-2), the size of the local marine compartment and the site-specific Met data (for gaseous discharges only).

227. Table 6-1 presents a summary of key input data used in the collective dose assessment.

Table 6-1 Input data for Collective Dose Assessment

Parameter	Value
Truncation time (y)	500
Exposed population	UK, EU and World
Effective stack Height (m)	20
Meteorological data	Site specific (Sizewell C centred wind rose)
Roughness length (m)	0.3
Dispersion parameters and environmental concentration factors for gaseous discharges to the atmosphere*	Default PLUME, FARMLAND, GRANIS and RESUS values
Occupancy rates for collective dose from gaseous discharges (h/y)	8,760
Fraction of time spent indoors	0.9
Cloud gamma factors	0.2
Deposited gamma factors	0.1
Cloud/ deposited beta	1
Inhalation rates (m^3/y)	8,100
Dispersion parameters and environmental concentration factors for aqueous discharges to the marine environment	Default DORIS values
Local marine compartment	Sizewell (size adjusted from the default as per the individual dose assessment)
Regional marine compartment	North Sea South West compartment
Beach occupancy (man h/ y/ m)	50
**Population data for per caput dose calculation (PC-CREAM default values)	• UK: 5.96E+07 • EU (12): 3.60E+08 • Sizewell Population EU: 6.80E+08 • World: 1E+10

* A deposition velocity of 5.00E-3 m/s and washout coefficient (1/s) of 1.00E-4 was applied to gaseous discharges of H-3.

**PC-CREAM population data for UK and EU(12) is from 2003 and the estimation of the World population is based on the UN estimate for 2050 [Ref 29]. Populations may increase or decrease with time in different regions, but it is not possible to predict a population in the year 2500 with accuracy, so the default populations were retained.

6.3 Results and Discussion

Collective Dose from Exposure to Aqueous and Gaseous Discharges from Sizewell C

228. The collective doses predicted to arise from aqueous and gaseous discharges from SZC at the proposed annual limits are summarised in Table 6-2 and Table 6-3 respectively.

Table 6-2 Collective Dose (manSv) to UK, EU12 and World Population from Exposure to Aqueous Discharges from Sizewell C

Population	Pathway					
	Fish	Crustaceans	Molluscs	Beach Sediment Gamma	Global Circulation	Total
UK	1.3E-02	1.3E-03	8.1E-03	3.7E-06	1.3E-02	**3.5E-02**
EU12	7.0E-02	9.5E-03	5.3E-02	3.9E-06	7.6E-02	**2.1E-01**
World	1.5E-01	1.4E-02	5.7E-02	3.9E-06	2.1E+00	**2.3E+00**

229. The collective dose from discharges of aqueous radionuclides to the marine environment from SZC at the proposed limits is assessed to be 0.035 manSv/y, 0.21 manSv/y and 2.3 manSv/y to UK, EU12 and World population respectively. Over 99% of the total collective dose to all three population groups is attributable to C-14. C-14 and H-3 doses from the global circulation pathway account for 37%, 36% and 90% of the collective dose to UK, EU12 and World populations respectively, with majority of the dose coming from C-14. The ingestion of fish and molluscs account for around 60% of the dose to UK and EU12 populations, and 9% of the dose to World population. These results are comparable to HPC predictions of 0.021 manSv/y, 0.2 manSv/y and 2.2 manSv/y to UK, EU12 and World population respectively [Ref 26].

Table 6-3 Collective Dose (manSv) to UK, EU and World Population from Exposure to Gaseous Discharges from Sizewell C

Population	Pathway					
	Inhalation (including resuspension)	External beta and gamma from plume	External Beta/ gamma from ground	Food ingestion	Global circulation	Total
UK	1.8E-03	9.4E-05	1.1E-05	8.6E-02	1.5E-01	**2.3E-01**
Sizewell Population EU	2.6E-03	1.4E-04	1.4E-05	1.3E-01	8.9E-01	**1.0E+00**
World*	N/A	N/A	N/A	N/A	2.5E+01	**2.5E+01**

* Only the global pass component of the collective dose is calculated world population.

230. The collective dose from gaseous discharges at proposed annual limits from SZC is estimated to be: 0.23 manSv/y, 1.0 manSv/y and 25 manSv/y to the UK, EU (‘Sizewell Population EU’) and World populations respectively. Over 99% of the collective dose to all three-population groups is predicted to arise from C-14. The collective dose to world population is only calculated for global circulation in PC-CREAM 08. These results are comparable to HPC predictions of 0.36 manSv/y, 3.0 manSv/y and 24.6 manSv/y to UK, EU (‘Sizewell Population EU’) and World populations respectively [Ref 26].

Collective Dose from Exposure to Aqueous and Gaseous Discharges from Sizewell B and C

231. The collective dose predicted to arise from aqueous and gaseous discharges from the combined discharges from Sizewell B and C are summarised in Table 6-4 and Table 6-5 respectively.

Table 6-4 Collective Dose (manSv) to UK, EU12 and World Population from Exposure to Aqueous Discharges from Sizewell B and C

Population	Pathway					
	Fish	Crustaceans	Molluscs	Beach Sed. Gamma	Global Circulation	Total
UK	1.4E-02	1.3E-03	8.3E-03	9.1E-06	1.3E-02	**3.6E-02**
EU12	7.5E-02	9.8E-03	5.5E-02	9.7E-06	7.7E-02	**2.2E-01**
World	1.6E-01	1.5E-02	5.9E-02	9.9E-06	2.1E+00	**2.4E+00**

232. The collective dose from discharges of aqueous radionuclides to the marine environment from SZB and SZC at annual limits is assessed to be 0.036 manSv/y, 0.22 manSv/y and 2.4 manSv/y to UK, EU12 and World population respectively. C-14 is the dominant radionuclide, contributing 96% of the collective dose to UK and EU population and 99% of the collective dose to World population. Cs-134, used as surrogate for 'other radionuclides' in the SZB permit, contributes 2.7% of the collective dose to UK and EU population. If SZB other radionuclides (which includes C-14) are modelled as all C-14 instead of Cs-134, the collective dose, summed across pathways is 0.059 manSv/y, 0.35 manSv/y and 3.9 manSv/y for the UK, EU12 and World populations respectively. These values are slightly higher relative to those given in Table 6-4, but not significantly so.

Table 6-5 Collective Dose (manSv) to UK, EU and World Population from Exposure to Gaseous Discharges from Sizewell B and C

Population	Pathway					
	Inhalation (including resuspension)	External beta and gamma from plume	External Beta/ gamma from ground	Food ingestion	Global circulation	Total
UK	2.5E-03	5.7E-04	5.7E-05	1.2E-01	2.0E-01	**3.2E-01**
EU	3.5E-03	8.2E-04	7.7E-05	1.8E-01	1.2E+00	**1.4E+00**
World*	N/A	N/A	N/A	N/A	3.3E+01	**3.3E+01**

* Only the global pass component of the collective dose is calculated for the world population.

233. The collective dose from the combined gaseous discharges at annual limits from SZB and SZC is estimated to be: 0.32 manSv/y, 1.4 manSv/y and 33 manSv/y to UK, EU and World population respectively. Over 99% of the collective dose to all three-population groups is predicted to arise from C-14. The collective dose to World population is only calculated for global circulation in PC-CREAM 08.

Per caput Dose

234. Table 6-6 below presents a summary of the per caput dose (i.e. individual dose derived from collective dose) to UK, EU and World populations predicted to arise from gaseous and aqueous discharges from both SZC and the combined discharges from SZB and SZC.

Table 6-6 Per caput Dose (nSv/y)

	Population group	Gaseous discharges	Aqueous discharges	Total
Sizewell C Discharges	UK	3.9E+00	5.9E-01	**4.5E+00**
	EU	1.5E+00	5.8E-01	**2.1E+00**
	World	2.5E+00	2.3E-01	**2.7E+00**
Sizewell B and C Discharges	UK	5.4E+00	6.1E-01	**6.0E+00**
	EU	2.0E+00	6.0E-01	**2.6E+00**
	World	3.3E+00	2.4E-01	**3.6E+00**

235. The per caput dose to UK, EU and World population from both aqueous and gaseous discharges is calculated to be between 2.1 nSv/y and 4.5 nSv/y for discharges from SZC, and between 2.6 nSv/y and 6.0 nSv/y for discharges from SZB and SZC.

236. The UK regulatory agencies and advisory bodies consider that the risks associated with annual average per caput dose in the nSv range are trivial and should be ignored in the authorisation decision-making processes [Ref 4]. The assessed per caput dose from SZC is of the order of a few nSv and therefore within the range that might be considered insignificant. This finding also applies if the worst-case scenario of modelling other radionuclides as C-14 was used.

7 BUILD-UP OF RADIONUCLIDES IN THE ENVIRONMENT

7.1 Assessment Methodology

237. The build-up of radionuclides discharged from SZC in the local marine and terrestrial environments by the end of the operational life of the power station (60 years) has been assessed. The potential to prejudice legitimate future uses of the land or sea, as a consequence of the build-up of radionuclides, has also been assessed.

a) Build-up of Radionuclides in the Marine Environment

238. The build-up of radionuclides in the local marine environment (marine sediment and seawater) has been calculated within the DORIS module of PC-CREAM 08. The same modelling approach as described in Section 2 and the parameters values shown in Table 2-3 were used. The assessment was undertaken using the proposed annual limit values presented in [Ref 6].

b) Build-up of Radionuclides in the Terrestrial Environment

239. The build-up of radionuclides in the terrestrial environment (soils) was calculated by modelling the deposition rates of relevant radionuclides (isotopes of caesium, cobalt and iodine, along with progeny where appropriate) for unit releases within the PLUME module of PC-CREAM 08. PLUME allows the scaling of model outputs to metrological data and the SZC site-specific Met data were applied to the model outputs. The model is based on a Gaussian source depletion model in which the ground-level concentration of radionuclides in the gaseous plume generally decreases with distance downwind of the emission stack. Thus, for the purpose of this assessment, a distance of 450 m was used, corresponding to the approximate distance to the site perimeter from the reference stack in the direction of maximum air concentrations and deposition. The modelling approach is described in greater detail in Section 2 and the parameters values used are shown in Table 2-4

240. Soil concentration factors for unit deposition rates (Bq/m^2/s) taken from the FARMLAND module of PC-CREAM 08 were then applied to the PLUME output and the results scaled to the proposed annual discharge limits for SZC (Table 2-2) to obtain activity concentrations in soil.

c) Build-up of Radionuclides in Freshwater Environments

241. The area around SZC also comprises freshwater bodies (lakes). PC-CREAM 08 does not contain a model for radionuclide transfer in lakes. The build-up of radionuclides deposited in a lake was therefore calculated using the SRS-19 screening model for a small lake [Ref 60]. The SRS-19 comprises simple, linear compartmental models suitable for undertaking pessimistic screening calculations of radionuclide dispersion for a range of environments (lakes, estuarine, river, coastal and atmospheric environments).

242. The SRS-19 model considers both direct deposition of radionuclides into the lake and indirect contributions from radionuclides deposited in the lake's watershed through runoff, surface soil erosion and groundwater seepage. It is a pessimistic model used for radiological screening purposes, hence the predicted doses will be very cautious. The model assumes that the watershed is 100 times the lake surface area, and that 2% of radionuclides deposited on to the watershed reach the lake [Ref 60]. Radionuclide deposition rates were modelled within the PLUME module of PC-CREAM 08 as described in Section 2 using the parameters shown in Table 2-4, at the proposed annual limit values presented in Table 2-2. As noted earlier, deposition parameters allow for some deposition of H-3, but no deposition of C-14, which is pessimistic.

243. The reference lake used for the assessment is situated in the centre of Minsmere Nature Reserve, within Minsmere-Walberswick Heaths and Marshes Special Protection Area [Ref 6]. The lake receives land drainage from ditches and reed beds in the area. However, the modelling pessimistically assumes that the lake is a standing water-body and the lake volume, rather than flow through the lake, is used to calculate dilution.

Table 7-1 Build-up Parameters for Freshwater Lake

Parameter	Value
Distance from reference stack (m)	2500
Bearing relative to reference stack (°)	345-15
Lake surface area [Ref 6] (m^2)	40,450
Lake depth (m)	2
Lake volume (m^3)	80,900
Flow rate (m^3/s)	0

d) Dose to Future Users of Sea and Land due to Build-Up of Radionuclides in the Marine and Terrestrial Environments

Dose from Future Land Use

244. The potential exposure of future SZC site users that could arise from the build-up of radionuclides deposited onto the land from gaseous releases to the atmosphere is assessed using the methodology described in NRPB-W36 [Ref 61]. The future use of the land affected by deposited radionuclides is expected to be similar to the current uses which include agriculture, housing and industrial use. The NRPB-36 methodology considers the following future land uses: agriculture, housing, construction, industrial, school, covered area and recreational use. The dominant scenario for Co-60 and Cs-137 for uniform exposed contamination is the construction worker scenario and therefore the construction worker scenario is considered to represent the limiting case and to provide a bounding assessment for other members of the public. The dose was assessed at the point in time at the end of the operational life of the power station (60 years).

245. The NRPB-W36 methodology provides a set of values for dose per unit activity concentration (DPUC) in soil for 36 radionuclides [Ref 61]. The DPUC values for the limiting age group are provided for a range of scenarios and contamination distribution profiles. The exposed uniform contamination distribution profile described in NRPB-W36

methodology is considered appropriate for land with a relatively small spatial dimension where atmospheric deposition of radionuclides has occurred. This contamination profile has been used to assess the dose to a construction worker.

246. The dose to a construction worker was calculated by scaling the DPUC values to the calculated soil concentration values from build-up of radionuclides in the terrestrial environment. DPUC values are not provided for Co-58, I-131 or I-133, so the DPUC for Co-60 was used for these radionuclides, which is conservative as it is the highest DPUC provided in reference [Ref 61]. The exposure pathways considered relevant to the construction worker scenario in the NRPB-W36 methodology are:

- external irradiation from ground with radionuclide contamination;
- external irradiation from contaminated soil on the skin;
- internal irradiation from inhalation of resuspended soil;
- internal irradiation from inadvertent ingestion of contaminated material.

247. The construction worker is pessimistically assumed to spend the whole working year (2,000 hours) on ground with radionuclide contamination. No allowance is made for attenuation provided by personal protective equipment or shielding provided by enclosures such as the cab of a mechanical excavator [Ref 61].

Dose from Future Use of Marine Environment

248. It is considered that the current uses of the marine environment (fishing and recreational activities) around SZC and the habits of members of the public identified in Section 2 are likely to persist long into the future. Given that the source term and marine modelling parameters (Sizewell local compartment with dose calculated in environmental concentrations after 60 years of discharge) remain the same as considered earlier (Section 2.3), no further dose assessment has been carried out. This approach is consistent to that used in the HPC assessment.

7.2 Results and Discussion

249. Table 7-2 to Table 7-7 below presents the results of assessment of build-up of radionuclides in the environment in the 60th year following discharges from aqueous and gaseous releases from SZC and the combined discharges from SZB and SZC.

a) Discharges from Sizewell C

250. Table 7-2 to Table 7-4 below present the concentrations of radionuclides in the marine (unfiltered seawater and seabed sediment) and terrestrial (soil and freshwater lake) environments due to discharges of aqueous and gaseous effluent from SZC at the proposed annual limits after 60 years of discharges.

Table 7-2 Build-up of Radionuclides in Unfiltered Seawater and Seabed Sediment from 60 years of Sizewell C Discharges

Radionuclide	Unfiltered seawater (Bq/l)	Seabed sediment (Bq/kg)
Ag-110m	9.78E-05	4.85E-03
C-14	1.74E-02	2.81E+01
Co-58	2.91E-04	4.88E-02
Co-60	4.93E-04	1.63E+00
Cr-51	7.38E-06	4.15E-04
Cs-134	9.72E-05	3.22E-02
Cs-137	1.73E-04	2.85E-01
H-3	1.84E+01	3.16E+01
I-131	4.17E-06	9.15E-07
Xe-131m (I-131)*	1.82E-06	1.02E-06
Mn-54	4.15E-05	2.93E-02
Ni-63	1.69E-04	1.58E+00
Sb-124	7.54E-05	9.43E-04
Sb-125	1.44E-04	2.46E-02
Te-125m (Sb-125)*	2.06E-05	2.46E-02
Te-123m	4.29E-05	1.05E-03
Te-123 (Te-123m)*	1.33E-19	1.27E-15

*Progeny of the parent radionuclide, which is shown in brackets.

Table 7-3 Build-up of Radionuclides in Soil from 60 years of Sizewell C Discharges

Radionuclides*	Deposition Rates for annual discharge (Bq/m²/s)	Soil Concentration Factors (Bq/kg per Bq/m²/s)	Soil Concentration (Bq/kg)
Co-58	1.98E-09	2.43E+04	4.82E-05
Co-60	2.33E-09	5.38E+05	1.25E-03
Cs-134	1.82E-09	2.30E+05	4.18E-04
Cs-137	1.63E-09	1.95E+06	3.18E-03
I-131	3.56E-07	2.30E+03	8.20E-04
I-133	6.89E-08	2.41E+02	1.66E-05

* Consistent with the approach taken for HPC [Ref 26], no net deposition of H-3 or C-14 to ground was used in the assessment.

Table 7-4 Build-up of Radionuclides in Freshwater Lake from 60 years of Sizewell C Discharges

Radionuclide	Deposition (Bq/m^2/s) for annual discharge	Radionuclide discharge rate, Q_i, (Bq/s)	Radionuclide concentration in lake water, C_w, (Bq/m3)	Radionuclide concentration in lake water, C_w, (Bq/l)
Co-58	1.94E-10	2.35E-05	2.57E-03	2.57E-06
Co-60	2.28E-10	2.76E-05	8.20E-02	8.20E-05
Cs-134	1.78E-10	2.16E-05	2.50E-02	2.50E-05
Cs-137	1.59E-10	1.93E-05	2.45E-01	2.45E-04
H-3*	2.44E-04	2.96E+01	1.98E+05	1.98E+02
I-131	2.67E-08	3.24E-03	4.01E-02	4.01E-05
I-133	5.14E-09	6.24E-04	8.33E-04	8.33E-07

* The higher deposition rate for H-3 and associated higher concentration in lake water is due to the greater proposed limits for H-3 compared to the other radionuclides considered here (i.e. four to five orders of magnitude higher).

b) Discharges from Sizewell B and C

251. Table 7-5 to Table 7-7 below present the concentrations of radionuclides in the marine (unfiltered seawater and seabed sediment) and terrestrial (soil and freshwater lake) environments due to the combined discharges of aqueous and gaseous effluent from SZB and SZC at the annual limits after 60 years of discharges.

Table 7-5 Build-up of Radionuclides in Unfiltered Seawater and Seabed Sediment from 60 years of Sizewell B and C Discharges

Radionuclide	Unfiltered seawater (Bq/l)	Seabed sediment (Bq/kg)
Ag-110m	9.78E-05	4.85E-03
C-14	1.74E-02	2.81E+01
Co-58	2.91E-04	4.88E-02
Co-60	4.93E-04	1.63E+00
Cr-51	7.39E-06	4.15E-04
Cs-134	1.16E-02	3.84E+00
Cs-137	1.99E-03	3.29E+00
H-3	2.57E+01	4.42E+01
I-131	4.17E-06	9.15E-07
Xe-131m	1.82E-06	1.02E-06
Mn-54	4.15E-05	2.93E-02
Ni-63	1.69E-04	1.58E+00
Sb-124	7.54E-05	9.43E-04
Sb-125	1.44E-04	2.46E-02
Te-125m (Sb-125)*	2.06E-05	2.46E-02
Te-123m	4.29E-05	1.05E-03
Te-123 (Te-123m)*	1.33E-19	1.27E-15

*Progeny of the parent radionuclide, which is shown in brackets.

Table 7-6 Build-up of Radionuclides in Soil from 60 years of Sizewell C and B Discharges

Radionuclides	Deposition ($Bq/m^2/s$) for annual discharge	Soil Concentration Factors (Bq/kg per $Bq/m^2/s$)	Soil Concentration (Bq/kg)
Co-58	1.98E-09	2.43E+04	4.82E-04
Co-60	2.05E-08	5.38E+05	1.10E-02
Cs-134	1.82E-09	2.30E+05	4.18E-04
Cs-137	1.63E-09	1.95E+06	3.18E-03
I-131	8.02E-07	2.30E+03	1.84E-03
I-133	6.89E-08	2.41E+02	1.66E-05

Table 7-7 Build-up of Radionuclides in Freshwater Lake from 60 years of Sizewell B and C Discharges

Radionuclide	Deposition rate ($Bq/m^2/s$) for annual discharge	Radionuclide discharge rate, Q_i, (Bq/s)	Radionuclide decay constant, λ, (1/s)	Radionuclide concentration in lake water, C_w, (Bq/m3)	Radionuclide concentration in lake water, C_w, (Bq/l)
Co-58	1.94E-10	2.35E-05	1.13E-07	2.57E-03	2.57E-06
Co-60	2.01E-09	2.44E-04	4.17E-09	7.24E-01	7.24E-04
Cs-134	1.78E-10	2.16E-05	1.07E-08	2.50E-02	2.50E-05
Cs-137	1.59E-10	1.93E-05	7.33E-10	2.45E-01	2.45E-04
H-3	3.66E-04	4.45E+01	1.78E-09	2.98E+05	2.98E+02
I-131	6.00E-08	7.28E-03	9.98E-07	9.03E-02	9.03E-05
I-133	5.14E-09	6.24E-04	9.26E-06	8.33E-04	8.33E-07

c) Dose from Future Land Use

252. The dose from future land use, assessed as total dose to a construction worker from the build-up of 60 years of gaseous radionuclides discharged from SZC and deposited on the ground is calculated to be 0.0034 µSv/y. The dose is dominated by external pathways [Ref 61]. The highest contributions to the dose are from Co-60, I-131 and Cs-137, contributing 41%, 27% and 22% of the dose respectively.

253. The corresponding dose from the build-up of radionuclides from the combined discharges from SZB and C is calculated to be 0.015 µSv/y via external pathways [Ref 6], with Co-60, I-131 and Cs-137 contributing 80%, 13% and 5% of the dose respectively.

254. Table 7-8 and Table 7-9 below present the breakdown of the calculated dose from future land use, i.e. to a construction worker by radionuclide due to discharges from SZC, and from the combined discharges from SZB and SZC.

255. As with the existing UK nuclear power generating reactors sites (whether currently operational or where power generation has ceased and they are at some stage of decommissioning), the expectation is that after final site clearance of all structures, and associated land remediation if required, the land will be released for unrestricted use. Before release, each operator will have to demonstrate to the ONR that any reasonably foreseeable exposure scenario would not lead to a dose greater than 10 µSv/y [Ref 62]. This is commonly known as the 'no danger' requirement. If land contamination is found that could lead, in any reasonably foreseeable situation, to exceedance of a future use dose value of 10 µSv/y, land remediation work will be required in order to meet the 'no danger' criterion. Therefore, future doses from unrestricted land use at SZC after final site clearance and release have not been considered here.

Table 7-8 Dose to Construction Worker due to 60 years of Gaseous Discharges from Sizewell C

Radionuclide	DPUC (Sv/y per Bq/g)	Soil Concentration (Bq/kg)	Dose µSv/y	% Contribution
Co-58*	1.11E-03	4.82E-05	5.4E-05	2%
Co-60	1.11E-03	1.25E-03	1.4E-03	41%
Cs-134	6.34E-04	4.18E-04	2.6E-04	8%
Cs-137	2.41E-04	3.18E-03	7.7E-04	22%
I-131*	1.11E-03	8.20E-04	9.1E-04	27%
I-133*	1.11E-03	1.66E-05	1.8E-05	1%
Total			**3.4E-03**	100%

*DPUC values not available in NRPB-W36. The most restrictive DPUC value of the listed radionuclides (Co-60) has been applied.

Table 7-9 Dose to Construction Worker due to 60 years of Discharges from Sizewell B and C

Radionuclide	DPUC (Sv/y per Bq/g)	Soil Concentration (Bq/kg)	Dose µSv/y	% Contribution
Co-58*	1.11E-03	4.82E-05	5.4E-05	0%
Co-60	1.11E-03	1.10E-02	1.2E-02	80%
Cs-134	6.34E-04	4.18E-04	2.6E-04	2%
Cs-137	2.41E-04	3.18E-03	7.7E-04	5%
I-131*	1.11E-03	1.84E-03	2.0E-03	13%
I-133*	1.11E-03	1.66E-05	1.8E-05	0%
Total			**1.5E-02**	100%

*DPUC values not available in NRPB-W36 and the most restrictive DPUC value of the listed radionuclides (Co-60) has been applied.

8 SENSITIVITY ANALYSES

8.1 Introduction

256. Prospective radiological impacts assessments are characterised by uncertainties inherent in the models and parameters used to quantify the dispersion and accumulation of radionuclides in the environment, as well as variability associated with assumptions regarding the habits of the assessed population and their consequent exposures [Ref 4] [Ref 63]. The Environment Agency recommends that a review of uncertainty and variability associated with key assumptions used in dose assessment be carried out in the event that the estimated dose to the representative person exceeds 20 µSv/y. This is to provide confidence that an appropriate level of caution has been applied, but also to ensure that the assessment is not overly pessimistic [Ref 4].

257. The European Commission suggested that performing sensitivity analysis is a useful exercise for identifying the input parameters with the greatest influence on estimated doses [Ref 63]. This involves changing the assumptions and parameters used in dose assessments and observing the effects of these changes on estimated doses.

258. Sensitivity analyses of the key assumptions and parameters used to assess the radiological impacts of aqueous and gaseous discharges from SZC have been carried out. In keeping with the recommendation for taking a proportionate approach [Ref 4], the sensitivity analysis for SZC focussed on food ingestion pathways which account for between 87% and 99% of the dose to the majority of CRPs assessed. The specific assumptions and parameters analysed are:

- Discharges - expected best performance discharges against proposed limits.
- Habits Data - generic food ingestion rate against site-specific food ingestion rates.
- Food Source – 100% locally sourced seafood against 50% locally sourced seafood.

8.2 Discharges at Expected Best Performance Compared to Discharges at Proposed Limits

a) Overview

259. The proposed annual discharge limits for SZC have been presented in Section 2 of this report. The expected best performance discharge rates of most radionuclides constitute a smaller proportion of the proposed limits given that they do not include contingency and reasonable headroom.

260. The doses to selected CRPs (members of fishing family and farming family) have been reassessed, assuming that aqueous and gaseous effluent are discharged at the expected best performance discharge rates. All other assessment models, parameters and assumed habits discussed in Sections 2 of this report have been retained.

b) Results and discussion

261. Table 8-1 presents the calculated dose to members of the fishing family due to aqueous discharges at the proposed annual limits and at expected best performance discharge rates. The dose to adult, child and infant members of the fishing family arising from discharge at expected best performance is calculated to be 2.4 µSv/y, 1.2 µSv/y and 0.32 µSv/y respectively. This corresponds to approximately, 23% to 24% of the dose predicted to arise from aqueous discharges at the annual limits, a reduction in dose by around a factor of four.

262. Table 8-2 presents the calculated dose to members of the farming family due to gaseous discharges at the proposed annual limits and at expected best performance discharge rates. The dose to adult, child and infant members of the farming family arising from discharges at expected best performance is calculated to be 1.9 µSv/y, 1.5 µSv/y and 3.2 µSv/y respectively. This corresponds to approximately 46 to 48% of the dose predicted to arise from gaseous discharges at the annual limits, a reduction in dose by around a factor of two.

Table 8-1 Dose (µSv/y) to Fishing Family from Aqueous Discharges from Sizewell C

Discharge rates	Age group	Crustaceans	Fish	Molluscs	Sea plant	External beta (coast)	External beta shing equipmen	Ext. gamma (coast)	External gamma (fishing equipment)	Sea spray inhalation	Total
Proposed Limit	Adult	2.1E+00	6.8E+00	5.7E-01	5.4E-02	1.1E-03	3.0E-03	5.8E-01	8.3E-03	2.2E-05	**1.0E+01**
	Child	4.2E-01	4.2E+00	2.0E-01	0.0E+00	1.3E-04	2.5E-05	6.5E-02	7.1E-05	2.9E-06	**4.9E+00**
	Infant	3.0E-01	9.4E-01	8.0E-02	0.0E+00	3.6E-05	2.5E-05	1.9E-02	7.1E-05	8.4E-07	**1.3E+00**
Expected best performance	Adult	5.1E-01	1.7E+00	1.4E-01	1.3E-02	1.2E-04	6.4E-04	3.8E-02	5.5E-04	1.1E-05	**2.4E+00**
	Child	1.0E-01	1.0E+00	4.7E-02	0.0E+00	1.4E-05	5.5E-06	4.3E-03	4.7E-06	1.5E-06	**1.2E+00**
	Infant	7.1E-02	2.3E-01	1.9E-02	0.0E+00	3.9E-06	5.5E-06	1.2E-03	4.7E-06	4.3E-07	**3.2E-01**

Table 8-2 Dose (µSv/y) to Farming Family from Gaseous Discharges from Sizewell C

Discharge rates	Age group	Inhalation	Beta/ gamma (Plume)	Beta/ gamma (Ground)	Resuspension	Cow meat	Cow milk	Fruit	Green veg.	Root veg.	Sheep meat	Total
Proposed Limit	Adult	1.3E-01	2.0E-02	1.7E-03	3.5E-06	3.5E-01	1.6E+00	2.2E-01	5.3E-01	1.0E+00	1.3E-01	**4.0E+00**
	Child	9.9E-02	1.8E-02	1.5E-03	4.8E-06	4.0E-01	2.2E+00	1.0E-01	1.4E-01	2.5E-01	7.3E-02	**3.3E+00**
	Infant	6.8E-02	1.4E-02	1.0E-03	5.4E-06	2.2E-01	6.0E+00	5.2E-02	2.0E-01	2.7E-01	4.4E-02	**6.9E+00**
Expected Best Performance	Adult	5.6E-02	7.1E-04	1.3E-04	4.3E-07	1.7E-01	7.4E-01	1.1E-01	2.6E-01	5.0E-01	6.5E-02	**1.9E+00**
	Child	4.4E-02	6.5E-04	1.1E-04	5.9E-07	2.0E-01	1.0E+00	5.1E-02	6.7E-02	1.2E-01	3.6E-02	**1.5E+00**
	Infant	3.0E-02	5.1E-04	7.6E-05	6.6E-07	1.1E-01	2.8E+00	2.5E-02	9.7E-02	1.3E-01	2.2E-02	**3.2E+00**

8.3 Generic Food Intake Rates Compared to Site Specific Intake Rates

a) Overview

263. Food ingestion pathways account for around 94% to 99% of the assessed doses to the CRPs for exposure to aqueous and gaseous discharges from SZC. Thus, assumptions made regarding food ingestion rates, location of food sources and the fraction produced locally will have a considerable impact on the assessed doses to these CRPs.

264. A detailed review of the NDAWG paper on the acquisition and use of habits data for prospective dose assessments [Ref 40] was undertaken at the outset of the RIA for SZC to identify the most suitable approach for determining the food intake habits of members of the public living in the surrounding areas. The review considered the following approaches:

- The Environment Agency’s screening approach
- Top two using generic habits data
- Top two using local or site specific habits data
- Habits profiles
- Adjusted habits profiling

265. Details of the above approaches can be found in the NDAWG paper [Ref 40]. Following consideration of available data and review of regulatory guidance [Ref 4], the top two approach using critical (97.5th percentile) and mean (of the high-rate group) ingestion rates from CEFAS habits data was adopted for the SZC RIA. This approach is considered to be more rounded and to provide the right balance between realism, robustness, future proofing and the other attributes described by NDAWG [Ref 40] when compared to the other approaches outlined above, for a facility with an expected operational lifecycle of 60 years.

266. The sections below compare the Sizewell site-specific ingestion data and the generic ingestion data using the top two approach and investigate the impact of substituting site-specific data with generic data on the assessed dose to selected CRPs.

b) Terrestrial Foodstuff

Comparison of Site Specific and Generic Food Ingestion Rates

267. Table 8-3 and Table 8-4 below compare the site specific food ingestion rates used in the main assessment based on the 2015 CEFAS habits survey [Ref 10] and the generic food ingestion rates published in NRPB-W41 [Ref 35].

Table 8-3 Comparison of Site Specific and Generic Food Ingestion Rates[22]

	Site Specific Ingestion Rates for Sizewell			Generic Ingestion Rates from NRPB-W41		
Food Category	**Adult**	**Child**	**Infant**	**Adult**	**Child**	**Infant**
Cow milk (kg/y) ^	240*	240*	320*	240*	240*	320*
Green vegetables (kg/y)	88.3	16.3	11.8	35	35	15
Cow meat (kg/y)	19.2	15.7*	4.3	45*	15	3
Sheep meat (kg/y)	7.2	2.88	0.86	8	4	0.8
Root vegetables (kg/y)	167.7*	30.2	16.3*	60	95*	45*
Fruit (kg/y)	36.9	12.5	3.1	20	15	9

^ no consumption of cow milk was recorded in the 2015 CEFAS survey, so values were taken from NRPB-W41.

* 97.5th ingestion rate (unmarked values are mean rates).

268. A top-two assessment was carried out using 97.5th percentile generic ingestion rates to identify the two food categories resulting in the highest doses. For each age group, 97.5th percentile generic ingestion rates were used for the two food categories resulting in the highest doses, and mean generic ingestion rates were used for the remaining food categories. It is noted that the food categories resulting in highest doses for site specific and generic ingestion rates are not the same. Ingestion of cow milk resulted in one of the two highest doses for all age groups with both site specific and generic ingestion rates. The other highest dose pathway was either ingestion of cow meat or root vegetables, which varied depending on rate used and age group.

Table 8-4 Ratio of Site Specific to Generic Food Ingestion Rates

Food Category	Adult	Child	Infant
Cow milk	1.00	1.00	1.00
Green vegetables	2.52	1.09	2.36
Cow meat	0.43	1.05	1.42
Sheep meat	0.90	0.72	1.08
Root vegetables	2.80	0.32	0.36
Fruit	1.85	0.83	0.34

269. Table 8-3 and Table 8-4 above show that:

- For the adult age group, the site-specific ingestion rates for all food categories other than sheep meat and cow meat are higher than the corresponding generic ingestion rates.
- For the child age group, the site-specific ingestion rates for green vegetables and cow meat are higher than the corresponding generic rates whereas the rates for sheep meat, root vegetables and fruit are lower than the corresponding generic rates.
- The site-specific infant ingestion rates for sheep meat, cow meat and green vegetables are higher than the corresponding generic rates and the rates for root vegetables and fruit are lower than the corresponding generic rates.

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[22] The food ingestion data for green vegetables in Table 4.3.1 is a sum of the individual ingestion rates for green vegetables and other vegetables for CEFAS data, the NRPB-W41 values are for reported combined 'green and other domestic vegetables' ingestion rates. The ingestion data for root vegetables is a sum of the individual rates for root vegetables and potatoes for CEFAS data and the NRPB-W41 values are for reported combined 'potatoes and root vegetables'.

Comparison of Dose Outcomes for Ingestion of Terrestrial Foodstuff at Site Specific and Generic Intake Rates

270. The results of the assessments, based on the generic food intake rates, are compared with the dose calculated using the site-specific ingestion rates and presented in Table 8-5 below.

Table 8-5 Comparison of Dose (µSv/y) from Sizewell C Calculated using Site Specific and Generic Terrestrial Food Ingestion Rates

Ingestion rates taken from	Age group	Cow meat	Cow milk	Fruit	Green vegetables	Root vegetables	Sheep meat	Total
CEFAS 2015 Habits Data*	Adult	3.5E-01	1.6E+00	2.2E-01	5.3E-01	1.0E+00	1.3E-01	**3.8E+00**
	Child	4.0E-01	2.2E+00	1.0E-01	1.4E-01	2.5E-01	7.3E-02	**3.2E+00**
	Infant	2.2E-01	6.0E+00	5.2E-02	2.0E-01	2.7E-01	4.4E-02	**6.8E+00**
NRPB-W41 Habits Data	Adult	8.3E-01	1.6E+00	1.2E-01	2.1E-01	3.6E-01	1.5E-01	**3.2E+00**
	Child	3.8E-01	2.2E+00	1.3E-01	1.3E-01	7.9E-01	1.0E-01	**3.7E+00**
	Infant	1.5E-01	6.0E+00	1.5E-01	8.5E-02	7.5E-01	4.1E-02	**7.2E+00**

* Milk ingestion rates were taken from NRPB-W41 as no consumption of milk was recorded in the 2015 CEFAS survey.

271. The use of site specific food ingestion rates resulted in slightly higher estimation of the dose to the adult age group (increased by a factor of 1.2) than the equivalent ingestion rates using generic data. Conversely, the site specific data resulted in slightly lower estimation of the dose to child and infant (reduced by a factor of 1.2 and 1.1 respectively) than the equivalent generic ingestion rates.

c) Marine Foodstuff

Comparison of Site Specific and Generic Food Ingestion Rates

272. CEFAS has compared the high (97.5th percentile) and mean site-specific ingestion rates from the Sizewell habits survey with the equivalent national habits data for the adult age group [Ref 10] [Ref 64] and found the 97.5th percentile ingestion rates for seafood were comparable to the site-specific ingestion rates [Ref 10]. Table 8-6 below compares the site-specific ingestion rates used in the main assessment to the generic 97.5th percentile ingestion rates taken from NRPB-W41 (no mean rates are provided) and the national 97.5th percentile and mean ingestion rates (as per the top two assessment, with fish and crustaceans being a high rate and molluscs a mean rate) used by CEFAS for their comparison.

Table 8-6 Comparison of Site Specific and Generic Food Ingestion Rates

Food Category	Site Specific Ingestion Rates for Sizewell			Generic Ingestion Rates from NRPB-W41 [Ref 35]			National Data [Ref 64]
	Adult	Child	Infant	Adult	Child	Infant	Adult
Fish (kg/y)	39	17.5	1.95	100	20	5	40
Crustaceans (kg/y)	12.1	1.7	0.605	20	5	0	10
Molluscs (kg/y)	3.2	0.8	0.16	20	5	0	-
Marine plants/algae (kg/y)	0.6	-	-	-	-	-	-

Table 8-7 Ratio of Site Specific-Generic Food Ingestion Rates

Food Category	CEFAS-NRPB-W41 Rates			CEFAS:National Rates
	Adult	Child	Infant	Adult
Fish (critical ingestion rates)	0.39	0.88	0.39	0.98
Crustaceans (critical ingestion rates)	0.61	0.34	-	1.21
Molluscs (mean ingestion rates)	0.16	0.16	-	-

273. Table 8-7 shows that for the adult and child age groups, the site-specific seafood ingestion rates are lower than the generic (NRPB-W41) intake rates but the adult site specific rates were comparable to the national rates. The fish ingestion rate is also lower than the generic (NRPB-W41) rate for infants. Infant ingestion rates for crustaceans and molluscs were not reported in either the CEFAS survey or NRPB-W41 (the data used in the main assessment were extrapolations from the adult ingestion rates).

Comparison of Dose Outcomes for Ingestion of Seafood at Site Specific and Generic Intake Rates

274. An assessment of the dose to adult, child and infant members of the public exposed via ingestion of seafood incorporating radionuclides entrained in aqueous effluent discharged from SZC (analogous to the fishing family) has been carried out using the generic NRPB-W41 food intake rates (Table 8-6 above). All other parameters and assumptions described in Section 2 of the main RIA report were retained.

275. The results of the assessments based on NRPB-W41 food intake rates have been compared with the dose estimates calculated using the CEFAS food presented in Table 8-8 below.

Table 8-8 Comparison of Dose (μSv/y) from Sizewell C Calculated using Site Specific and Generic Seafood Ingestion Rates

Ingestion Rates	Age Group	Crustaceans	Fish	Molluscs	Seaweed	Total
CEFAS 2015 Habits Data	Adult	2.1E+00	6.8E+00	5.7E-01	5.4E-02	**9.6E+00**
	Child	4.2E-01	4.2E+00	2.0E-01	0.0E+00	**4.8E+00**
	Infant	3.0E-01	9.4E-01	8.0E-02	0.0E+00	**1.3E+00**
NRPB-W41 Habits Data	Adult	3.5E+00	1.8E+01	3.6E+00	0.0E+00	**2.5E+01**
	Child	1.2E+00	4.8E+00	1.2E+00	0.0E+00	**7.3E+00**
	Infant	0.0E+00	2.4E+00	0.0E+00	0.0E+00	**2.4E+00**

276. Use of the generic food ingestion rates gives a higher dose to all age groups by factors of 2.6, 1.5 and 1.8 for the adult, child and infant age groups, respectively when compared to the equivalent ingestion rates using site-specific data.

8.4 The Effect of Assumptions Regarding Locality of Seafood Source

277. In undertaking the RIA for SZC, it was assumed that 100% of all seafood (fish, crustaceans, molluscs and sea plants) were sourced from the local marine compartment. This represents a cautious approach compared to the approaches reported in some of the literature reviewed. For instance, the Environment Agency assumes that 50% of fish are caught in the local compartment and the remainder 50% caught from the adjacent regional compartment in its IRAM [Ref 16].

278. The assessment of dose due to ingestion of seafood incorporating radionuclides discharged from SZC has therefore been repeated assuming 50% of all seafood are caught in the regional compartment. All other parameters and assumptions described in Section 2 remain unchanged. The regional compartment is significantly bigger than the local compartment (a factor of 1125). As such environmental concentrations of radionuclides averaged across the area are significantly less (two to four orders of magnitude lower, depending on the radionuclide). Hence the dose contributions from food caught in the regional compartment are negligible.

Table 8-9 Comparison of Dose (μSv/y) from Sizewell C Calculated using 100% and 50% Locally Sourced Seafood

Seafood Locality	Age Group	Crustaceans	Fish	Molluscs	Seaweed	Total
100% Locally Sourced Seafood	Adult	2.1E+00	6.8E+00	5.7E-01	5.4E-02	**9.6E+00**
	Child	4.2E-01	4.2E+00	2.0E-01	0.0E+00	**4.8E+00**
	Infant	3.0E-01	9.4E-01	8.0E-02	0.0E+00	**1.3E+00**
50% Locally Sourced Seafood	Adult	1.1E+00	3.5E+00	2.9E-01	2.7E-02	**4.9E+00**
	Child	2.1E-01	2.1E+00	1.0E-01	0.0E+00	**2.5E+00**
	Infant	1.5E-01	4.8E-01	4.0E-02	0.0E+00	**6.7E-01**

279. From Table 8-9 above, it can be seen that the assumptions regarding the locality of seafood source are directly proportional to the calculated dose. The assumption that 50% of seafood is caught in the local compartment and the remaining 50% in the regional compartment, resulted in a reduction in dose by a factor of approximately two, compared to the dose outcome calculated assuming 100% of seafood is sourced from the local compartment.

8.5 Screening Assessments

280. The sensitivity analyses presented above focus on key exposure pathways associated with predicted aqueous and gaseous discharges from SZC. However, operational, environmental or habit factors may result in higher than expected doses from otherwise unimportant exposure pathways and a number of screening assessments to this effect were carried out. These are detailed in Appendix A and are summarised below.

Dose to foetus and breastfed infant

281. The ICRP and HPA recognise that there are circumstances in which the foetus and breastfed infant may receive higher doses than the mother and have published dose coefficients and guidance for assessing doses to the foetus and breastfed infant for discharges to the environment [Ref 65] [Ref 66]. Therefore, a screening assessment of dose to the foetus and breastfed infant has been carried out for discharges from SZC.

282. The dose to foetus was calculated to be higher than for other age groups, though still less than 6% of the dose constraints, and the dose to breastfed infant was comparable with that of an infant member of the fishing family exposed to both aqueous and gaseous discharges. The details of the assessment and discussion of the results are provided in Appendix A.2

Inadvertent ingestion of sediment and seawater

283. Members of the public may be exposed to discharged aqueous radionuclides through inadvertent ingestion of seawater and coastal sediment. The contribution of these pathways to the overall dose is insignificant when

compared to other pathways associated with marine discharges (e.g. seafood ingestion and external exposure over sediment) [Ref 29] and these pathways are considered to be unimportant [Ref 37] [Ref63]. However, it is recognised that they may merit investigating under certain circumstances, for instance, the relative contribution from the ingestion of sediment may be higher for infants, as they receive less exposure from conventional pathways [Ref 63] and a screening assessment for discharges from SZC has therefore been carried out.

284. The calculated doses determined that the contribution of inadvertent ingestion pathways to the overall dose to members of the public is of the order of a few nSv/y and is therefore insignificant. The details of the assessment and discussion of the results are provided in Appendix A.3.

Inhalation of Sea spray incorporating enhanced radionuclide concentration

285. Studies investigating the sea-to-land transfer of radionuclides discharged to sea have reported the enrichment of actinides in airborne materials up to three orders of magnitude greater than that of the seawater concentration [Ref 68]. These studies also suggest that the formation of 'spume' or stable foam, which has a high particulate loading, can be an important medium for the sea-to-land transfer of radionuclides in areas where this occurrence is prevalent. Members of the public spending time along coastal areas may therefore inhale enhanced levels of radionuclides entrained in sea spray. An assessment of potential exposure of users of the coastal area adjacent to SZC via inhalation of enhanced concentration of radionuclides in sea spray has therefore been undertaken.

286. The calculated doses determine that the contribution of sea spray inhalation and the inhalation of resuspended coastal sediment to the overall dose to members of the public is of the order of a few tens of nSv/y and can therefore be considered to be insignificant. The details of the assessment and discussion of the results are provided in Appendix A.4.

Enhanced Discharge of Tritium in Aqueous Effluent

287. The release of enhanced levels of HTO in aqueous discharges during certain activities (e.g. shut down operations) in the operational cycle of a UK EPR^{TM} reactor is a feature of the reactor design. It is estimated that up to 80% of the H-3 annual inventory may be discharged over a period of two months. The potential impact such releases is considered in Appendix A.5.

288. The dose predicted to arise from the ingestion of seafood incorporating elevated levels of H-3 represents an increase of around one order of magnitude when compared to the dose from routine discharges of H-3. However, it is a trivial dose when compared to the overall dose to the CRP.

8.6 Conclusions

289. The use of expected best discharge data results in a reduction in dose by around a factor of four for aqueous discharges and a factor of two for gaseous discharges.

290. The difference in dose from the use of site specific and generic ingestion rates is small for terrestrial foodstuff. However, the use of site-specific ingestion data for seafood resulted in a lower dose for all age groups compared to an equivalent assessment using generic intake rates.

291. Overall, it is considered that the approach for assessing the dose to CRPs via food ingestion pathways adopted for the SZC RIA represents a reasonable and robust approach and has not resulted in a significant underestimation of the dose to CRPs.

9 SUMMARY AND CONCLUSIONS

292. The proposed SZC nuclear power station will dispose of low level radioactive waste during operations; this will include operational discharges of lower activity radioactive aqueous and gaseous effluent into the environment.

293. This report presents the methodology used and the results of prospective radiological assessments of dose to members of the public associated with the operational phase of SZC. Assessments have been carried out as follows, along with sensitivity analyses and screening assessments.

- Annual doses to CRP, i.e. an individual receiving a prospective dose that is representative of the more highly exposed individuals in the population arising from continuous discharges of aqueous and gaseous radionuclides into the environment.
- Collective dose to UK, EU and world populations.
- Dose from exposure to direct radiation and skyshine from site infrastructure.
- Annual dose to the representative person from aqueous, gaseous and external radiation (including direct radiation and skyshine).
- Dose from short-term releases of gaseous radionuclides into the atmosphere.
- Build-up of radionuclides in the environment.

294. The approaches advocated by the NDAWG, the Environment Agency and international and national advisory bodies such as the ICRP and PHE have been adopted for assessing the impact of continuous discharges from SZC. This has included an initial assessment using the IRAT developed by the Environment Agency and a more detailed assessment using the PC-CREAM 08 software suite of dispersion and dose assessment modules. Assessment of short-term discharges has been undertaken using the industry standard ADMS modelling tool. Impacts have been assessed at the proposed discharge limits, which were derived based on the limits permitted for HPC.

295. The annual dose to the adult, child and infant members of the fishing family from exposure to aqueous discharges from SZC, summed across the relevant marine pathways, is calculated to be 10 µSv/y, 4.9 µSv/y and 1.3 µSv/y, respectively. The dominant pathway for all age groups is the ingestion of fish which contributes around 67%, 86% and 70% to the doses for adult, child and infant respectively. C-14 is the dominant radionuclide, contributing between 93% and 98% of the assessed dose to the fishing family. The cumulative annual dose to the adult, child and infant members of the fishing family from exposure to combined aqueous discharges from SZB and C was calculated to be 12 µSv/y, 5.3 µSv/y and 1.4 µSv/y, respectively. Again, C-14 was the dominant radionuclide and ingestion of fish was the dominant exposure pathway. The annual dose to an adult houseboat occupant and a wildfowler from exposure to aqueous discharges from SZC, and from SZB and C combined were less than 0.2 µSv/y.

296. The annual dose to the adult, child and infant members of the farming family from exposure to gaseous discharges from SZC, summed across the relevant terrestrial pathways, is calculated to be 4.0 µSv/y, 3.3 µSv/y and 6.9 µSv/y, respectively. The dominant pathway is the ingestion of cow milk which contributes around 40%, 67% and 87% of the assessed dose to adult, child and infant age groups respectively. C-14 is the dominant radionuclide, contributing between 89% and 94% of the assessed dose to the farming family. The corresponding dose to the SZB worker is 4.1 µSv/y and is dominated by the ingestion of cow milk and root vegetables. The annual dose to the adult, child and infant members of the farming family from exposure to combined gaseous discharges from SZB and SZC was calculated to be 5.6 µSv/y, 4.7 µSv/y and 9.8 µSv/y respectively. Again, ingestion of milk is the dominant pathway and C-14 was the dominant radionuclide. The annual dose to the SZB worker from the combined discharges of gaseous radionuclides from SZB and C was calculated to be 5.9 µSv/y.

297. The exposure of members of the public from direct radiation emanating from the SZC reactor buildings will be negligible due to the shielding incorporated into the design of the reactor buildings (for instance as demonstrated by SZB). Direct radiation from SZC is therefore largely attributable to the HHK and HHI on site. The annual dose to the SZB worker from exposure to direct radiation from SZC is calculated to be 3.7 µSv/y. The dose to a local resident is calculated to be significantly lower (0.0029 µSv/y to an adult), as was the dose to a dog walker (0.022 µSv/y). Skyshine doses were at least one order of magnitude smaller than the direct dose for all CRPs. A sensitivity analysis indicated that if skyshine doses were increased by two orders of magnitude, the total dose from radiation emanating from the stores would still be of the order of a few nanosieverts, except in the case of the SZB worker, for whom the

total dose would be 3.8 µSv/y.Typical cosmic background is in the order of 45 nGy/hr i.e. slightly less than 350 µSv/y (using a Gy to Sv conversion of 0.85) [Ref 44] [Ref 42]. Hence direct radiation exposure to the SZB worker is about 1% of natural cosmic background, and dose to a local resident is negligible in comparison.

298. The highest dose from exposure to the combined aqueous and gaseous discharges and from exposure to direct radiation from SZC is 13 µSv/y to an adult member of the fishing family. This individual is therefore considered to be the representative person. This dose is significantly less than the current source dose constraint of 300 µSv/y, and a factor of 10 lower than the dose constraint of 150 µSv/y proposed by HPA for new nuclear facilities.

299. Short-term doses are required to be assessed explicitly, in addition to the doses from continuous releases. The dose to the adult, child and infant members of the farming family from exposure to short-term discharges of gaseous radionuclides from SZC, summed across the relevant terrestrial pathways, is calculated to be 3.8 µSv/y, 3.5 µSv/y and 6.9 µSv/y, respectively. The dominant pathway is the ingestion of cow milk which contributes around 43%, 64% and 87% of the short-term dose to adult, child and infant age groups respectively. Ingestion pathways account for around 98% to 99% of the calculated short-term doses. C-14 is the dominant radionuclide, accounting for 99% of the assessed dose to the farming family.

300. The collective dose is the time-integrated dose to a population from a single year of discharge. The collective dose from discharges of aqueous radionuclides to the marine environment from SZC at the proposed limits is assessed to be 0.035 manSv/y, 0.21 manSv/y and 2.3 manSv/y to UK, EU and World population respectively. The collective dose from gaseous discharges at proposed annual limits from SZC is estimated to be: 0.23 manSv/y, 1.0 manSv/y and 25 manSv/y to UK, EU and World population respectively. In both instances, over 99% of the collective dose to all three population groups was predicted to arise from C-14. The per caput dose to UK, EU and World population from both aqueous and gaseous discharges was calculated to be between 2.1 nSv/y and 4.5 nSv/y for discharges from SZC (and between 2.6 nSv/y and 6.0 nSv/y for discharges from SZB and SZC). The UK regulatory agencies and advisory bodies consider that the risks associated with annual average per caput dose in the nSv range are trivial and should be ignored in the authorisation decision making processes.

301. The dose from the build-up of gaseous radionuclides discharged from SZC and deposited on the ground, assessed as total dose to a construction worker, is trivial, calculated to be 0.0034 µSv/y.

302. The dose to the representative person from the site (i.e. SZB and SZC) was 17 µSv/y, which is 3.4% of the site dose constraint (500 µSv/y), The annual dose to the representative person including historical and future discharges was estimated to be 53 µSv/y, 5.3% of the 1 mSv public dose constraint.

303. The Environment Agency recommends that a review of uncertainty and variability associated with key assumptions used in dose assessment be carried out in the event that the estimated dose to the representative person exceeds 20 µSv/y. The specific assumptions and parameters analysed were:

- Discharges - expected best performance discharges against proposed limits.
- Habits Data - generic food ingestion rate against site specific food ingestion rates.
- Food Source – 100% locally sourced seafood against 50% locally sourced seafood.

304. The dose to adult, child and infant members of the fishing family arising from discharge at expected best performance is calculated to be 2.4 µSv/y, 1.2 µSv/y and 0.32 µSv/y respectively. This corresponds to approximately, 23% to 24% of the dose predicted to arise from discharges at the annual limits, a reduction in dose by around a factor of four. The dose to adult, child and infant members of the farming family arising from discharges at expected best performance is calculated to be 1.9 µSv/y, 1.5 µSv/y and 3.2 µSv/y respectively. This corresponds to approximately 46% to 48% of the dose predicted to arise from discharges at the annual limits, a reduction in dose by around a factor of two. The use of site-specific food ingestion rates results in a dose estimate that is broadly comparable to that calculated using generic ingestion rates. Revised habitat data may affect the results, but given similarity to national rates, which are commonly assumed to be relatively pessimistic, any changes in local habitat

data are unlikely to result in a significant increase in ingestion doses. However, if only 50% of all seafood is sourced from the local compartment then this ingestion dose pathway is effectively halved. Overall, it is considered that the approach for assessing the dose to CRPs via food ingestion pathways adopted for the SZC RIA represents a reasonable and robust approach, and has not resulted in a significant underestimation of the dose to CRPs.

305. Dose to a foetus was calculated assuming that the mother was the representative person – an adult member of the fishing family. The calculated dose to the foetus was 17 µSv/y, which is higher than the doses calculated for other age groups for combined discharges from SZC. However, the dose constitutes less than 6% of the statutory (source and site) dose constraints of 300 and 500 µSv/y and is considered to be low.

306. All individual doses calculated were significantly less than the corresponding source and site constraints and public dose limit. Sensitivity analyses have shown that the predicted doses are likely to be bounding and that actual exposure will be less. Collective dose has also been shown to be trivial.

APPENDIX A SCREENING ASSESSMENTS

A.1 Introduction

307. The RIAs carried out in support of the application for an environmental permit application under the EPR16 for the proposed SZC nuclear power station focussed on key exposure pathways associated with predicted aqueous and gaseous discharges from the power station. However, it is recognised that there are circumstances where operational, environmental or habit factors may result in higher than expected doses from otherwise unimportant exposure pathways.

308. This appendix forms an addendum to the main RIA Report for SZC. It presents a concise account of the methodology and results of the following screening assessments:

- Dose to foetus and breastfed infant.
- Inadvertent ingestion of sediment and seawater.
- Inhalation of sea spray incorporating enhanced radionuclide concentration.
- Discharge of elevated levels of tritium in aqueous discharges over a short duration.

309. Furthermore, regulatory guidance recommends that a review of uncertainty and variability associated with key assumptions used in dose assessment be carried out where the estimated dose to the representative person exceeds 20 μSv/y - to provide confidence that an appropriate level of caution has been applied, but also to ensure that the assessment is not overly pessimistic [Ref 4]. Such reviews may include sensitivity analyses of key input parameters used in carrying out the radiological assessments [Ref 63]. Thus, sensitivity analyses of selected parameters used to undertake the RIA for SZC have also been carried out and presented in this document (see Section 8). The parameters analysed are:

- Discharges - expected best performance discharges against proposed limits.
- Habits Data - generic food ingestion rate against site-specific food ingestion rates.
- Food Source – 100% locally sourced seafood against 50% locally sourced seafood.

A.2 Dose to Foetus and Breastfed Infant

A.2.1 Introduction

310. It is recognised that there are circumstances in which the foetus and breastfed infant may receive higher doses than the mother and the ICRP has published dose coefficients for assessing doses to the foetus and breastfed infant for discharges to the environment [Ref 66].

311. The HPA (now PHE) has published a guidance document on the assessment of foetal dose and considers that, for planned discharges, the additional risk from exposure in utero is small compared with the lifetime risk [Ref 65]. The HPA advises that dose to the foetus need only be considered for four radionuclides (i.e. P-32, P-33, Ca-45 and Sr-90) in situations where these radionuclides form a significant part of any release to the environment [Ref 65]. For discharges of other radionuclides, the assessment of doses to other age groups is considered appropriate and explicit assessment of dose to the foetus is not required to be undertaken [Ref 65].

312. However, it is recognised that H-3 and C-14 also have an increased multiplier for foetal doses (albeit, not to the same extent as the previously identified radionuclides) [Ref 65] [Ref 69]. Given the dominance of C-14 in terms of dose contribution and the higher multiplier of H-3 (see Table A-1 below), a screening assessment of dose to the foetus and breastfed infant has been carried out for discharges from SZC.

A.2.2 Assessment Methodology

313. The screening assessment of the dose to foetus and breastfed infant was carried out by multiplying the annual dose to the representative person (adult member of the fishing family) from ingestion of radionuclides for SZC discharges by a 'dose multiplier' for key radionuclides, taken from reference [Ref 69][23]. The dose multipliers were derived as the ratio of offspring (foetus and breastfed infant) dose to reference adult dose.

314. The methods used to calculate the dose to foetus and breastfed infant are described in Phipps [Ref 69] [Ref 70]. The methods consider the intake (via ingestion and inhalation) of radionuclides by pregnant women and breastfeeding mothers for a number of chronic and acute intake scenarios (before, during and after conception and birth). Transfer from mother to foetus (in utero) and breastfed infant (via milk), and the consequent doses are evaluated using biokinetic and dosimetric models largely based on ICRP recommendations. The dose to reference adult is calculated using dose coefficients for a worker taken from ICRP Publication 68 [Ref 71]. Further details can be found in references [Ref 69] [Ref 70].

315. Table A-1 below presents the dose multipliers (the ratio of offspring dose to the reference adult dose) for key radionuclides predicted to be discharged from SZC. They are appropriate for the case where there is chronic ingestion by the mother throughout pregnancy and lactation [Ref 69].

Table A-1 Ratio of the Dose to Foetus and Breastfed Infant to that of an Adult* (mother) for key Radionuclides in the SZC Inventory [taken from reference [Ref 69]].

Radionuclide	**Ratio of offspring to adult dose for:**			
	Chronic ingestion throughout pregnancy, exposure of:		**Chronic intake throughout lactation, exposure of infant via milk**	**Chronic intake throughout pregnancy and lactation; fraction of offspring dose via milk#**
	Foetus##	**Infant via milk**		
C-14 (organic)	1.4	0.12	0.45	0.29
Co-60 (*f1=0.1*)	0.56	0.03	0.58	0.52
Cs-137	0.44	0.07	0.2	0.38
H-3 (HTO)	1.7	0.06	1.1	0.41
I-131	1.1	0.001	2.52	0.7

*Reference adult dose coefficients from ICRP Publication 68 [Ref 71].

**Gut uptake fractions (f1) are given only in cases where results are available for more than one value.

#Derived as the sum of columns 3 and 4 divided by the sum of columns 2, 3 and 4.

##Includes dose received in utero and from activity retained by the child at birth, taken from Phipps et al. 2001 [Ref 70].

A.2.3 Results and Discussion

316. Table A-2 presents the dose to foetus and breastfed infant, scaled from the assessed dose to the representative person for SZC. The dose to foetus and breastfed infant from aqueous and gaseous discharges from SZC, at proposed annual limits, is calculated to be 17 µSv/y and 5.6 µSv/y respectively. C-14 accounts for 97-99% of the calculated dose.

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[23] These ratios are similar to those published by HPA [Ref 65], but contain slightly expanded list of radionuclides relevant to Sizewell C.

Table A-2 Dose to Foetus and Breastfed Infant due to Discharges of Aqueous and Gaseous Effluent from Sizewell C

Radionuclide	Terrestrial dose (µSv/y)	Marine dose (µSv/y)	Total dose to mother (µSv/y)	% Contribution to total mother dose	Ratio of foetus to mother dose	Ratio of breastfed infant to mother dose	Dose to foetus (µSv/y)	Dose to breastfed infant (µSv/y)
C-14	2.5E+00	9.5E+00	1.2E+01	90.3%	1.4E+00	4.5E-01	1.7E+01	5.4E+00
Co-60	1.6E-05	1.8E-02	1.8E-02	0.1%	5.6E-01	5.8E-01	1.0E-02	1.0E-02
Cs-137	4.8E-04	8.0E-03	8.4E-03	0.1%	4.4E-01	2.0E-01	3.7E-03	1.7E-03
H-3	7.5E-02	1.8E-02	9.3E-02	0.7%	1.7E+00	1.1E+00	1.6E-01	1.0E-01
I-131	2.4E-02	1.0E-04	2.4E-02	0.2%	1.1E+00	2.5E+00	2.6E-02	5.9E-02
Total	2.6E+00	9.5E+00	1.2E+01	91.4%	-	-	**1.7E+01**	**5.6E+00**

317. The dose to foetus from SZC is higher than the doses calculated for other age groups for combined discharges. However, the dose constitutes less than 6% of the statutory (source and site) dose constraints of 300 and 500 µSv/y and is considered to be low. The dose to breastfed infant is comparable to the dose to an infant member of the fishing family, both of which are much lower than the dose to foetus.

A.3 Inadvertent Ingestion of Sediment and Seawater

A.3.1 Introduction

318. Members of the public pursuing recreational activities along coastal environments may be exposed to discharged aqueous radionuclides through inadvertent ingestion of seawater and coastal sediment. The contribution of these pathways to the overall dose is insignificant when compared to other pathways associated with marine discharges (e.g. seafood ingestion and external exposure over sediment) [Ref 29] and these pathways are considered to be unimportant [Ref 37] [Ref 63]. However, it is recognised that these pathways may merit investigating under certain circumstances, for instance, the relative contribution from the ingestion of sediment may be higher for infants, as they receive less exposure from conventional pathways [Ref 63].

319. A screening assessment of potential doses from inadvertent ingestion of seawater and coastal sediment incorporating radionuclides entrained in aqueous discharges from SZC has therefore been carried out.

A.3.2 Assessment Methodology

320. The assessment of dose from the inadvertent ingestion of seawater and sediment has been carried out by combining the radionuclide concentration in unfiltered seawater and seabed sediment (modelled within the DORIS module of PC-CREAM 08 using SZC proposed annual discharge limits), ICRP ingestion dose coefficients taken from PC-CREAM 08 [Ref 28], and inadvertent ingestion rates taken from NRPB-W41 [Ref 35]. Table A-3 to Table A-5 below present the data used to calculate the dose to adult, child and infant age groups from inadvertent ingestion of seawater and coastal sediment.

Table A-3 Environmental Concentration Parameters

Radionuclide	Annual limit discharges (Bq/y)		Environmental concentration (for unit discharge in the 60th year)	
	Sizewell C	Sizewell B and C	Activity concentration in seawater (Bq/l)	Activity concentration in seabed sediment (Bq/kg)
Ag-110m	1.12E+09	1.12E+09	8.73E-14	4.33E-12
C-14	1.90E+11	1.90E+11	9.18E-14	1.48E-10
Co-58	4.07E+09	4.07E+09	7.16E-14	1.20E-11
Co-60	6.00E+09	6.00E+09	8.22E-14	2.72E-10
Cr-51	1.18E+08	1.18E+08	6.26E-14	3.52E-12
Cs-134	1.10E+09	1.31E+11	8.83E-14	2.93E-11
Cs-137	1.90E+09	2.19E+10	9.09E-14	1.50E-10
H-3	2.00E+14	2.80E+14	9.18E-14	1.58E-13
I-131	9.83E+07	9.83E+07	4.24E-14	9.31E-15
Xe-131m (I-131)*	9.83E+07	9.83E+07	1.85E-14	1.04E-14
Mn-54	5.31E+08	5.31E+08	7.82E-14	5.51E-11
Ni-63	1.89E+09	1.89E+09	8.92E-14	8.36E-10
Sb-124	9.63E+08	9.63E+08	7.83E-14	9.79E-13
Sb-125	1.60E+09	1.60E+09	9.01E-14	1.54E-11
Te-125m (Sb-125)*	1.60E+09	1.60E+09	1.29E-14	1.54E-11
Te-123m	5.11E+08	5.11E+08	8.39E-14	2.06E-12
Te-123 (Te-123m)*	5.11E+08	5.11E+08	2.61E-28	2.49E-24

* Progeny of the parent radionuclide, which is shown in brackets

Table A-4 Ingestion Dose Coefficients [Taken from PC-CREAM 08]

Radionuclide	Adult ingestion dose coefficient (Sv/Bq)	Child ingestion dose coefficient (Sv/Bq)	Infant ingestion dose coefficient (Sv/Bq)	F1*
Ag-110m	2.80E-09	5.20E-09	1.40E-08	5.00E-02
C-14	5.80E-10	8.00E-10	1.60E-09	1.00E+00
Co-58	7.40E-10	1.70E-09	4.40E-09	1.00E-01
Co-60	3.40E-09	1.10E-08	2.70E-08	1.00E-01
Cr-51	3.80E-11	7.80E-11	2.30E-10	1.00E-01
Cs-134	1.90E-08	1.40E-08	1.60E-08	1.00E+00
Cs-137	1.30E-08	1.00E-08	1.20E-08	1.00E+00
H-3	1.80E-11	2.30E-11	4.80E-11	1.00E+00
I-131	2.20E-08	5.20E-08	1.80E-07	1.00E+00
Xe-131m (I-131)	-	-	-	-
Mn-54	7.10E-10	1.30E-09	3.10E-09	1.00E-01
Ni-63	1.50E-10	2.80E-10	8.40E-10	5.00E-02
Sb-124	2.50E-09	5.20E-09	1.60E-08	1.00E-01
Sb-125	1.10E-09	2.10E-09	6.10E-09	1.00E-01
Te-125m (Sb-125)	8.70E-10	1.90E-09	6.30E-09	3.00E-01
Te-123m	1.40E-09	2.80E-09	8.80E-09	3.00E-01
Te-123 (Te-123m)	4.40E-09	5.40E-09	9.30E-09	3.00E-01

* This is the gut transfer factors, which approximates the fraction of radionuclide intake that reaches the circulatory system from the gastrointestinal tract.

Table A-5 Inadvertent Ingestion Rates [Taken from NRPB-W41 [Ref 35]]

Ingestion Rates	Adult	Child (10y)	Infant (1y)
Inadvertent ingestion of seawater (l/y) (higher than average)	5.00E-01	5.00E-01	2.00E-01
Inadvertent ingestion rates of soil (kg/y) (high-rate ingestion rates)	8.30E-03	1.80E-02	4.40E-02

A.3.3 Results and Discussion

321. The highest dose from exposure through the combined inadvertent ingestion of seawater and seabed sediment incorporating radionuclides from aqueous discharges from SZC is calculated to be 0.0044 µSv/y to an infant. The corresponding dose from the combined aqueous discharges from SZB and SZC is calculated to be 0.0088 µSv/y. The breakdown of the doses by radionuclides in presented in Table A-6 below.

Table A-6 Dose from Inadvertent Ingestion of Seawater and Sediment (µSv/y) from Sizewell C Discharges

Radionuclide	SZC Discharges			SZB and C Discharges		
	Adult	Child	Infant	Adult	Child	Infant
Ag-110m	2.5E-07	7.1E-07	3.3E-06	2.5E-07	7.1E-07	3.3E-06
C-14	1.4E-04	4.1E-04	2.0E-03	1.4E-04	4.1E-04	2.0E-03
Co-58	4.1E-07	1.7E-06	9.7E-06	4.1E-07	1.7E-06	9.7E-06
Co-60	4.7E-05	3.3E-04	1.9E-03	4.7E-05	3.3E-04	1.9E-03
Cr-51	2.7E-10	8.7E-10	4.5E-09	2.7E-10	8.7E-10	4.5E-09
Cs-134	6.0E-06	8.8E-06	2.3E-05	7.2E-04	1.0E-03	2.7E-03
Cs-137	3.2E-05	5.2E-05	1.5E-04	3.7E-04	6.0E-04	1.7E-03
H-3	1.7E-04	2.2E-04	2.4E-04	2.4E-04	3.1E-04	3.4E-04
I-131	4.6E-08	1.1E-07	1.6E-07	4.6E-08	1.1E-07	1.6E-07
Xe-131m (I-131)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Mn-54	1.9E-07	7.1E-07	4.0E-06	1.9E-07	7.1E-07	4.0E-06
Ni-63	2.0E-06	8.0E-06	5.8E-05	2.0E-06	8.0E-06	5.8E-05
Sb-124	1.1E-07	2.8E-07	9.1E-07	1.1E-07	2.8E-07	9.1E-07
Sb-125	3.0E-07	1.1E-06	6.8E-06	3.0E-07	1.1E-06	6.8E-06
Te-125m (Sb-125)	1.9E-07	8.6E-07	6.9E-06	1.9E-07	8.6E-07	6.9E-06
Te-123m	4.2E-08	1.1E-07	4.8E-07	4.2E-08	1.1E-07	4.8E-07
Te-123 (Te-123m)	4.7E-20	1.2E-19	5.2E-19	4.7E-20	1.2E-19	5.2E-19
Total	**4.0E-04**	**1.0E-03**	**4.4E-03**	**1.5E-03**	**2.7E-03**	**8.8E-03**

322. The dose to infant, the most exposed member of the public, from SZC discharges is dominated by C-14 and Co-60, which contribute 45% and 44% respectively. For the combined discharges from SZB and SZC, the dominant radionuclides are Cs-134, which accounts for 31% of the dose, C-14 and Co-60, which contribute around 22% each and Cs-137, which contributes 20%.

A.3.4 Conclusion

323. From the above, it can be seen that the contribution of inadvertent ingestion pathways to the overall dose to members of the public is of the order of a few nSv/y and is therefore insignificant.

A.4 Inhalation of Sea Spray Incorporating Enhanced Radionuclide Concentration

A.4.1 Introduction

324. The inhalation of radionuclides entrained in sea spray is normally considered to be a minor exposure pathway when compared to other pathways associated with discharges of aqueous radionuclides into the marine environment such as ingestion of seafood and exposure over coastal sediment [Ref 63]. However, studies investigating the sea-to-land transfer of radionuclides discharged to sea have reported that the enrichment of actinides in airborne materials is up to three orders of magnitude greater than that of the seawater concentration [Ref 68]. These studies also suggest that the formation of 'spume' or stable foam, which has a high particulate loading, can be an important medium for the sea-to-land transfer of radionuclides in areas where this occurrence is prevalent.

325. Aqueous radionuclides discharged into the sea, partitioned between the particulate and dissolved fractions of the marine environment, are scavenged by rising air bubbles created when breaking waves force air into the water column which is then brought to the surface, forming a layer of foam with potentially enriched levels of radioactivity. This enriched layer may then be incorporated into fine aerosol generated by the action of the wind on the sea surface (wave shearing and bubble bursting) and blown across coastal areas as sea spray [Ref 68]. Members of the public spending time along coastal areas may therefore inhale enhanced levels of radionuclides entrained in sea spray.

326. Thus, an assessment of potential exposure of users of the coastal area adjacent to SZC via inhalation of enhanced concentration of radionuclides in sea spray has been undertaken. SZC aqueous discharges do not include actinides and therefore are not subject to the high enrichment in airborne materials observed for actinides. Inhalation of radionuclides in sea spray is therefore a minor exposure pathway for SZC.

A.4.2 Assessment Methodology

327. The assessment of sea spray dose follows the cautious approach adopted by the Environment Agency for HPC, which is based on CEFAS' aquatic dosimetric model (ADO) [Ref 72]. The ADO methodology is based on the application of simple, cautious 'vapour in air' and 'particle in air' loading factors, taken from references [Ref 73] and [Ref 74] respectively, to estimate the concentration of radionuclides in air, relative to the concentration in seawater and coastal sediment, respectively.

328. Sea spray (vapour in air component) is assumed to be present in air at an enhanced atmospheric concentration of 10 g/m^3, with an activity concentration equivalent to the unfiltered seawater component of the local marine compartment (modelled within the DORIS module in PC-CREAM 08). Resuspended coastal sediment is (the particle in air component) assumed to be present in air at a concentration of 0.1 mg/m^3 [Ref 74], with an activity concentration equivalent to that of the seabed sediment component of the local marine compartment (modelled within DORIS module of PC-CREAM 08).

329. The mathematical relationship and parameter values used to calculate the dose from the sea spray and resuspended sediment are provided below:

Equation 7

$$D_{inh} = Conc._{usw}\, CF_{vapour} DC_{inh}\, Inh.Rate\; Occ._{coast}\;\; M$$

330. Where

***Conc.**usw, sbs.* = concentration in unfiltered seawater or seabed sediment (Bq/kg, a conversion factor of 1 l = 1 kg was used for seawater) (PC-CREAM 08 DORIS output for Sizewell local compartment, scaled to proposed discharge limits. Values as shown in Table A-3.

$CF_{vapour, particle}$ = vapour in air or particle in air loading factor (g/m^3)

DC_{inh} = inhalation dose coefficients (Sv/Bq) (Table A-7, taken from PC-CREAM 08; H-3, C-14 and I-131 taken from ICRP Publication 119 [Ref 41] for the vapour doses, consistent with the approach described in the main RIA Report).

Inh. Rate = inhalation rate (m^3/h) (based on the fishing family described in the main RIA Report).

$Occ._{coast}$ = occupancy along the coast (h/y) (based on the 2015 CEFAS survey as described in the main RIA Report).

M = 1.0E-3 (kg/g mass correction factor).

Table A-7 Inhalation Dose Coefficients [Taken from PC-CREAM 08]

Radionuclide	Adult	Child	Infant	Absorption type*
Ag-110m	7.60E-09	1.20E-08	2.80E-08	m
C-14 (particle)	2.00E-09	2.80E-09	6.60E-09	m
C-14 (vapour)	5.80E-10	7.90E-10	1.60E-09	v
Co-58	1.60E-09	2.40E-09	6.50E-09	m
Co-60	1.00E-08	1.50E-08	3.40E-08	m
Cr-51	3.70E-11	6.60E-11	2.10E-10	s
Cs-134	6.60E-09	5.30E-09	7.30E-09	f
Cs-137	4.60E-09	3.70E-09	5.40E-09	f
H-3 (particle)	1.80E-11	2.30E-11	4.80E-11	v
H-3 (vapour)	4.50E-11	8.20E-11	2.70E-10	m
I-131 (particle)	7.40E-09	1.90E-08	7.20E-08	f
I-131 (vapour)	2.00E-08	4.80E-08	1.60E-07	v
Xe-131m (I-131)*	0.00E+00	0.00E+00	0.00E+00	g
Mn-54	1.50E-09	2.40E-09	6.20E-09	m
Ni-63	4.80E-10	7.00E-10	1.90E-09	m
Sb-124	6.40E-09	9.60E-09	2.40E-08	m
Sb-125	4.80E-09	6.80E-09	1.60E-08	m
Te-125m (Sb-125)*	3.40E-09	4.80E-09	1.10E-08	m
Te-123m	4.00E-09	5.70E-09	1.30E-08	m
Te-123 (Te-123m)*	1.90E-09	2.30E-09	4.40E-09	m

[#]Inhalation dose coefficients for H-3, C-14 and I-131 in vapour are based on ICRP Publication 119 [Ref 41].

*The radionuclide in brackets is the parent of the radionuclide listed.

Table A-8 Assessment Parameters

Parameter	Adult	Child	Infant
Inhalation rates (m^3/h) (fishing family)	1.69	1.12	0.35
Occupancy on coast (h/y) (97.5th percentile rates)	2960	331	94
Particle-in-air (resuspension) concentration factor (g/m^3)	1.0E-04	1.0E-04	1.0E-04
Vapour-in-air concentration factor (g/m^3)	10	10	10

A.4.3 Results and Discussion

331. The highest dose from exposure through the inhalation of sea spray vapour incorporating enhanced concentrations of radionuclides from aqueous discharges from SZC was calculated as 0.042 µSv/y to an adult, and the corresponding dose from the combined aqueous discharges from SZB and C was calculated to be 0.063 µSv/y. The breakdown of the doses by radionuclides is presented in Table A-9 below.

Table A-9 Sea spray Vapour Inhalation Dose (µSv/y) from Sizewell C Discharges and combined Sizewell B and C Discharges

Radionuclide	SZC Discharges			SZB and C Discharges		
	Adult	Child	Infant	Adult	Child	Infant
Ag-110m	3.7E-05	4.3E-06	9.0E-07	3.7E-05	4.3E-06	9.0E-07
C-14	5.1E-04	5.1E-05	9.2E-06	5.1E-04	5.1E-05	9.2E-06

Co-58	2.3E-05	2.6E-06	6.2E-07	2.3E-05	2.6E-06	6.2E-07
Co-60	2.5E-04	2.7E-05	5.5E-06	2.5E-04	2.7E-05	5.5E-06
Cr-51	1.4E-08	1.8E-09	5.1E-10	1.4E-08	1.8E-09	5.1E-10
Cs-134	3.2E-05	1.9E-06	2.3E-07	3.8E-03	2.3E-04	2.8E-05
Cs-137	4.0E-05	2.4E-06	3.1E-07	4.6E-04	2.7E-05	3.5E-06
H-3	4.1E-02	5.6E-03	1.6E-03	5.8E-02	7.8E-03	2.3E-03
I-131 (Xe-131m)*	4.2E-06	7.4E-07	2.2E-07	4.2E-06	7.4E-07	2.2E-07
Mn-54	3.1E-06	3.7E-07	8.5E-08	3.1E-06	3.7E-07	8.5E-08
Ni-63	4.0E-06	4.4E-07	1.1E-07	4.0E-06	4.4E-07	1.1E-07
Sb-124	2.4E-05	2.7E-06	6.0E-07	2.4E-05	2.7E-06	6.0E-07
Sb-125 (Te-125m)*	3.8E-05	4.0E-06	8.3E-07	3.8E-05	4.0E-06	8.3E-07
Te-123m (Te-123)*	8.6E-06	9.1E-07	1.8E-07	8.6E-06	9.1E-07	1.8E-07
Total	**4.2E-02**	**5.7E-03**	**1.6E-03**	**6.3E-02**	**8.2E-03**	**2.3E-03**

***** Dose from progeny (shown in brackets) was calculated explicitly and is included in the dose from the parent

332. The highest dose from exposure through the inhalation of suspended seabed sediment incorporating enhanced concentrations of radionuclides from aqueous discharges from SZC was calculated as 3.8E-05 µSv/y to an adult, and the corresponding dose from the combined aqueous discharges from SZB and SZC was calculated to be 6.2E-05 µSv/y. The breakdown of the doses by radionuclides is presented in Table A-10 below.

Table A-10 Sea spray Sediment Inhalation Dose (μSv/y) from Sizewell C Discharges and combined Sizewell B and C Discharges

Radionuclide	**SZC Discharges**			**SZB and C Discharges**		
	Adult	Child	Infant	Adult	Child	Infant
Ag-110m	1.8E-08	2.2E-09	4.5E-10	1.8E-08	2.2E-09	4.5E-10
C-14	2.8E-05	2.9E-06	6.1E-07	2.8E-05	2.9E-06	6.1E-07
Co-58	3.9E-08	4.3E-09	1.0E-09	3.9E-08	4.3E-09	1.0E-09
Co-60	8.2E-06	9.1E-07	1.8E-07	8.2E-06	9.1E-07	1.8E-07
Cr-51	7.7E-12	1.0E-12	2.9E-13	7.7E-12	1.0E-12	2.9E-13
Cs-134	1.1E-07	6.3E-09	7.7E-10	1.3E-05	7.5E-07	9.2E-08
Cs-137	6.6E-07	3.9E-08	5.1E-09	7.6E-06	4.5E-07	5.8E-08
H-3	2.8E-07	2.7E-08	5.0E-09	4.0E-07	3.8E-08	7.0E-09
I-131 (Xe-131m)*	3.4E-12	6.4E-13	2.2E-13	4.2E-06	6.4E-13	2.2E-13
Mn-54	2.2E-08	2.6E-09	6.0E-10	2.2E-08	2.6E-09	6.0E-10
Ni-63	3.8E-07	4.1E-08	9.9E-09	3.8E-07	4.1E-08	9.9E-09
Sb-124	3.0E-09	3.4E-10	7.4E-11	3.0E-09	3.4E-10	7.4E-11
Sb-125 (Te-125m)*	1.0E-07	1.1E-08	2.2E-09	1.0E-07	1.1E-08	2.2E-09
Te-123m (Te-123)*	2.1E-09	2.2E-10	4.5E-11	2.1E-09	2.2E-10	4.5E-11
Total	**3.8E-05**	**4.0E-06**	**8.2E-07**	**6.2E-05**	**5.1E-06**	**9.7E-07**

* Dose from progeny (shown in brackets) was calculated explicitly and is included in the dose from the parent

333. The doses resulting from inhalation of vapour are three orders of magnitude larger than those resulting from inhalation of suspended particles. The doses to all age groups are dominated by the inhalation of H-3 in sea spray vapour, which accounts for 98-99% of the dose from the inhalation of sea spray at the proposed annual limits for SZC and 92-98% of the dose from the inhalation of sea spray using combined SZB and SZC limits.

334. Compared to the dose to the members of the fishing family from other aquatic discharge exposure pathways, doses here are ≤0.4 % of the total dose for all age groups for discharges from SZC and ≤0.5% of the total dose for all age groups for discharges from SZB and SZC combined.

A.4.4 Conclusion

335. From the above, it can be seen that the contribution of sea spray inhalation and the inhalation of resuspended coastal sediment to the overall dose to members of the public is of the order of a few nSv/y and can therefore be considered insignificant.

A.5 Enhanced Discharge of Tritium in Aqueous Effluent

A.5.1 Introduction

336. The transfer and accumulation of H-3 in aquatic environments and living tissues is controlled, largely, by the chemical form in which it occurs. Tritium normally occurs in two chemical forms in aquatic and biological systems - tritiated water (HTO) and organically bound tritium (OBT).

337. Tritiated water is the most abundant form of H-3 in organisms and the natural environment; this is the dominant form of H-3 discharges released by nuclear facilities. It is also formed through the oxidation of gaseous H-3 (HT) by light or the action of microorganisms [Ref 75]. Tritiated water readily exchanges with water (H2O) and is distributed relatively homogenously in environmental and biological systems. The heavier atomic mass of H-3 compared to

hydrogen (H-1) often results in low level enrichment of HTO in the condensed phase. H-3 has an average biological half-life of around ten days in adults, hence has a relatively low radiological toxicity because it is rapidly excreted from the body [Ref 76].

338. Organically bound H-3 is formed when H-3 is incorporated into organic molecules (for instance, through photosynthesis) which may subsequently become fixed in biological tissues. Thus, OBT may concentrate in a medium and its distribution in environmental and biological systems is more heterogeneous (than HTO), depending on the properties of the host molecules and system chemistry. OBT may occur in the exchangeable or non-exchangeable form, depending on its affinity to - and the nature of bonding to - the host organic molecule and system chemistry [Ref 75].

339. Tritium discharged from SZC will be in the form HTO, although it is recognised that a fraction of this discharge may become incorporated into biological tissues and transform into OBT. OBT has a longer residence time in tissue than HTO and is therefore of greater radiological concern than HTO [Ref 75]. The specific activity model for H-3 in PC-CREAM 08, does not take account of the effects of OBT [Ref 29] and OBT has therefore not been assessed separately for the purpose of the SZC RIA. However, it is considered that this would not result in significant underestimation of assessed doses for the following reasons:

- The ratio of OBT in organisms to HTO seawater (OBTorg/HTOsea) is observed to be largely dependent on the chemical form of the H-3 ingested [Ref 75]. Thus, the concentration of OBT in marine organisms (that is attributable to SZC, which predominantly discharges HTO) can be expected to be low.
- A large fraction of OBT ingested by organisms and humans will be reconverted and lost as HTO during metabolic processes and only a limited fraction of OBT will be incorporated into tissues and organs [Ref 17] [Ref 77];

340. Furthermore, in PC-CREAM 08 (DORIS), the uptake of radionuclides (including H-3) by marine organisms is dependent on the activity concentration of the radionuclides in the water column (filtered seawater). Thus, the transfer of H-3 onto organic sediment will serve to reduce the concentration of the radionuclide in the water column and therefore reduce the overall bioavailability of the H-3 [Ref 78].

341. The impacts of OBT associated with the discharge of H-3 from SZC is therefore considered to be insignificant.

A.5.2 Potential Impact of Enhanced Levels of Tritium in Aqueous Discharges from Sizewell C

342. The release of enhanced levels of HTO in aqueous discharges during certain activities (e.g. shut down operations) in the operational cycle of a UK EPR^{TM} reactor is a feature of that reactor design. It is estimated that up to 80% of the H-3 annual inventory may be discharged over a period of two months. The potential impact such releases is considered in the below paragraphs.

343. The NDAWG considers that due to the low variability in the frequency of tidal currents, which mostly drive dispersion in coastal environments, and the high mobility of fish (the dominant pathway for exposure to aqueous discharges to the marine environment); that the dose from enhanced discharges of aqueous radionuclides to coastal environments over short durations, will not differ significantly from the dose assessed assuming a continuous release [Ref 54].

344. It was however recognised that there may be circumstances where assessment of the impact of enhanced discharge of radioactive effluent may be beneficial. For example, fish/shellfish could be caught over a short period of time and preserved (e.g. by freezing) for consumption over the remainder of the year and if these fish were exposed to a plume from a short-term release to coastal or estuarine waters then this may lead to elevated radionuclide concentrations in these fish/shellfish.

345. The assessed dose to the worst affected CRP for exposure to aqueous discharges from SZC (an adult member of a fishing family), at proposed annual limits, is calculated to be 13 µSv/y. The component of this dose from the ingestion of H-3 in seafood is approximately 0.018 µSv/y, around 0.1% of the annual dose to the CRP.

346. If it is assumed that:

- 80% of the annual aqueous H-3 inventory of SZC is released within a short duration (one month),
- the plume of aqueous effluent containing enhanced H-3 concentration is not dispersed beyond the local compartment,
- 100% of the seafood was caught within this compartment, and
- the seafood caught is preserved (i.e. no H-3 is lost) and ingested for the remainder of the year.

347. The resultant dose can be estimated by multiplying the assessed dose from routine discharges by the fraction of the annual tritium discharges released over one month and the number of months in a calendar year:

Equation 8

$$D_{ing,et} = 12\left(0.8D_{ing,t}\right)$$

348. Where

$D_{ing,\,et}$ = Dose due to ingestion of seafood incorporating tritium from elevated discharges

$D_{ing,\,t}$ = Dose due to ingestion of seafood incorporating tritium from routine discharges

349. The dose predicted to arise from the ingestion of seafood incorporating elevated levels of H-3 is 0.17 µSv/y. This is a trivial dose when compared to the overall dose to the CRP of 13 µSv/y (although it represents an increase of around one order of magnitude when compared to the dose from routine discharges of H-3).

350. The approach above assumes uniform dilution through the local compartment and hence does not consider localised areas of higher concentration. However, the discharge velocity of the cooling water discharge and the action of tidal currents and wave driven turbulence will disperse the tritium. Marine fauna which contribute to seafood consumption will also include mobile species that move around the area. Hence, the approach remains pessimistic for these exposure pathways.

351. It is therefore concluded that the impact of discharge of enhanced levels of H-3 into the marine environment over short periods is insignificant.

APPENDIX B SITE MAPS, PLANS AND DRAWINGS

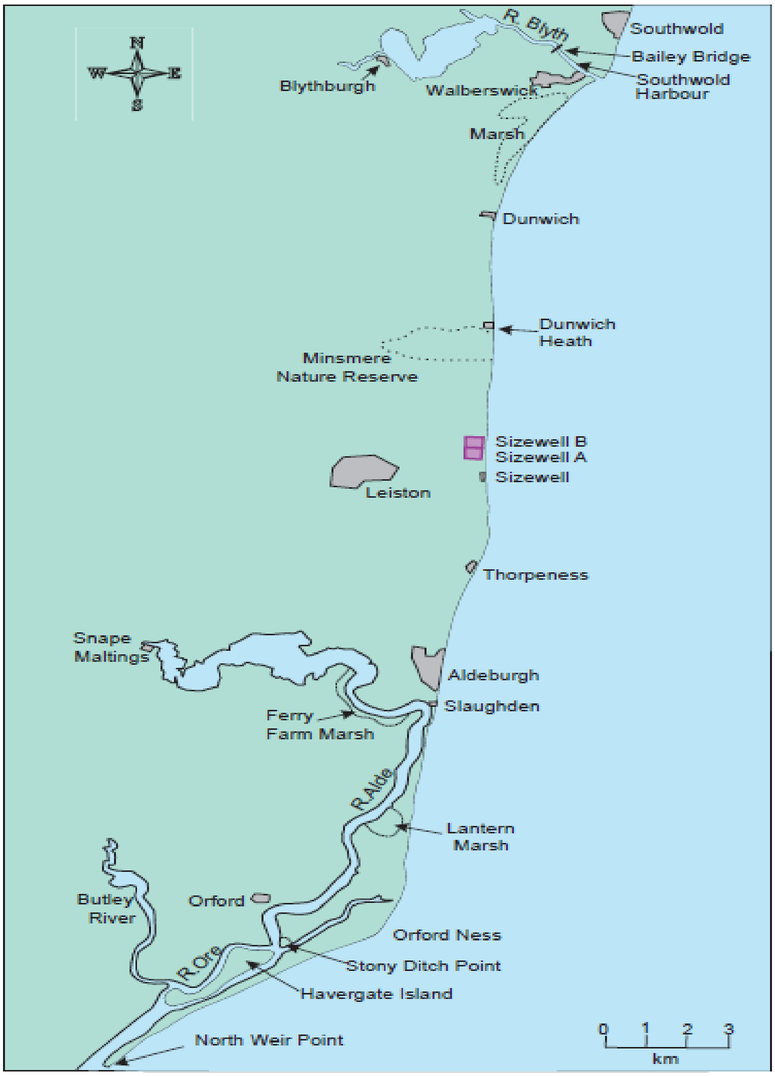

Figure 9-1 2010 CEFAS Habits Survey – Aquatic Habits Survey Area [Ref 38]

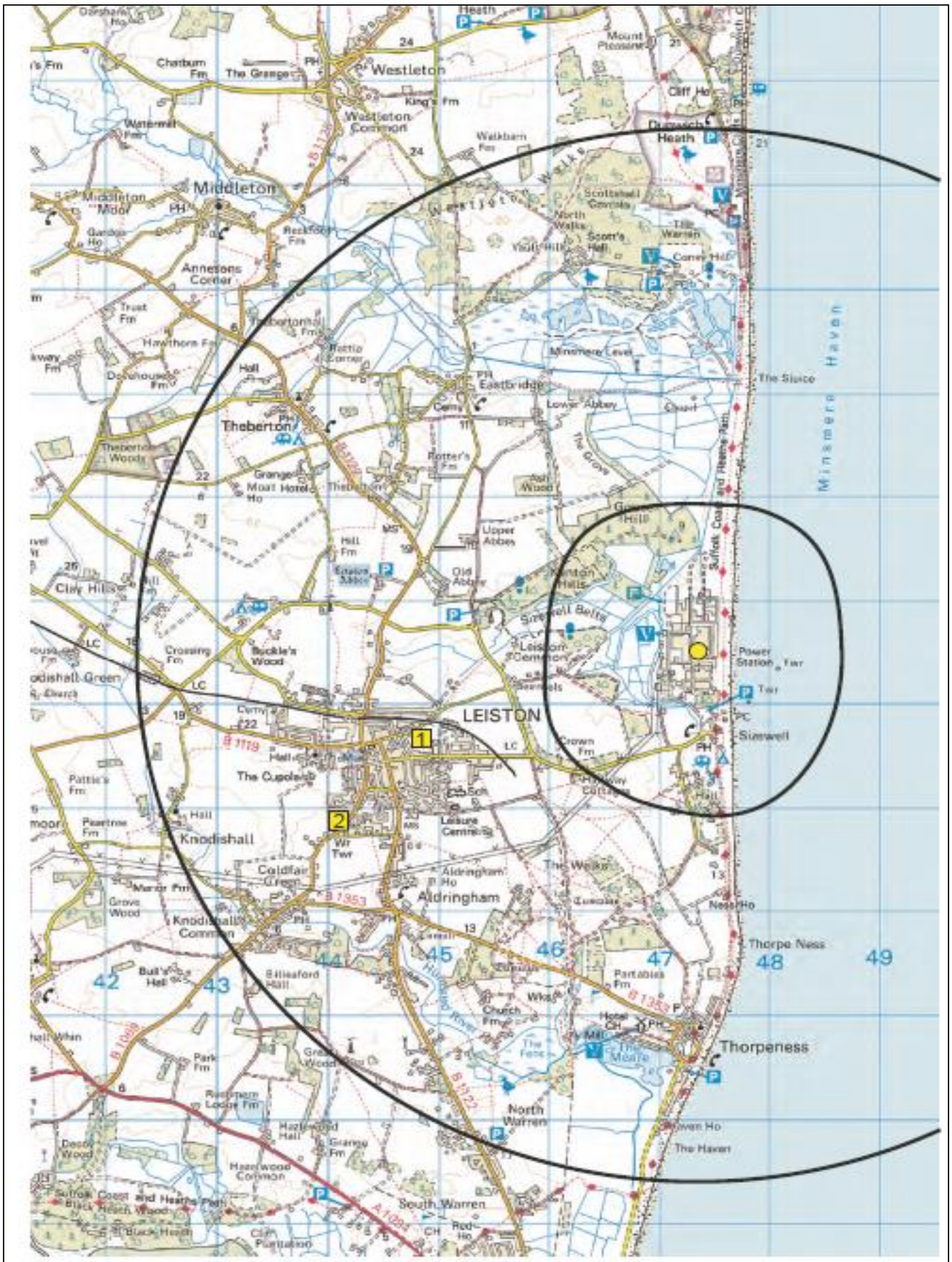

Figure 2. The Sizewell terrestrial (outer ring) and direct radiation (inner ring) survey areas

○ Sizewell site centre

1 Valley Road Allotments

2 Haylings Road Allotments

Figure 9-2 2010 CEFAS Habits Survey – Terrestrial Habits Survey Area [Ref 38]

APPENDIX C PC-CREAM 08 MODEL PARAMTERS

C.1 DORIS Default Parameters

Table C-11 Element Dependent Parameters (DORIS Default)

Element	Partition Coefficient, Kd (Bq/t per Bq/m^3)		Concentration Ratios, CR (Bq/t per Bq/m^3)			
	Deep	Coastal	Fish	Crustaceans	Molluscs	Seaweed
Ag	1.0E+04	1.0E+03	5.0E+02	5.0E+03	1.0E+04	2.0E+03
Sb	5.0E+02	1.0E+03	4.0E+02	2.5E+01	2.0E+01	2.0E+01
Cs	2.0E+03	3.0E+03	1.0E+02	3.0E+01	3.0E+01	5.0E+01
C	2.0E+03	2.0E+03	2.0E+04	2.0E+04	2.0E+04	1.0E+04
Cr	5.0E+04	5.0E+04	2.0E+02	5.0E+02	8.0E+02	2.0E+03
Co	1.0E+07	2.0E+05	1.0E+03	1.0E+04	5.0E+03	1.0E+04
H	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00
I	2.0E+02	2.0E+01	1.0E+01	1.0E+01	1.0E+01	1.0E+03
Mn	2.0E+08	2.0E+05	4.0E+02	5.0E+02	5.0E+04	6.0E+03
Ni	1.0E+06	1.0E+05	1.0E+03	1.0E+03	2.0E+03	2.0E+03
Te	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+03	1.0E+04
Xe	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

C.2 FARMLAND Default Parameters

Table C-12 FARMLAND Default Plant Dependant Model Parameter

Parameter	Green Vegetables	Pasture	Root Vegetables	Fruit
Yield Fresh Weight (kg/km^2)	1.00E+06	5.00E+05	3.00E+06	1.69E+06
Plant Interception Factor	3.00E-01	2.50E-01	4.00E-01	7.40E-01
Seed Interception Factor	-	-	-	-
Fruit Interception factor	-	-	-	7.00E-03
Weathering half-life for plant (d)	1.40E+01	1.40E+01	1.40E+01	1.40E+01
Weathering half-life for seeds (d)	-	-	-	-
Weathering half-life for winter (d)	-	2.80E+01	-	-
Weathering half-life for fruit (d)	-	-	-	1.40E+01
Soil Contamination (%)	1.00E-01	-	1.00E-01	1.00E-01
Preparation Loss	8.00E-01	-	0.00E+00	0.0E+00
Dry Weight (%)	2.00E+01	2.00E+01	2.00E+01	1.56E+01
Soil density (g/cm^3)	1.50E+00	1.50E+00	1.50E+00	1.50E+00
Resuspension coefficient (1/m)	8.00E-08	1.00E-08	8.00E-08	8.00E-08
Deposition Velocity (m/s)	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Half-life in 30cm soil (d)	3.65E+04	3.29E+02	3.65E+04	3.65E+04

Table C-13 FARMLAND Default Animal Dependant Model Parameters

Parameter	Cow	Sheep
Dry weight intake of pasture (kg/d)	13	1.5
Fraction of dry matter intake as soil (%)	4	20
Inhalation rate (m^3/s)	1.5E-03	1.0E-04
Mean life span (y)	6	1
Grazing density (1/km^2)	400	500
Mass of Carcass (kg)	230	18
Mass of liver (kg)	6	0.8
Milk production rate (l/d)	10	-

Table C-14 FARMLAND Default Soil to Plant Equilibrium Concentration Ratios (Bq/kg of wet mass of plant to Bq/kg of dry mass of soil)

Element	Green Vegetables	Pasture	Root vegetables	Fruit
Argon	0.0E-00	0.0E-00	0.0E-00	0.0E-00
Barium	1.0E-02	1.0E-02	5.0E-03	1.0E-02
Caesium	1.0E-02	3.0E-02	6.0E-03	3.0E-03
Cobalt	1.0E-02	1.0E-02	1.0E-02	5.0E-03
Iodine	2.0E-02	2.0E-02	2.0E-02	2.0E-02
Krypton	0.0E-00	0.0E-00	0.0E-00	0.0E-00
Xenon	0.0E-00	0.0E-00	0.0E-00	0.0E-00

Table C-15 FARMLAND Default Animal Equilibrium Transfer Factors (Bq/kg of animal product per Bq/d ingested)

Element	Cow Milk	Cow Meat	Sheep Meat
Argon	0.0E-00	0.0E-00	0.0E-00
Barium	5.0E-04	5.0E-04	5.0E-03
Caesium	5.0E-03	3.0E-02	5.0E-01
Cobalt	1.0E-04	1.0E-04	1.0E-03
Iodine	5.0E-03	2.0E-03	5.0E-02
Krypton	0.0E-00	0.0E-00	0.0E-00
Xenon	0.0E-00	0.0E-00	0.0E-00

Table C-16 FARMLAND - Other Element Dependant Parameters

Element	Bio half-life meat (y)	Bio half-life liver (y)	Fraction inhaled/ingested	Element Mobility
Barium	9.00E-02	9.00E-02	7.04E-01	Semi-mobile
Caesium	-	-	3.48E-01	Mobile
Cobalt	5.00E-01	5.00E-01	1.15E+00	Semi-mobile
Iodine	-	-	3.48E-01	Mobile

APPENDIX D METEOROLOGICAL DATA

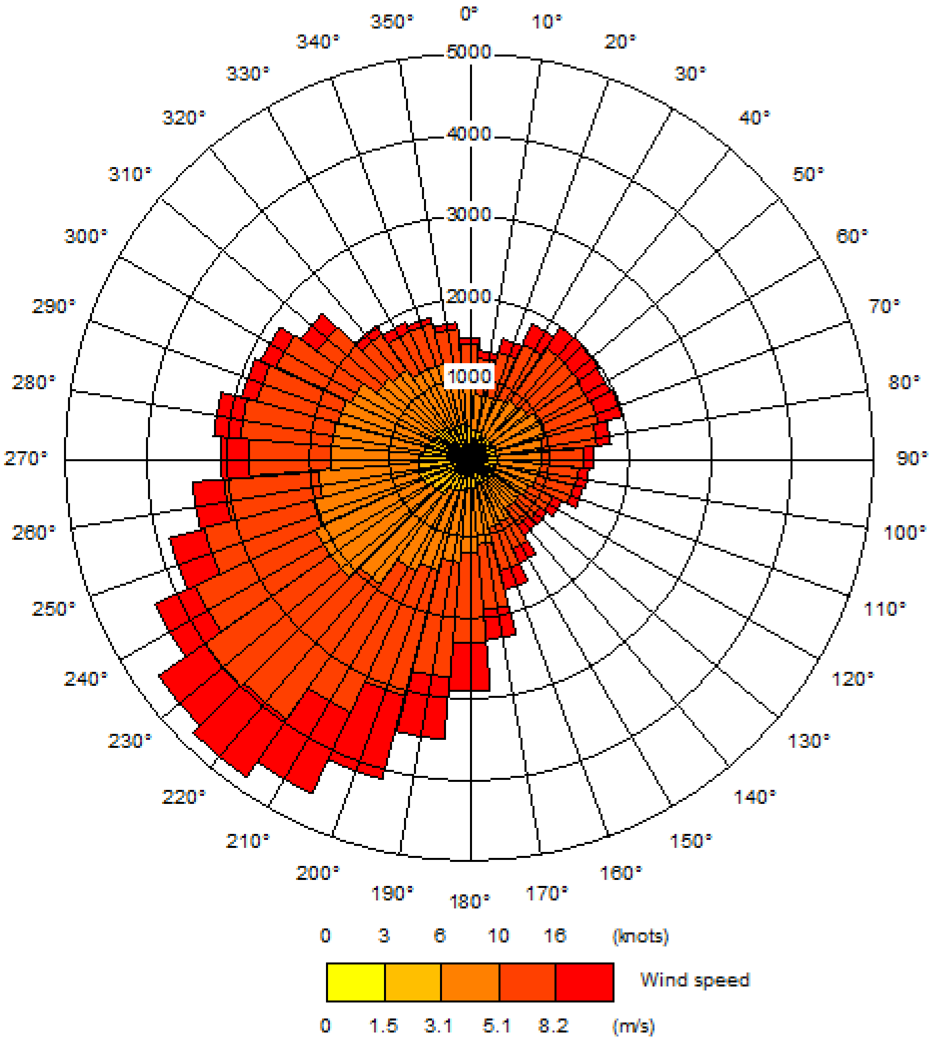

Figure 9-3 Sizewell C Centred Windrose

Table D-17 10 Year (2003-2012) Meteorological Data in PC-CREAM 08 Format

Stability Category	**Wind Angle (°)**											
	15-45	**45-75**	**75-105**	**105-135**	**135-165**	**165-195**	**195-225**	**225-255**	**255-285**	**285-315**	**315-345**	**345-15**
A,	0E+00	1.14E-05	1.14E-05	2.28E-05	1.14E-05	1.14E-05	1.14E-05	0E+00	1.14E-05	1.14E-05	0E+00	3.42E-05
B,	2.28E-04	2.40E-04	4.22E-04	3.99E-04	2.05E-04	2.05E-04	3.08E-04	1.59E-03	1.94E-03	1.90E-03	1.03E-03	4.56E-04
C,	6.98E-03	8.08E-03	8.89E-03	1.01E-02	5.74E-03	4.25E-03	6.98E-03	1.14E-02	8.81E-03	7.85E-03	8.69E-03	1.35E-02
D,	6.57E-02	6.87E-02	5.13E-02	4.31E-02	2.32E-02	1.67E-02	2.10E-02	2.34E-02	1.84E-02	1.42E-02	1.33E-02	3.49E-02
E,	3.21E-02	3.56E-02	2.54E-02	1.68E-02	1.02E-02	8.16E-03	8.73E-03	1.04E-02	1.11E-02	8.70E-03	9.78E-03	1.69E-02
F,	3.56E-03	4.35E-03	3.97E-03	3.05E-03	2.28E-03	2.25E-03	2.42E-03	2.26E-03	2.43E-03	2.67E-03	3.03E-03	3.07E-03
C+Rain,	1.64E-03	2.01E-03	1.73E-03	1.90E-03	1.76E-03	1.51E-03	1.53E-03	1.69E-03	1.09E-03	8.44E-04	1.00E-03	1.94E-03
D+Rain	4.44E-02	2.75E-02	1.85E-02	1.95E-02	2.16E-02	1.88E-02	2.01E-02	1.64E-02	1.12E-02	8.78E-03	1.27E-02	2.84E-02

VOLUME 2, CHAPTER 25, APPENDIX 25C: RADIOACTIVE SUBSTANCES REGULATIONS PERMIT APPLICATION SUPPORT DOCUMENT: D2 - NON-HUMAN RADIOLOGICAL IMPACT ASSESSMENT FOR SIZEWELL C

Sizewell C Project

Radioactive Substances Regulations (RSR) Permit Application

Appendix D

Support Document D2 - Non-Human Biota Radiological Impact Assessment

EXECUTIVE SUMMARY

NNB Generation Company (SZC) Limited (SZC Co.) plan to construct and operate a new nuclear power station comprising two UK EPR^{TM} units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as Sizewell C (SZC), will be situated to the north of both Sizewell B (SZB) and Sizewell A (SZA) nuclear power stations which are operational and defueled respectively.

This report provides an assessment of the potential radiological impacts to flora and fauna from Normal Operational Radiological Discharges (both gaseous and aqueous) from the proposed SZC nuclear power station and in combination with discharges from the SZB power station. The assessment was based on the proposed annual discharge limits for SZC, and the permitted discharge limits for the neighbouring SZB facility were used in the assessment of in-combination effects.

The potential impacts on a range of organisms representative of those inhabiting the areas close to the facility have been assessed. For all of the organisms evaluated, dose rates (biological impacts of ionising radiation) remained substantially lower than the Environment Agency current assessment threshold of 40 µGy/h. The dose rates were also lower than broader internationally considered thresholds. These included the:

- Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) screening value that is considered protective of populations of Non-Human Biota (NHB) across all ecosystems (10 µGy/h); and
- Derived consideration reference levels, the most stringent of which is 4 µGy/h (for the duck, rat, deer and pine tree Reference Animals and Plants (RAPs)), applicable to planned exposure situations.

The assessment results have shown the dose rate from SZC discharges to the worst affected organism (polychaete worm occupying a marine habitat) to be 0.80 µGy/h, with a risk quotient value (RQ, the ratio of the estimated dose rate to the assessment threshold of 40 µGy/h) of 0.020. The worst affected organism from the combined discharges of radioactive effluent from the SZB and SZC facilities (insect larvae occupying a marshland habitat) was 2.7 µGy/h, with a RQ value of 0.067. These dose rates are more than one order of magnitude below the current Environment Agency threshold dose rate of 40 µGy/h, and well below the ERICA screening value of 10 µGy/h.

The impacts of radioactive effluent discharges on NHB from the proposed SZC nuclear power plant alone and in combination with SZB are therefore predicted to be very low. As such, based on the internationally recognised models used in this assessment, the output of which are well below regulatory threshold levels and furthermore comparable to or below previous assessments undertaken by the Environment Agency for the Natura 2000 sites, it can be concluded that there would be no significant effects on any Natura 2000 site and hence radiological effects are screened out of the Shadow Habitats Regulations Assessment. Likewise no significant effects are predicted on any other ecological receptor or designated site, such as Site of Special Scientific Interest (SSSI).

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1. SZC Co. plan to construct and operate a new nuclear power station comprising two UK EPR^{TM} units and associated infrastructure near Sizewell in Suffolk. The proposed nuclear power station, known as SZC, will be situated to the north of both SZB and SZA nuclear power stations which are operational and defueled respectively.

1.2 Scope

2. This report provides an assessment of the radiological impacts of Normal Operational Radiological discharges to air and to the marine environment (collectively referred to as permitted discharges) from the proposed SZC nuclear power station on flora and fauna (collectively referred to as NHB). Impacts from the combined discharges of the existing SZB nuclear power station and the proposed SZC nuclear power station were also assessed.

3. This report forms part of the documentation prepared in support of the Radioactive Substances Regulations (RSR) permit application for SZC. The report is also prepared in the context of the SZC Habitats Regulations Assessment (HRA) Evidence Plan, October 2014 [Ref 1] which screened out potential radiological effects on NHB during construction of the proposed power station, but identified a need for a site-specific NHB assessment of representative habitats and species to consider impacts during the operational phase.

1.3 Definitions

Term / Abbreviation	Definition
BSS	Basic Safety Standards
C&M	Care and Maintenance
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CR	Concentration Ratio
DCC	Dose Conversion Coefficient
EC	European Commission
EMCL	Environmental Media Concentration Limits
EPR16	Environmental Permitting Regulations 2016 (As Amended)
ERICA	Environmental Risk from Ionising Contaminants: Assessment and Management
FASSET	Framework for the Assessment of Environmental Impact
HPC	Hinkley Point C
HRA	Habitats Regulations Assessment
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
Kd	Distribution Coefficients
Met	Meteorological
NHB	Non-Human Biota
SZC Co.	NNB Generation Company (SZC) Limited
NRPB	National Radiological Protection Board
RAP	Reference Animal and Plant

Term / Abbreviation	Definition
R&D	Research and Development
RIFE	Radioactivity in Food and the Environment
RPD	Radiological Protection Division
RQ	Risk Quotient
RSR	Radioactive Substances Regulations
SAC	Special Areas of Conservation
SCI	Site of Community Importance
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SZA	Sizewell A
SZB	Sizewell B
SZC	Sizewell C
UF	Uncertainty Factors

1.4 References

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[2]	The Environmental Permitting (England and Wales) Regulations 2016	1154	-	http://www.legislation.gov.uk/uksi/2016/1154/pdfs/uksi_20161154_en.pdf	Statutory Instruments
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[5]	RSR Environmental Principles	RSR 1	-	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296388/geho0709bqsb-e-e.pdf	Environment Agency

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[12]	Sizewell Marshes SSSI	-	-	https://designatedsites.naturalengland.org.uk/PDFsForWeb/Citation/1003416.pdf Last Accessed: 19/02/2020	Natural England
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[23]	Radioactivity in Food and the Environment 2017	RIFE-23	-	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/750730/Radioactivity_in_food_and_the_environment_2017_RIFE_23.pdf Last Accessed: 19/02/2020	CEFAS
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1.5 Overview of Regulatory Framework

4. The proposed SZC nuclear power station will make operational discharges of aqueous and gaseous effluent into the environment under specific limits and conditions stipulated in an environmental permit granted under Schedule 23 of the Environmental Permitting (England and Wales) Regulations 2016 (as amended) (EPR16) [Ref 2] also known as the Radioactive Substances Regulations.

5. The Environment Agency has obligations under the European Union Wild Birds and Natural Habitats Directives [Ref 3] to ensure that no Environment Agency permitted activity results in an adverse effect,

either directly or indirectly, on the integrity of Natura 2000 sites[1] [Ref 4]. The Environment Agency is also required to ensure that the integrity of Natura 2000 sites is not adversely impacted by any new (or variation of existing) permits they issue [Ref 3].

6. Furthermore, one of the key environmental principles underpinning the RSR in the UK is the provision of adequate protection to non-human species from exposure to ionising radiation [Ref 5]. The Environment Agency requires key species that need protection in particular habitats, and key habitat features to be identified and that the dose rates to such species estimated and compared to the current guideline dose rate of 40 µGy/h [Ref 4] [Ref 5].

7. The above requirements have been implemented as part of the requirements for an environmental permit under the RSR regime in respect of nuclear sites. Permit applicants are required to carry out a prospective assessment of dose rates to NHB alongside human dose assessment as part of the permit application process.

8. The assessment of potential impacts of radioactive discharges on NHB has been embedded in the Basic Safety Standards (BSS) Directive (2013/59/Euratom), adopted on the 5th December 2013 [Ref 6][2]. The BSS Directive, which implements the latest recommendations of the International Commission on Radiation Protection (ICRP) [Ref 7], recognises that ‘the contamination of the environment may pose a threat to human health…’and that ‘while the state of the environment can impact long-term human health, this calls for a policy protecting the environment against the harmful effects of ionising radiation’. This provision formally introduces the protection of the environment into radiation protection legislation. The BSS Directive has been transposed into UK law in 2018/2019.

1.6 Document Structure

9. This document is set out in the following way:

- Section 2 – Sets out the ecological context in the area around the Sizewell C nuclear power station area.
- Section 3 – Describes the source term used for the dose assessment, including the annual limits proposed for gaseous and aqueous radioactive discharges from the operation of the Sizewell C nuclear power station.
- Section 4 – Dispersion modelling, describing the habitats selected and assessed, including a discussion of the PC-CREAM 08 modelling software used.
- Section 5 – Assessment approach – ERICA integrated approach and the R&F 128 methodology.
- Section 6 – Reference organisms considered in the assessment.
- Section 7 – Results and Discussion, presenting the doses rates due to Sizewell C radiological discharges as well as the combined radiological discharges from Sizewell B and Sizewell C.
- Section 8 – Conclusion, summarises the results and conclusions of the Non-Human Biota Radiological Impact Assessment.

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[1] Natura 2000 is made up of sites designated as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) under Council Directives 79/409/EEC on the conservation of wild birds and 92/43/EEC on the conservation of natural habitats and wild flora and fauna [3].

[2] The new BSS Directive [6] brings together and consolidates the existing EURATOM directives and incorporates the latest recommendations from the ICRP (ICRP Publication 103) [7].

2 ECOLOGICAL CONTEXT

10. The proposed SZC nuclear power station is situated within the Suffolk Coast and Heaths Area of Outstanding Natural Beauty and is surrounded by an ecologically diverse environment comprising designated sites of regional, national and international importance [Ref 1]. SZC Co. have commissioned extensive baseline ecological studies of the terrestrial and marine environments which identified the key sensitive ecological receptors (habitats and species) in the vicinity of the proposed SZC site [Ref 8] [Ref 9]. Some of the key ecological receptors in the vicinity of the site include (see Appendix A for locations of these areas):

- **Minsmere-Walberswick Heaths and Marshes** is a designated SSSI, to the north of the proposed SZC site, part of which is also designated as a Special Protection Area (SPA), Special Area of Conservation (SAC) and Ramsar site. The SPA comprises two large marshes, the tidal Blyth estuary and associated habitats and contains areas of marsh with dykes, extensive reedbeds, mud-flats, lagoons, shingle, woodland and areas of lowland heath. It supports nationally important numbers of breeding and wintering birds including Bittern (*Botaurus stellaris*), Marsh Harrier (*Circus aeruginosus*) and a range of breeding waders (e.g. Avocets *(Recurvirostra avosetta)*) [Ref 10]. The shingle beaches support important numbers of Little Tern (*Sterna albifrons*), which feed substantially outside the SPA in adjacent marine waters, and is important for wintering Bitterns and raptors [Ref 10]. In addition to the habitats identified in the SPA, the SSSI also contains heathland and grazing marsh. There is extensive Lowland European dry heaths dominated by heather (*Calluna vulgaris*), but also containing bell heath (*Erica cinerea)* and cross-leaved heath (*E. tetralix)* [Ref 11]. Shingle beach forms the coastline at Walberswick and Minsmere, which supports a variety of scarce shingle plants including sea pea (*Lathyrus japonicus*) and sea campion (*Silene maritima*) [Ref 11].

- **Sizewell Marshes SSSI** lies immediately to the north and to the west of the SZC site and a small part of the proposed site lies within the SSSI. The SSSI comprises a range of wetland habitats including grazing marsh, open water and fen meadow, supporting a variety of assemblages of invertebrates including terrestrial and aquatic beetles (*Coleoptera*), flies (*Diptera*), moths (*Lepidoptera*), dragonflies (*Odonata*) and spiders (*Araneae*) [Ref 12]. The site is also important for breeding birds, especially those typical of wet grassland and related habitats such as Shoveler, Gadwall, Teal, Snipe and Lapwing [Ref 12].

- **Leiston-Aldeburgh SSSI** [Ref 13] **and Sandlings SPA** [Ref 14] to the south and south west of the Sizewell site. The SSSI comprises a mosaic of habitats including acid grassland, heath, scrub, woodland, fen, open water and vegetated shingle, and supports a diverse and abundant community of breeding and overwintering birds, a high number of dragonfly species and many scarce plants [Ref 13]. The SPA is characterised by remnant of heath, interspersed with bracken (*Pteridium aquilinum*), shrubs and trees. The heaths support both acid grassland and heather-dominated plant communities with dependent invertebrate and bird communities of conservation value – including Woodlark (*Lullula arborea*) and Nightjar (*Caprimulgus europaeus*), which have adapted to breeding in the surrounding areas of conifer plantations and open ground [Ref 14].

- **Outer Thames Estuary SPA to the east of the Sizewell site** is classified for the protection of the largest aggregation of wintering red-throated diver *(Gavia stellata)* in the UK, and for the protection of little tern (*Sternula albifrons*) and common tern (*Sterna hirundo*) [Ref 15]. The SPA lies along the east coast of England in the southern North Sea and extends northward from the

Thames Estuary to the sea area off Great Yarmouth on the East Norfolk Coast. The Outer Thames Estuary SPA overlaps with a candidate SAC/Site of Community Importance (SCI) that has been identified for the protection of Harbour porpoise – the Southern North Sea cSAC/SCI.

11. In order to gather appropriate and aligned data typical of the major environment the ICRP has developed a set of RAPs. Five indicative habitats representative of designated areas found locally around the proposed SZC site have been identified as potentially sensitive to radiological impacts due to their ecological significance and their location relative to the site of the proposed SZC facility [Ref 16][3]. These are:

- **Habitat 1**, a terrestrial habitat, representative of Sizewell Marshes SSSI, lies adjacent and to the west and north of the Sizewell site. This terrestrial habitat was selected as it will experience the highest air concentrations and deposition due to both the proximity to the site and being in the direction of maximum air concentrations (as modelled in PC CREAM, see Section 4). The dose rates calculated will therefore be the highest of the terrestrial habitats of interest.

- **Habitat 2**, a marine habitat, representative of the Outer Thames Estuary SPA area to the east of the Sizewell site.

- **Habitat 3**, a coastal habitat, representative of the area to the north of the Sizewell site within the Minsmere-Walberswick Heaths and Marshes SSSI, SPA and Ramsar includes both shoreline and the adjacent terrestrial area. This habitat is therefore assumed to be impacted by both aqueous and gaseous discharges.

- **Habitat 4**, a freshwater habitat, representative of the scrape in the centre of Minsmere Nature Reserve, within Minsmere-Walberswick Heaths and Marshes SPA.

- **Habitat 5**, encompasses a mixed habitat representative of the marshland within the Minsmere-Walberswick Heaths and Marshes SSSI, SPA and Ramsar.

12. With the exception of Habitat 3 (coastal habitat), the habitats described above are broadly consistent with the default ecosystems within the ERICA tool used to assess the impact of radiological discharges on NHB (described in later sections). The coastal habitat is a mix of terrestrial and marine habitats, such as those of Habitats 1 and 2 above. The aggregate radiological impacts to the organisms for Habitats 1 and 2 were therefore considered to be bounding for those occupying Habitat 3. Some organisms can move between different environments, and as such can be exposed in more than one environment. However, ERICA only considers birds and mammals in both the marine and terrestrial habitats; the other organisms are considered to inhabit one or the other habitat. Since the mammals considered are different (a rat or deer on land and a porpoise in water), movement between the two habitats is not considered for mammals. Movement between different habitats has been considered for bird species, i.e. for semi-aquatic birds such as the Gadwall, by assuming a 50/50 occupancy in terrestrial and marine environments.

13. The models and approaches described in further detail in Section 5 do not consider the specifics of whether the environment is marine, acid heath, chalkland heath, acid bog, marsh etc. Rather, only generic biota types and their general ecological behaviour (e.g. proportion of time on ground or within ground etc.) are considered. In the ERICA modelling system [Ref 15], it is possible to modify the 'concentration

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[3] The Leiston-Aldeburgh SSSI and the Sandlings SPA are further away from the site than the locations identified as representative for each habitat type and are not in the direction of maximum air concentration and deposition. It is therefore expected that dose rates to organisms at the Leiston-Aldeburgh SSSI or the Sandlings SPA sites will be lower than calculated in this assessment.

ratio' (CR) values that are used to predict the organism body burden relative to an environment concentration (whether in soil or water etc.). Determining site specific CR values is possible, but requires extensive field research involving collection of environmental media and species collection for laboratory analysis. As such, use of default values is appropriate unless the resultant dose is above the screening values, which would warrant a site specific investigation to determine the level of conservatism in the assessment.

14. This is in line with International Standards and Best Practice. In the assessment, the CR values were generic values for the terrestrial environment, set as default within the ERICA assessment tool, and derived from the International Atomic Energy Agency (IAEA) TRS 479 [Ref 17]. CRs were recognised as being a key area of uncertainty in assessments with large variability in values being observed for different soils (see for example Smith et al. [Ref 18]). However, noting the resultant dose rates for terrestrial biota were several orders of magnitude below the current Environment Agency assessment threshold of 40 µGy/h (ca. 4 orders of magnitude), variation in the CR values are unlikely to result in dose rates above the threshold. The generic values are therefore sufficient for this scenario and any sensitivity associated with the CR does not require further consideration.

3 SOURCE TERM

15. Discharges of aqueous radionuclides into the marine environment will be made via outfall structures to be constructed at two locations approximately 3.5 km distance offshore with OS grid references (651080, 264125) & (651155, 264125) within a local compartment of the North Sea [Ref 19]. Releases of gaseous radionuclides into the atmosphere will be made via two emission stacks with physical heights of 70m, protruding approximately 10m above the reactor buildings housing the two UK EPR^{TM} units [Ref 20].

16. The assessment considers discharges at the proposed annual limits. Table 3-1 and Table 3-2 present the proposed annual limits for discharges of aqueous and gaseous radionuclides from the SZC facility, along with expected best performance values.

17. The cumulative impacts of the combined discharges from SZC and the neighbouring SZB facility on NHB were also assessed. The discharge limits and reported annual discharges for the SZB facility were taken from the three most recent Radioactivity in Food and the Environment (RIFE) Reports as compiled by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) on behalf of the UK Environment Agencies [Ref 21] [Ref 22] [Ref 23] and are presented in Table 3-1 and Table 3-2.

18. SZA is defueled and is expected to have entered into the Care and Maintenance (C&M) phase before the proposed SZC facility begins power generation [Ref 24. Discharges from SZA have therefore not been considered in the assessment of cumulative site impacts. Any future impacts associated with the decommissioning of SZA or B will be assessed under the Environmental Impact Assessment for Decommissioning Regulations and, where applicable, associated permit variations or applications

Table 3-1 Annualised Aqueous Discharges for Sizewell C and Sizewell B Facilities

Radionuclide	SZC		SZB	
	Proposed limits (Bq/y)	Expected best performance (Bq/y)	Annual discharge limits (Bq/y)	Annual discharges (Bq/y) (based on a 3 year average)
Ag-110m	1.12E+09	7.51E+07	-	-
C-14	1.90E+11	4.60E+10	-	-
Co-58	4.07E+09	2.73E+08	-	-
Co-60	6.00E+09	3.95E+08	-	-
Cr-51	1.18E+08	7.91E+06	-	-
Cs-134	1.10E+09	7.38E+07	1.30E+11	4.50E+09
Cs-137	1.90E+09	1.10E+08	2.00E+10	7.82E+08
H-3	2.00E+14	1.04E+14	8.00E+13	2.39E+13
I-131	9.83E+07	6.59E+06	-	-
Mn-54	5.31E+08	3.56E+07	-	-
Ni-63	1.89E+09	1.27E+08	-	-
Sb-124	9.63E+08	6.46E+07	-	-
Sb-125	1.60E+09	1.07E+08	-	-
Te-123m	5.11E+08	3.43E+07	-	-

Note: SZB is permitted for H-3, Cs-137, and other radionuclides. Here it has been assumed that other radionuclides can be assessed as Cs-134.

19. In the Hinkley Point C (HPC) permit, the Environment Agency assigned annual limits on aqueous discharges of H-3, C-14, Co-60 and Cs-137. Other fission and activation products were grouped together as ‘other radionuclides’ and assigned a single annual aqueous discharge limit. For the purpose of the SZC radiological assessments, the typical percentage of the individual radionuclides comprising the ‘other radionuclides’ group [Ref 25] has been applied to derive the annual limits for the individual radionuclides, based on the limits granted for ‘other radionuclides’ for HPC.

20. The annual aqueous discharges for SZB have been derived as the average of reported discharges for 2015-2017, in order to reduce the effect of annual variations in reported discharges from the station (for instance as a result of shut-down for maintenance or other reasons).

21. SZB has annual limits specified for aqueous discharges of H-3, Cs-137 and ‘other radionuclides’ [Ref 21] [Ref 22] [Ref 23]. Cs-134 is used as a surrogate for SZB discharges of ‘other radionuclides’: the dose from this group is estimated by calculating the dose from an equivalent activity of Cs-134. This approach was also used for the HPC RIA [Ref 25], and was therefore used for SZC.

Table 3-2 Annualised Gaseous Discharges for Sizewell C and Sizewell B Facilities

Radionuclide	SZC		SZB	
	Proposed limits (Bq/y)	Expected best performance (Bq/y)	Annual discharge limits (Bq/y)	Annual discharges (Bq/y) (based on a 3 year average)
Ar-41	1.31E+12	4.64E+10	3.00E+13	2.94E+12
C-14	1.40E+12	7.00E+11	5.00E+11	2.33E+11
Co-58	1.09E+07	7.24E+05	-	-
Co-60	1.28E+07	8.54E+05	1.00E+08	7.67E+06
Cs-134	9.98E+06	6.65E+05	-	-
Cs-137	8.95E+06	5.96E+05	-	-
H-3	6.00E+12	1.00E+12	3.00E+12	6.73E+11
I-131	4.00E+08	5.00E+07	5.00E+08	1.30E+07
I-133	7.74E+07	5.16E+06	-	-
Kr-85	6.26E+12	2.22E+11	-	-
Xe-131m	1.35E+11	4.80E+09	-	-
Xe-133	2.84E+13	1.01E+12	-	-
Xe-135	8.92E+12	3.17E+11	-	-

Note: SZB permit specifies limits for noble gases (assessed as Ar-41), particulate beta (assessed as Co-60) and H-3, C-14 and I-131.

22. In the HPC permit, the Environment Agency assigned annual limits on gaseous discharges of H-3, C-14, I-131 and noble gases. Other fission and activation products were grouped together as ‘beta-emitting radionuclides associated with particulate matter’ and assigned a single annual gaseous discharge limit. For the purpose of the SZC radiological assessments, the typical percentage of the individual radionuclides comprising the noble gases and the grouped radionuclides [Ref 16] has been applied to derive the annual limits for the individual radionuclides based on the limits granted for noble gases and other beta-emitting radionuclides for HPC C.

23. Co-60 is used as a surrogate for SZB discharges referred to as ‘particulate beta’ in the RIFE Reports [Ref 21] [Ref 22] [Ref 23] in accordance with the approach used for the HPC RIA [Ref 25] [Ref 26]. Dose from ‘particulate beta’ is therefore estimated by calculating the dose from an equivalent activity of Co-60.

24. It is evident from Table 3-1 and Table 3-2 above that the actual discharges from SZB are significantly below the permitted discharge limits; similarly, the predicted discharges from SZC will be less than the proposed permit limits. The use of annual discharge limit data for the purpose of this radiological assessment therefore represents a bounding assessment, where actual exposure is likely to be lower.

4 DISPERSION MODELLING

25. The dispersion and subsequent environmental accumulation of radionuclides discharged from the SZC facility were modelled using the supporting modules within the PC-CREAM 08 software [Ref 27]. This is a well-established software system used by operators and regulators for human and NHB dose assessment modelling. Site-specific model parameters were used to provide realistic estimates of environmental concentrations arising from radionuclide releases.

4.1 Habitat 1 (Terrestrial Habitat)

26. The dispersion, deposition and build-up of radionuclides from gaseous discharges into the atmosphere were modelled using the PLUME and FARMLAND modules within PC-CREAM 08.

27. PC-CREAM 08 does not account for the entrainment of gaseous releases in the wake of nearby buildings; thus an effective stack height (physical stack height plus wake effects of nearby buildings) has to be determined and input into PLUME [Ref 27] [Ref 28].

28. An effective stack height of 20 m, equivalent to one-third of the height of the adjacent reactor building, has been applied in modelling the atmospheric dispersion of gaseous discharges on the basis of the approach described in National Radiological Protection Board (NRPB) report NRPB-R-157 [Ref 29]. This is widely recognised as a pessimistic approach and is consistent with the approach adopted during the Generic Design Assessment [Ref 30] in the radiological assessments undertaken in support of the HPC permit application [Ref 25].

29. The atmospheric dispersion modelling utilised hourly sequential meteorological (Met) data for the SZC site for the period covering 2003-2012 as supplied by the UK Met Office[4]. These data were provided in the Pasquill stability category format compatible with PC-CREAM 08. These data are presented in Appendix B and have been used to model the air concentration and deposition rates of gaseous radionuclides released into the atmosphere.

30. Discharges of gaseous radionuclides to the atmosphere were modelled using the PLUME model parameters with values summarised in

31. Table 4-1. Deposition of tritium is considered (in accordance with the approach adopted for HPC) using values for deposition velocity and washout coefficient from the HPC RIA [Ref 25].

Table 4-1 Gaseous Dispersion and Deposition Parameters

Parameter	Value
Distance from reference stack (m)	450
Bearing from reference stack (°)	15-45
Physical stack height (m)	70
Height of tallest building affecting stack releases (m)	60
Effective stack height (m)	20
Meteorological data	Site specific (SZC centred windrose)
Roughness length (m)[5]	0.3
Deposition velocity (m/s)	5.00E-3 (tritium) 0 (noble gases and C-14) 1.00E-2 (iodine) 1.00E-3 (particulates)
Washout coefficient (1/s)	1.00E-4 (excluding gases, which were 0)
Deposition rates (Bq/m^2/s)	1

4.2 Habitat 2 (Marine Habitat)

32. The dispersion and accumulation of radioactivity in Habitat 2 (unfiltered seawater and seabed sediment from the local marine compartment) from continuous release of radionuclides in aqueous discharges were

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[4] The Met data used in the 2015 assessment has not been updated, as the ten year average is unlikely to be significantly affected by altering three years' worth of data.

[5] Surface roughness considers the effects of attributes such as landscape, buildings and vegetation on wind speed. The roughness length is the height above the ground at which the wind speed, due to building and vegetation etc., drops to zero. The roughness length value of 0.3 m used corresponds to generic agricultural land, which represents the predominant land use of the area around the Sizewell C site.

modelled using the DORIS module of PC-CREAM 08 [Ref 27]. DORIS calculates the time-dependent activity concentration of aqueous radionuclide discharges in the local and regional marine compartments.

33. The local marine compartment is modelled as a single well-mixed body of water and associated sediment, extending 4 km out to sea and 5km along the coastline either side of the proposed SZC site (i.e. 10 km in total). The local compartment is contained within the larger regional compartment with which it interacts and exchanges water and suspended sediment [Ref 27].

34. The focus of protection in biota dose assessments is on the population, not an individual or sub-set of individuals within that population [Ref 5]. The DORIS module of PC-CREAM 08 [Ref 27] predicts concentrations of radioactivity in environmental media (i.e. water and sediment) that are averaged across the local marine compartment. These environmental concentrations have then been used to predict the dose rates to NHB.

35. Aqueous discharges from the neighbouring SZB facility were considered to be released into the same marine compartment as SZC discharges.

36. The DORIS model parameters and values used to model the dispersion of aqueous radionuclides discharged into the marine environment from SZC are provided in Table 4-2 below.

Table 4-2 Marine Dispersion Parameters

Parameter	Local compartment	Regional compartment
Volume (m^3)	4.00E+08	4.50E+11
Depth (m)	1.00E+01	3.10E+01
Coastline length (m)	1.00E+04	-
Volumetric exchange rate (m^3/y)	1.10E+10	-
Suspended sediment load (t/m^3)	8.00E-05	6.00E-06
Sedimentation Rate (t/m^2/y)	1.00E-04	1.00E-04
Sediment density (t/m^3)	2.60E+00	2.60E+00
Diffusion rate (m^2/y)	3.15E-02	3.15E-02

37. All parameters in are the PC CREAM 08 default values, except for the volume of the local compartment, which has been increased from 3.00E+08 m^3 to 4.00E+08 m^3 to ensure that the discharge point (roughly 3.5 km from the coast) is within the local compartment. The default volumetric exchange rate corresponds to a local compartment volume of 3.00E+8 m^3. This has been retained as a new volumetric exchange rate cannot be derived without hydrographical data relevant to the area [Ref 31]. A local compartment of 4.00E+8m^3 would have a higher exchange rate, which would result in lower doses, so it is conservative to retain the default value [Ref 31]. The change in volume is small compared to the volume of the regional compartment, so the impact on the regional compartment is expected to be small.

4.3 Habitat 3 (Coastal Habitat)

38. Given that this habitat is considered to comprise terrestrial and marine habitats, analogous to Habitats 1 and 2 above, and to be inhabited by the same organisms that occupy Habitats 1 and 2 above, a separate assessment was not considered necessary. Instead, the environmental concentration data calculated for Habitats 1 and 2 using supporting models in PC-CREAM 08 were adopted for Habitat 3.

4.4 Habitats 4 and 5 (Scrape and Marshland Habitats)

39. The concentration of radionuclides in the scrape (Minsmere Nature Reserve, within the Minsmere-Walberswick Heaths and Marshes SPA) and marshland (the Minsmere-Walberswick Heaths and Marshes SSSI, SPA and Ramsar) from the deposition of gaseous releases was calculated using the IAEA SRS-19 model [Ref 32]. The SRS-19 model considers both direct deposition of radionuclides into a small lake (< 400 km^2) and indirect contributions from radionuclides deposited into its watershed through runoff, surface soil erosion and groundwater seepage. It is assumed that the watershed is 100 times the lake surface area, and that 2% of radionuclides deposited on to the watershed reach the scrape [Ref 32] [Ref 31]. As scrape and marshland contain freshwater bodies, this is an appropriate model to use. The parameters used to define the scrape and marshland are given in Table 4-3.

40. The deposition rates from radionuclides discharged into the atmosphere were modelled within the PLUME module of PC-CREAM 08 in the manner described for Habitat 1. The calculated deposition rates were used to derive the radionuclide discharge rates into the scrape (due to direct deposition and the contributions from the surrounding catchment) in accordance with the SRS-19 methodology for small lakes [Ref 32].

41. The parameters used for this assessment are presented in Table 4-3. The environmental concentrations data calculated are presented in Appendix C.

Table 4-3 Parameters for Freshwater Habitats (Scrape and Marshland)

Parameter	Value
Generic PLUME Model Parameters	
Distance from reference stack (m)	2500
Bearing from reference stack (°)	345
Effective stack height (m)	20
Meteorological data	Site specific (SZC centred windrose)
Roughness length (m)	0.3
Deposition velocity (m/s)	5.00E-3 (tritium) 0 (noble gases and C-14) 1.00E-2 (iodine) 1.00E-3 (particulates)
Washout coefficient (1/s)	1.00E-04 (excluding gases, which were 0)
Scrape Parameters [Ref 16]	
Scrape surface area (m^2)	40450
Scrape depth (m)	2
Scrape volume (m^3)	80900
Inflow (m^3/s)	0
Outflow (m^3/s)	0
Marshland Parameters [Ref 16]	
Marshland surface area (m^2)	1861554
Marshland depth (m)	0.1
Marshland volume (m^3)	186155
Inflow (m^3/s)	0
Outflow (m^3/s)	0

5 ASSESSMENT APPROACH

42. The assessment of radiological impacts due to discharges from SZC and the neighbouring SZB facility on NHB was undertaken using the ERICA Integrated Approach, which comprises the ERICA tool and the associated FREDERICA database [Ref 33] [Ref 34]. The ERICA approach was the product of the Framework for the Assessment of Environmental Impact (FASSET) (2004) and ERICA (2007) research projects commissioned by the European Commission (EC) (the ERICA project was effectively a continuation and consolidation of the FASSET project) and provides a comprehensive methodology for assessing the ecological effects of ionising radiation on NHB and ecosystems [Ref 33]. It is an internationally recognised tool for NHB radiological assessments. The Environment Agency's Research & Development (R&D)128 methodology [Ref 35] was used to assess the impacts of releases of noble gases, which are not currently included in the ERICA approach.

5.1 ERICA Integrated Approach

43. Version 1.2 of the ERICA tool was released in November 2014, and was further updated to Version 1.2.1 in February 2016 [Ref 36]. A subsequent version (Version 1.3.1.49) was released in June 2019. Version 1.2

introduced a new database with a new index list (new reference organisms) based on the IAEA wildlife transfer database [Ref 17]. There were a number of improvements in Version 1.2 including rationalisation of reference organisms, modification to occupancy factors and improvements to the CRs [Ref 36]. Version 1.2.1 included further amendments to the CRs for some radionuclides. Although Version 1.2.1 was used for this assessment, the terrestrial assessment was repeated using Version 1.3.1.49 and the results were found to be unchanged[6].

44. The ERICA tool is a multi-tiered software programme with supporting databases that allows the assessment of absorbed dose rates to a set of reference organisms that are representative of those commonly found in terrestrial, freshwater and marine ecosystems, for a range of radionuclides. The ERICA reference organisms incorporate the ICRP’s RAPs as well as some species protected under European legislation [Ref 37].

45. The ERICA tool calculates dose rates to organisms through the application of dose conversion coefficients (DCCs) to the concentrations of radionuclides in environmental media or in biota. DCCs are defined as the absorbed dose rate (µGy/h) per unit activity concentration in an organism (Bq/kg fresh weight (fw)) or environmental media (Bq/kg or Bq/l media fw). A range of DCCs for both internal and external exposures have been calculated for reference organisms-radionuclides-radiation type combinations and are contained in databases embedded within the ERICA tool. Details of the derivation of the DCCs can be found in [Ref 33] and [Ref 38].

46. External dose rates are calculated through the application of external DCCs to environmental media concentrations of radionuclides; occupancy factors are also applied to account for the fraction of time an organism spends in different locations/compartments of the reference ecosystem (for instance, the amount of time a rat spends on-soil or in-soil). External dose rates are calculated on the basis of a simplified ellipsoid geometry which considers only the main body of organisms (extremities such as legs are not accounted for) [Ref 33]. Work to demonstrate that the simplified geometry approach is fit for purpose in providing a pessimistic dose estimate is currently ongoing within the IAEA Modelling and Data for Radiological Impact Assessments programme. The Initial findings of which suggest that the ellipsoidal approach is indeed fit for purpose [Ref 37].

47. Dose rates from internally incorporated radionuclides are assessed in two stages [Ref 39]:

    - Stage 1 involves the estimation of the activity concentrations in biota through the application of equilibrium CRs to corresponding media activity concentrations (soil or air for terrestrial ecosystems and water for aquatic ecosystems). CRs assume equilibrium conditions and a uniform distribution of the radionuclide within the organism (i.e. with no accumulation of radionuclides within individual tissues). The ERICA tool comprises a database containing default CR values for key elements and reference organisms derived from review of published data, augmented with data acquired through the use of analogues, taxonomic considerations or modelled data, or a combination of approaches [Ref 33] and [Ref 34].

    - Stage 2 involves the application of internal DCCs to the radionuclide concentrations in organisms (from Stage 1 above) to calculate the dose due to internal irradiation of exposed organisms.

48. Radiation weighting factors are applied to take account of the differing biological effectiveness of different types of ionising radiation. The default radiation weighting factors for alpha of 10, low energy beta of 3

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[6] Version 1.3.1.49 was released in June 2019 while this report was being prepared. The updates mainly affected the user interface, but one update had the potential to affect dose rates in the terrestrial ecosystem. The terrestrial assessment was repeated using version 1.3.1.49 of ERICA, and it was found that the results were unchanged.

and gamma/beta of 1 in the ERICA tool [Ref 33] [Ref 34] were used for the NHB assessments. The result is expressed as a 'weighted absorbed dose' in Gy/h.

49. Total dose rates to the reference organisms are calculated as the sum of the weighted internal and external dose rates.

50. The ERICA tool also contains a database of distribution coefficients (Kd) for all default radionuclides, used to estimate activity concentrations in sediment from water concentrations and vice versa (the Kd is the ratio of activity concentration per unit mass of sediment to the activity concentration per unit volume of water) [Ref 33] [Ref 34].

51. The ERICA assessment tool is organised in three tiers where satisfying certain criteria in Tiers 1 and 2 allows the user to exit the assessment process while being confident that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are not shown to be negligible, the assessment should continue to the next Tier (Tier 2 and 3, respectively). Further details on the different Tiers is provided below:

- Tier 1 of the ERICA tool enables a simple and pessimistic screening assessment to be carried out. This tier incorporates Environmental Media Concentration Limits (EMCLs) for each radionuclide-reference organism combination, derived on the basis of a screening dose rate of 10 µGy/h. Input media concentrations (e.g. activity concentration in sediment or unfiltered water) are compared with the EMCL for the most limiting reference organism for each radionuclide to calculate the RQ[7]. If the sum of RQ values is less than one, there is a very low probability that the absorbed dose rate to any organism would exceed the screening dose rate and the assessment can be concluded at this stage [Ref 33].

- Tier 2 is also a screening tier however it is more interactive and affords greater flexibility in the choice of model parameters. It allows the modification of default model parameters (including Kd, CR, occupancy factors and radiation weighting factors) and the addition of non-default radionuclides and organisms (with user-defined geometries and attributes). In Tier 2, the estimated total weighted absorbed dose rates for each reference organism assessed are compared directly with the selected screening dose rate to produce a RQ for the organism [Ref 39]. Tier 2 also facilitates the inclusion of uncertainty factors (UF) to account for uncertainties in the dose rate calculations and estimate the probability of exceeding the screening dose rates. The UF is multiplied by the RQ to obtain a 'conservative RQ' value. A UF of 3, (corresponding to the 95th percentile values) [Ref 34] was adopted for the SZC NHB assessments.

- Tier 3 facilitates the undertaking of probabilistic risk assessment in which uncertainties associated with the results may be estimated using sensitivity analysis. It allows access to the FREDERICA database and the use of up-to-date scientific literature on the biological effects of exposure to ionising radiation in a number of different species. Together, these allow the user to estimate the probability (or incidence) and magnitude (or severity) of the environmental impacts likely to occur [Ref 33].

52. The impacts of aqueous and gaseous radioactive discharges from SZC on NHB were assessed at Tier 2 of the ERICA tool. No further assessment was required at Tier 3 level due to the results satisfying the criteria in Tier 2 providing confidence that the effects on biota are low or negligible. Details of the ERICA parameters used in the SZC assessment are provided in Appendix E.

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[7] The ratio of the predicted absorbed dose rate to the screening dose rate.

5.2 R&D 128 methodology

53. The Environment Agency's R&D 128 methodology was developed for the assessment of radiological impacts on Natura 2000 sites for compliance with the EC Habitats Directive in England and Wales [Ref 35]. The methodology is accompanied by an Excel spreadsheet-based model which uses a similar approach to that of the ERICA tool, but considers a smaller range of organisms and radionuclides. An updated version of the terrestrial ecosystem spreadsheet was issued in 2014, which included additional isotopes Kr-88, Xe-131m and Xe-133 isotopes and introduced additional organisms [Ref 40]. The R&D 128 methodology also provides guidance on the estimation of CR values for a given radionuclide-organism combination, and includes additional organisms of conservation significance in the UK that are not included in the ERICA default reference organisms [Ref 35]. Such organisms can be assessed in ERICA using the data presented in the R&D 128 documentation.

54. The assessment of impacts on NHB due to releases of noble gases from SZC, which constitute the largest component of predicted gaseous releases from the facility in terms of activity released, is not possible using the ERICA tool. Such assessments can however be carried out using the R&D 128 methodology (which incorporates representative noble gases) and the R&D 128 approach was used to calculate the dose rates to organisms occupying Habitat 1 arising from the discharge of noble gases from SZC.

55. The R&D 128 methodology does not allow for additional organisms to be added and, hence, the standard list of organisms was used to calculate dose from noble gases. The R&D 128 organisms were not themselves matched to the ERICA default reference organisms, described below in Section 6, as the older R&D 128 system is not directly consistent with ERICA. There are nonetheless similarities between the sets of organisms in the two models. For example, a bee is used in R&D 128, and the reference flying insect in ERICA is based on a bee. Whilst some organisms are broadly consistent, there are notable differences in the representation of others. The calculation of dose to a tree within R&D 128 focusses on the root, whereas in ERICA the focus is on the trunk. There are also some organisms within ERICA that are not included within R&D 128, such as an amphibian.

56. With the differences in the organisms between the two methodologies, species have not been matched, and as such dose rates are presented separately for ERICA derived values and those calculated using R&D 128. With the publication of the new Ar-Kr-Xe dose calculator [Ref 40], dose from exposure to selected noble gases can now be evaluated for the ERICA default organisms based on a derived Excel-based R&D 128 methodology. Hence, dose rate calculations could all be updated to a common framework. However, due to the very low doses predicted, i.e. NHB doses well below national / international thresholds and screening values, there is no technical basis to drive further work.

57. The R&D 128 methodology recognises two representative noble gases, Ar-41 and Kr-85, which are included in the assessment spreadsheet tool. The spreadsheet does not allow the inclusion of additional radionuclides. Ar-41 - which has higher gamma and beta energies than Kr-85 and the isotopes of xenon - was therefore used as a surrogate for the isotopes of xenon (Xe-131m, Xe-133 and Xe-135) [Ref 35][8], which provides a pessimistic assessment.

6 REFERENCE ORGANISMS

58. Radiological impact assessments that employ tools and approaches such as R&D 128, ERICA and the ICRP RAPs methodology aim to determine whether there could be ecological harm, based on a range of organism types and associated ecology within a generic habitat type. The default organisms within these

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[8] This is consistent with the approach used for the HPC NHB assessments, and with the Environment Agency's Initial Radiological Assessment Tool which uses Ar-41 as surrogate for Xe-133.

assessment tools and approaches have been selected to encompass the types of plant and animal that would be expected to be present in terrestrial, freshwater and marine ecosystems throughout temperate climates. The ERICA reference organisms were also selected to enable all protected species within Europe to be addressed [Ref 33].

59. The approach used in the demonstration of environmental protection in terms of NHB radiological protection is akin to comparison of chemical concentrations relative to environmental quality standards. This differs from an Ecological Impact Assessment that may focus not just on a species, but a population or even individuals within a sub-population. Such detail is not normally considered unless there is clear reason to believe that there may be environmental damage. However, based on initial results, more detailed assessments can then be undertaken if required.

60. On the basis of the calculated dose rates across the different habitats and organisms, no impact on populations of NHB from authorised discharges from SZC is likely as a result of exposure to radiation. Furthermore, the dose rates were calculated on the basis of maximum radioactivity concentrations, consistent with a cautious assumption that discharges occur at permit limits.

61. The plant and animal species occupying the habitats around the SZC Site, identified in the SZC Stage 1 Report (Table 4.2.2 and 4.2.4, and Paragraph 4.2.8) [Ref 8] have been compared to ERICA default reference organisms and two additional organisms (bat and badger) were included in the SZC NHB assessment. Further detailed comparisons of local species and the ERICA default organisms have been carried out on behalf of SZC Co. [Ref 16].

62. The majority of species identified in the Stage 1 report are broadly similar to ERICA reference organisms and the additional organisms. It is however noted that there are disparities in the physical dimensions of some local species compared to the ERICA representative organisms. For instance, a wide variety of bird species were reported to inhabit the designated sites close to SZC including species such as the bearded tit (Panurus biarmicus), woodlark (Lullula arborea) and black redstart (Phoenicurus ochruros), which are smaller than the equivalent ERICA reference organism (duck).

63. The ERICA default bird size, evaluated in the assessment, is based on the ICRP reference duck with a mass of 1.26 kg and dimensions of 30 cm x 10 cm x 8 cm. In terms of predicted dose, the implication of size variation is small with variation in ellipsoid dimensions having only a limited effect (up to a factor of 2 for a mass range of 1 g to 100 kg) on dose rate calculations [Ref 43]. For organisms lighter than 1 g (i.e. dimensions in the order of millilitres), geometry becomes more important. The variation in dose rate across different bird species, attributable to differences in bird size, is therefore trivial.

64. The ERICA default reference organisms for marine, terrestrial and freshwater ecosystems were adopted for the assessment of impacts to NHB. Non-default organisms including bats (e.g. Pipistrellus pipistrellus and Barbastella barbastellus), badgers (Meles meles), harbour porpoise (Phocoena phocoena) and lamprey (Petromyzontiformes) have been identified as present and of conservation significance for the environment surrounding the proposed SZC site [Ref 16].

65. Bats and badgers are not represented by the default ERICA reference organisms, which exclude flying mammals[9] and large burrowing mammals. They were therefore added to, and modelled explicitly within, ERICA.

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[9] Flying organisms are conservatively represented within ERICA as having an ‘on-soil’ occupancy in the terrestrial environment. The small mammal default reference organism is based on a rat and has occupancy within the soil column. Use of the small mammal reference organism would not, therefore, be representative of the occupancy habits of bats within an ERICA assessment context.

66. The Harbour Porpoise was not explicitly considered. The default ERICA organism list for the marine environment includes a marine mammal. The default dimensions for a marine mammal in ERICA are 180 cm x 44 cm x 44 cm. The length of the default marine mammal is broadly consistent with that of a Harbour Porpoise, noting that variation in dimensions of larger mammals has a trivial impact on dose calculations. The marine mammal reference organism is therefore considered to be sufficiently representative of the Harbour Porpoise. Total dose rate from SZC discharges for the marine mammal was calculated as 0.0040 µGy/h, which is several orders of magnitude below the assessment threshold.

67. The lamprey was also not explicitly modelled. However, both the marine and scrape habitats included benthic and pelagic fish. Benthic fish are the maximising case due to exposure to radioactivity in the sediment. Dose rates for fish in the marine environment were assessed to be 0.37 µGy/h (benthic) and 0.0019 µGy/h (pelagic). In the scrape environment dose rates were 0.015 µGy/h (benthic) and 0.0018 µGy/h (pelagic). Whilst lamprey may vary in size from the default fish reference organisms, the difference in dose rate attributable to size differences are likely to be trivial.

68. The radioecology parameters (CR) for badger and bat were based on the ERICA default values for mammals of comparable respective size. Bats are assumed to reside ‘on soil’ all the time (which represents a pessimistic basis for an organism that spends most of their time flying or roosting at height above ground, allowing external exposure to radionuclides deposited on soil), whilst badgers are assumed to spend half the time ‘in soil’ and the other half ‘on soil’.

69. Data on the physical attributes (weight and geometry) of non-default organisms were sourced from publications by relevant conservation organisations (e.g. ARKive, Bat Conservation Trust and Badger Trust). The ERICA approach for modelling dose-rates to organisms ‘in-soil’ is restricted to an upper mass range of 6.6 kg. To assess the total dose rate to badger (13 kg) due to in-soil occupancy, the upper range value (6.6 kg) was applied. The ERICA documentation indicates that the external dose rates to organisms with masses above the allowed upper mass limit are lower than the exposure specified at the limit. The internal dose rate to an in-soil organism with a mass of 10 kg is estimated to be <25% (for exposure to a 1 MeV photon) and <2% (for alpha/beta) higher than the dose rate to an organism at the upper mass limit of 6.6 kg. However, H-3 and C-14 (both weak beta emitters) contribute >99% of the internal dose rate to in-soil badger; the net effect of the difference in mass between the badger and the upper limit for in soil organisms is therefore considered to be insignificant and no correction factors were applied.

70. The full list of organisms assessed (comprising the default ERICA reference organisms and the additional organisms) and their attributes are reproduced in Appendix E. The reference organisms used to represent local species are also identified in Appendix F.

Occupancy Habits

71. The occupancy habits of reference organisms within ERICA are described in terms of the proportion of time reference organisms spend in different compartments of the relevant ecosystems [Ref 34] as explained in the following paragraphs.

72. For aquatic (marine and freshwater) ecosystems, the occupancy options include:

- Water-surface – refers to time spent by an organism such as a duck on the water surface.
- Water - refers to time spent by organisms such as pelagic fish (e.g. a salmon or trout) swimming through the water column.
- Sediment-surface - refers to time spent by organisms close to the bottom of the water column (e.g. a benthic fish such as flounder or carp) or on the surface of the sediment (such as some macrophytes).
- Sediment - refers to time spent by organisms (e.g. marine polychaete worms) buried in the sediment.

73. The occupancy options for terrestrial ecosystems are:

- On-soil - refers to time spent by organisms on the surface of the soil, for instance when a mammal such as a mouse is foraging for food.
- In-soil - refers to time spent by an organism within the soil matrix (e.g. organisms like earthworms or a burrowing mammal) when they are buried in the soil.
- In-air - refers to time spent in the air and applies to flying organisms such as birds.

74. Organisms inhabiting coastal habitats (e.g. wading birds) are assumed to spend equal amounts of time in the terrestrial and marine environments.

75. Details of the occupancy habits of the reference organisms on and around the SZC site are reproduced in Appendix E.

7 RESULTS AND DISCUSSION

76. The dose rates to organisms occupying the five habitats identified in the preceding sections were assessed at Tier 2 of the ERICA approach due to the need to consider non-default organisms. The assessment was carried out for all the default marine, terrestrial and freshwater organisms within ERICA that are applicable to a UK context[10]. Dose rates to the non-default organisms identified earlier have also been assessed.

77. The Environment Agency, together with Natural England and the Countryside Council for Wales (now part of Natural Resources Wales) have concluded that 40 µGy/h is the threshold below which adverse effects on the integrity of protected sites (SACs and SPAs) are not anticipated to occur [Ref 4] [Ref 35]. This criterion has been used as the current Environment Agency threshold dose rate against which the assessed dose rates were compared. The results are also compared with the ERICA recommended screening dose rate of 10 µGy/h.

7.1 Dose Rates due to Sizewell C Discharges

7.1.1 Habitat 1

78. The dose rates to terrestrial organisms residing within Habitat 1 from exposure to gaseous discharges from the SZC facility that deposit to ground were assessed based on the pessimistic assumption that the organisms inhabit the location of maximum offsite air concentration and deposition rates, 450 m and 15-45° from the reference stack. Large and small burrowing mammals (large and small-burrowing) received the highest dose rates of 0.005 µGy/h calculated using the ERICA tool; these dose rates are around four orders of magnitude below the current Environment Agency screening dose rate of 40 µGy/h and around three orders of magnitude below the ERICA recommended screening dose rate of 10 µGy/h. The corresponding RQ value is 0.00012. Thus, the probability that the estimated dose rate these organisms receive will exceed the screening dose rate is extremely low and any consequent risk to the organisms is considered trivial. The dose rate to the worst affected terrestrial organism (caterpillar) from exposure to noble gases, calculated using the R&D 128 spreadsheet, was 0.0018 µGy/h.

79. Table 7-1 below presents a summary of the assessed dose rates and the corresponding RQs for terrestrial organisms.

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[10] There are no marine reptile species associated with the coastal waters of the UK and the default reference organism 'reptile' was therefore excluded.

Table 7-1 Dose Rates to Habitat 1 (Terrestrial) Organisms due to Gaseous Discharges from Sizewell C at Proposed Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Amphibian	4.8E-03	1.2E-04
Annelid	2.0E-03	4.9E-05
Arthropod - detritivorous	2.0E-03	4.9E-05
Bat	4.9E-03	1.2E-04
Bird	5.0E-03	1.2E-04
Flying insects	1.9E-03	4.8E-05
Grasses & Herbs	3.4E-03	8.5E-05
Lichen & Bryophytes	3.4E-03	8.6E-05
Mammal - large	5.0E-03	1.2E-04
Mammal - small-burrowing	5.0E-03	1.2E-04
Mollusc - gastropod	2.0E-03	4.9E-05
Reptile	5.0E-03	1.2E-04
Shrub	3.4E-03	8.5E-05
Tree	4.9E-03	1.2E-04
Badger	4.9E-03	1.2E-04

80. C-14 accounts for between 70% and 88% of internal dose rates, which in turn constitutes over 99% of the total dose rates to terrestrial organisms. Co-60 accounts for up to 54% of the external dose rates. A breakdown of dose rates by radionuclides is provided in Appendix D, Table D-10.

7.1.2 Habitat 2

81. The dose rates to marine organisms residing within Habitat 2 from exposure to aqueous discharges from the SZC facility were assessed based on the assumption that the organisms inhabit the local marine compartment. The worst affected organism was the polychaete worm with a dose rate of 0.80 µGy/h. This dose rate is more than an order of magnitude below the current Environment Agency screening dose rate of 40 µGy/h and the ERICA recommended screening dose rate of 10 µGy/h. The corresponding RQ value is 0.020, thus the probability that the estimated dose rate to this organism will exceed the screening dose rate is very low and any consequent risk to the organism is trivial.

82. Table 7-2 below presents a summary of the assessed dose rates and the corresponding RQs for marine organisms.

Table 7-2 Dose Rates to Habitat 2 (Marine) Organisms due to Aqueous Discharges from Sizewell C at Proposed Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Bird	2.1E-03	5.2E-05
Benthic fish	3.7E-01	9.2E-03
Crustacean	3.7E-01	9.2E-03
Macroalgae	4.0E-01	1.0E-02
Mammal	4.0E-03	1.0E-04
Mollusc - bivalve	3.9E-01	9.9E-03
Pelagic fish	1.9E-03	4.8E-05
Phytoplankton	6.3E-04	1.6E-05
Polychaete worm	8.0E-01	2.0E-02
Sea anemones & True coral	4.0E-01	9.9E-03
Vascular plant	3.9E-01	9.8E-03
Zooplankton	5.4E-03	1.3E-04

83. The three dominant radionuclides accounting for the highest proportions of dose rates to marine organisms are C-14 and Ag-110m for internal dose rates and Co-60 for external dose rates. The contribution of external and internal dose rates to the total dose rates is variable, with external dose rates dominating the exposure for some organisms and vice versa for internal dose rates. A breakdown of dose rates by radionuclides is provided in Appendix D.

7.1.3 Habitat 3

84. Habitat 3 is a coastal environment considered to straddle Habitats 1 and 2 (terrestrial and marine) and dose rates calculated for default terrestrial and marine reference organisms in Habitats 1 and 2 are therefore considered bounding for this case, with organisms being assumed to reside permanently within their natural habitat (i.e. either the terrestrial or marine habitats). The dose rates to coastal organisms are therefore considered to be the same as those presented in Table 7-1 and Table 7-2 above. However, for some coastal bird species, such as Eurasian teal and Gadwall, occupancy of both marine and terrestrial habitats will occur. For such birds it is assumed that equal time is spent in each of the two habitats.

85. Table 7-3 below presents the dose rates experienced by bird species inhabiting the coastal environment. The dose rate (assuming a 50/50 occupancy in terrestrial and marine habitats) is calculated to be 0.0035 µGy/h, which is slightly lower than that for birds occupying only the terrestrial environment. Dose rates to coastal birds are around four orders of magnitude below the current Environment Agency screening dose rate of 40 µGy/h and more than three orders of magnitude below the ERICA recommended screening dose rate of 10 µGy/h. The corresponding RQ value is <0.0001 (i.e. the probability that the estimated dose rate to this organism will exceed the screening dose rate is extremely low and any consequent risk to the organism is considered trivial).

Table 7-3 Dose Rates to Habitat 3 (Coastal) Organisms due to Aqueous and Gaseous Discharges from Sizewell C at Proposed Limits

Coastal Habitat	Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Terrestrial compartment	Bird	5.0E-03	1.2E-04
Marine compartment	Bird	2.1E-03	5.2E-05
Both compartments (assuming 50/50 occupancy)	Bird	3.5E-03	8.8E-05

86. A breakdown of dose rates by radionuclides is not provided separately for coastal organisms – however, this can be inferred from the breakdown provided for terrestrial (Habitat 1) and marine (Habitat 2) organisms in Appendix D.

7.1.4 Habitat 4

87. The dose rate to the worst affected organism residing within Habitat 4 (freshwater scrape) is 0.032 µGy/h to insect larvae, arising from exposure to gaseous radionuclides deposited onto the scrape and its catchment. This dose rate is more than three orders of magnitude below the current Environment Agency screening dose rate of 40 µGy/h and more than two orders of magnitude below the ERICA recommended screening dose rate of 10 µGy/h. The corresponding RQ value is 0.0008, thus the probability that the estimated dose rate to this organism will exceed the screening dose rate is very low and any consequent risk to the organism is trivial. Table 7-4 below presents a summary of the assessed dose rates and the corresponding RQs for freshwater scrape organisms.

Table 7-4 Dose Rates to Habitat 4 (Freshwater Scrape) Organisms due to Gaseous Discharges from Sizewell C at Proposed Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Amphibian	1.8E-03	4.5E-05
Benthic fish	1.5E-02	3.6E-04
Bird	1.8E-03	4.4E-05
Crustacean	1.7E-02	4.2E-04
Insect larvae	3.2E-02	8.0E-04
Mammal	1.8E-03	4.4E-05
Mollusc - bivalve	1.6E-02	3.9E-04
Mollusc - gastropod	1.6E-02	4.0E-04
Pelagic fish	1.8E-03	4.5E-05
Phytoplankton	1.6E-03	4.1E-05
Reptile	1.4E-02	3.6E-04
Vascular plant	1.7E-02	4.2E-04
Zooplankton	1.6E-03	4.1E-05

88. H-3 accounts for between 89% and 100% of internal dose rates, while Co-60 dominates external dose rates accounting for between 41% and 52% to the total dose rates to the scrape organisms. The

contribution of external and internal dose rates to the total dose rates is variable, with external dose rates dominating the exposure for some organisms and vice versa for others. A breakdown of dose rates by radionuclides is provided in Appendix D Table D-12.

7.1.5 Habitat 5

89. The marshland habitat was assessed as a shallow scrape adopting the same approach used for the freshwater scrape. The dose rate to the worst affected organism within this habitat is 0.64 µGy/h to insect larvae, arising from exposure to gaseous radionuclides deposited onto the scrape and its catchment. This dose rate is more than an order of magnitude below the current Environment Agency screening dose rate of 40 µGy/h and the ERICA recommended screening dose rate of 10 µGy/h. The corresponding RQ value is 0.016; thus, the probability that the estimated dose rate to this organism will exceed the screening dose rate is very low and any consequent risk to the organism is trivial.

90. Table 7-5 below presents a summary of the assessed dose rates and the corresponding RQs for freshwater scrape organisms.

Table 7-5 Dose Rates to Habitat 5 (Marshland) Organisms due to Gaseous Discharges from Sizewell C at Proposed Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Amphibian	3.6E-02	9.0E-04
Benthic fish	2.9E-01	7.3E-03
Bird	3.5E-02	8.8E-04
Crustacean	3.4E-01	8.4E-03
Insect larvae	6.4E-01	1.6E-02
Mammal	3.5E-02	8.9E-04
Mollusc - bivalve	3.1E-01	7.8E-03
Mollusc - gastropod	3.2E-01	8.0E-03
Pelagic fish	3.6E-02	9.0E-04
Phytoplankton	3.3E-02	8.2E-04
Reptile	2.9E-01	7.2E-03
Vascular plant	3.4E-01	8.4E-03
Zooplankton	3.3E-02	8.2E-04

91. H-3 accounts for between 89% and 100% of internal dose rates, while Co-60 dominates external dose rates accounting for between 41% and 52% of the total dose rates to the scrape organisms. The contribution of external and internal dose rates to the total dose rates is variable, with external dose rates dominating the exposure for some organisms and vice versa for internal dose rates. A breakdown of dose rates by radionuclides is provided in Appendix D Table D-13.

7.2 Dose Rates due to the Combined Discharges from Sizewell B and C facilities

92. The Environment Agency has carried out a study assessing the impact of radioactive waste discharges on Natura 2000[11] sites in England and Wales [Ref 4]. The assessments calculated dose rates to organisms in coastal, freshwater and terrestrial environments due to the combined impact of all discharges authorised

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[11] Natura 2000 is made up of sites designated as SACs and SPAs.

under the Radioactive Substances Act 1993 (now superseded by the EPR16 in England and Wales), that could have an impact on a Natura 2000 site. The assessment was based on the cautious assumption that all discharges occur at permit limits.

93. It should be noted that the Environment Agency Natura 2000 study results are based on a precursor methodology to ERICA, and are not consistent with the ERICA assessment methods. In addition, at the time of the Environment Agency Natura 2000 site assessment, the Outer Thames Estuary was not designated as a SPA.

94. Table 7-6 below presents the Environment Agency calculated dose rates to the worst affected organisms inhabiting the designated sites close to the SZC site (Minsmere to Walberswick SPA, Minsmere to Walberswick Heaths and Marshes SAC, and Sandlings SPA) [Ref 4]. The Environment Agency results show the total dose rate to biota at the Minsmere to Walberswick SPA based on existing site permits (SZA and SZB) at the time of the study was 9.3 µGy/h and that the highest dose rate at the sites of interest was for the Sandlings Heath SPA of 16 µGy/h. These values are pessimistic and are based on discharges at operational authorisation limits. All but two of these values are below the recommended screening value in ERICA of 10 µGy/h. Nonetheless, all the values are still well below the current Environment Agency threshold of 40 µGy/h, the dose rate below which the Environment Agency and relevant conservation bodies have agreed that there will be no adverse effect on the integrity of a conservation site.

Table 7-6 Dose Rates to the worst affected Organisms Residing in Natura 2000 Sites near Sizewell C (Taken from the Environment Agency Study [Ref 4])

Environment Agency Site Code	Site name	Priority[12]	Total dose rate (µGy/h)[13]	Coastal – Local comp. (µGy/h)	Coastal– Regional comp. (µGy/h)	Total coastal (µGy/h)	Fresh-water (µGy/h)	Max water dose rate (µGy/h)	Terrestrial dose rate (µGy/h)
A28	Minsmere to Walberswick SPA	M	9.3	1.3E-01	1.3E-02	1.4E-01	3.1E-01	3.1E-01	9.0
A29	Minsmere to Walberswick Heaths and Marshes SAC	M	9.1	1.3E-01	1.3E-02	1.4E-01	0.0	1.4E-01	9.0
A46	Sandlings pSPA	L	16	1.5	1.3E-02	1.5	3.6	3.6	12
A35	Orfordness – Shingle Street cSAC	L	1.5	1.5	1.3E-02	1.5	0.0	1.5	0.0
A02	Alde-Ore Estuary SPA	M	9.3	1.3E-01	1.3E-02	1.4E-01	3.1E-01	3.1E-01	9.0
A03	Alde, Ore and Butley Estuaries cSAC	M	12	1.3E-01	1.3E-02	1.4E-01	0.0	1.4E-01	12

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[12] Allot et al. (2009) [4] categorised Natura 2000 sites as either high, medium or low priority based on the sites' value to conservation. Sites considered here were either medium (M) or low (L) priority.

[13] The Environment Agency calculate the total dose rate as the sum of the terrestrial dose rate and the maximum water dose rate (where the water dose rate is the sum of the freshwater and coastal water dose rates, inclusive of local and regional compartments)

95. The results of the current in-combination effects assessment for SZC have been evaluated against the Environment Agency dose rates [Ref 4] discussed above.

96. In-combination effects arising from the combined discharges of aqueous and gaseous radioactive effluent from SZB (at current permitted discharge limits) and SZC (at proposed discharge limits) have been assessed here using the source terms shown in Table 3-1 and Table 3-2.

97. Discharges from the decommissioning of the SZA facility have not been included in the assessment on the basis that the site would have entered the C&M decommissioning phase by the time SZC becomes operational and discharges from the site would be trivial [Ref 24].

98. There is the potential that in-combination impacts at a regional level (particularly on organisms inhabiting the Outer Thames Estuary SPA) could occur due to discharges associated with the accelerated decommissioning programme for the Bradwell nuclear power station. However, as with SZA, the Bradwell site is scheduled to enter the C&M phase before the SZC site becomes operational [Ref 24], so in-combination effects from discharges from Bradwell were not considered.

7.2.1 Habitat 1

99. The dose rate to the worst affected terrestrial organisms (small-burrowing mammal, large mammal, bird and reptile) from the combined discharges of gaseous effluent from the Sizewell Site (SZB and SZC) is calculated to be 0.0069 µGy/h, with a corresponding RQ of 0.00017. This dose rate is nearly four orders of magnitude below the current Environment Agency threshold dose rate of 40 µGy/h and more than three orders of magnitude lower than the ERICA recommended screening dose rate of 10 µGy/h. The dose rate to the worst affected terrestrial organism (caterpillar) from exposure to noble gases, calculated using the R&D 128 spreadsheet, is 0.0033 µGy/h.

100. By comparison, the dose rates to the worst affected terrestrial organisms reported by the Environment Agency from SZA and SZB were 9.0 µGy/h for Minsmere to Walberswick SPA and SAC, and 12 µGy/h for Sandlings SPA. These dose rates are more than three orders of magnitude above the assessed dose rates for the Sizewell Site discharges.

101. Table 7-7 below presents a summary of the assessed dose rates and the corresponding RQs for terrestrial organisms.

Table 7-7 Dose Rates to Habitat 1 (Terrestrial) Organisms due to the Combined Discharges of Gaseous Effluent from Sizewell B and C at Annual Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Amphibian	6.7E-03	1.7E-04
Annelid	2.7E-03	6.9E-05
Arthropod - detritivorous	2.8E-03	6.9E-05
Bat	6.8E-03	1.7E-04
Bird	6.9E-03	1.7E-04
Flying insects	2.7E-03	6.7E-05
Grasses & Herbs	4.7E-03	1.2E-04
Lichen & Bryophytes	4.8E-03	1.2E-04
Mammal - large	6.9E-03	1.7E-04
Mammal - small-burrowing	6.9E-03	1.7E-04
Mollusc - gastropod	2.7E-03	6.9E-05
Reptile	6.9E-03	1.7E-04
Shrub	4.7E-03	1.2E-04
Tree	6.7E-03	1.7E-04
Badger	6.8E-03	1.7E-04

7.2.2 Habitat 2

102. The dose rate to the worst affected marine organism (polychaete worm) from the combined discharges of aqueous effluent from the Sizewell Site is calculated to be 0.91 µGy/h, with a corresponding RQ of 0.023. This dose rate is more than one order of magnitude below the current Environment Agency threshold dose rate of 40 µGy/h and the ERICA recommended screening dose rate of 10 µGy/h.

103. By comparison, the dose rates to the worst affected organisms inhabiting the local coastal habitats of the Minsmere to Walberswick SPA and SAC, and the Sandlings SPA as reported by the Environment Agency were 0.13 and 1.5 µGy/h respectively. These dose rates fall either side of the dose rates assessed for the combined discharges from the SZB and SZC stations.

104. Table 7-8 below presents a summary of the assessed dose rates and the corresponding RQs for marine organisms.

Table 7-8 Dose Rates to Habitat 2 (Marine) Organisms due to the Combined Discharges of Aqueous Effluent from Sizewell B and C at Annual Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Bird	3.5E-03	8.8E-05
Benthic fish	4.2E-01	1.1E-02
Crustacean	4.2E-01	1.0E-02
Macroalgae	4.6E-01	1.1E-02
Mammal	5.7E-03	1.4E-04
Mollusc - bivalve	4.5E-01	1.1E-02
Pelagic fish	2.2E-03	5.5E-05
Phytoplankton	7.1E-04	1.8E-05
Polychaete worm	9.1E-01	2.3E-02
Sea anemones & True coral	4.5E-01	1.1E-02
Vascular plant	4.5E-01	1.1E-02
Zooplankton	5.6E-03	1.4E-04

7.2.3 Habitat 3

105. The dose rates to coastal organisms are considered to be the same as those presented in Table 7-7 and Table 7-8, except for the dose rates to coastal birds, which are given in Table 7-9. Table 7-9 shows that the dose rate to the bird from the combined discharges of aqueous effluent from the Sizewell Site is calculated to be 0.0052 µGy/h, with a corresponding RQ of 0.00013. This dose rate is more than three orders of magnitude below the current Environment Agency threshold dose rate of 40 µGy/h and the ERICA recommended screening dose rate of 10 µGy/h. Table 7-7 and Table 7-8 show that the dose rate to the worst affected coastal organism (polychaete worm) from the combined discharges of aqueous effluent from the Sizewell Site is calculated to be 0.91 µGy/h, with a corresponding RQ of 0.023.

106. By comparison, the dose rates to the worst affected organisms inhabiting the local marine compartments of the Minsmere to Walberswick SPA and SAC, and the Sandlings SPA as reported by the Environment Agency were 0.13 and 1.5 µGy/h respectively. These dose rates fall either side of the dose rates assessed for the combined discharges from the SZB and SZC stations. The dose rate to the worst affected organisms inhabiting the terrestrial compartment of the Minsmere to Walberswick SPA and SAC, and the Sandlings SPA, as reported by the Environment Agency were 9.0 and 12 µGy/h. These dose rates are over four orders of magnitude higher than that assessed for the combined discharges from the Sizewell site.

Table 7-9 Dose Rates to Habitat 3 (Coastal) Organisms due to the Combined Discharges of Aqueous and Gaseous Effluent from Sizewell B and C at Annual Limits

Coastal Habitat	Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Terrestrial compartment	Bird	6.9E-03	1.7E-04
Marine compartment	Bird	3.5E-03	8.8E-05
Both compartments (assuming 50/50 occupancy)	Bird	5.2E-03	1.3E-04

7.2.4 Habitat 4

107. The dose rate to the worst affected scrape organism (insect larvae) from the combined discharges of gaseous effluent from the Sizewell Site, deposited onto the scrape and its watershed, is calculated to be 0.13 µGy/h, with a corresponding RQ of 0.0034. This dose rate is more than two orders of magnitude below the current Environment Agency threshold dose rate of 40 µGy/h and approximately two orders of magnitude lower than the ERICA recommended screening dose rate of 10 µGy/h.

108. By comparison, the dose rates to the worst affected organisms inhabiting the local freshwater habitats of the Minsmere to Walberswick SPA, SAC and the Sandlings SPA were 0.31 and 3.6 µGy/h respectively as reported by the Environment Agency. The dose rates for the Sandlings SPA organisms are more than one order of magnitude greater than the worst dose rates due to the combined discharges from the Sizewell Site. The dose rate for the Minsmere to Walberswick SPA and SAC are comparable to those from the combined discharges from the Sizewell Site.

109. Table 7-10 below presents a summary of the assessed dose rates and the corresponding RQs for scrape organisms.

Table 7-10 Dose Rates to Habitat 4 (Scrape) Organisms due to the Combined Discharges of Gaseous Effluent from Sizewell B and C at Annual Limits

Organism	Total Dose Rate per organism (µGy/h)	Risk Quotient (expected value) (unitless)
Amphibian	2.6E-03	6.6E-05
Benthic fish	6.2E-02	1.6E-03
Bird	2.7E-03	6.8E-05
Crustacean	6.9E-02	1.7E-03
Insect larvae	1.3E-01	3.4E-03
Mammal	2.7E-03	6.6E-05
Mollusc - bivalve	6.7E-02	1.7E-03
Mollusc - gastropod	6.8E-02	1.7E-03
Pelagic fish	2.7E-03	6.7E-05
Phytoplankton	2.5E-03	6.2E-05
Reptile	6.1E-02	1.5E-03
Vascular plant	6.8E-02	1.7E-03
Zooplankton	2.5E-03	6.3E-05

7.2.5 Habitat 5

110. The dose rate to the worst affected marshland organism (insect larvae) from the combined discharges of gaseous effluent from the Sizewell Site, deposited onto the marshland and its watershed, is calculated to be 2.7 µGy/h, with a corresponding RQ of 0.067. This dose rate is more than an order of magnitude below the current Environment Agency threshold dose rate of 40 µGy/h and is around an order of magnitude lower than the ERICA recommended screening dose rate of 10 µGy/h.

111. By comparison, the dose rates to the worst affected organisms inhabiting the local freshwater habitats of the Minsmere to Walberswick SPA, SAC and the Sandlings SPA, as calculated by the Environment Agency, were 0.31 and 3.6 µGy/h respectively. The dose rate for the Sandlings SPA organism is comparable to the worst dose rates due to the combined discharges from the Sizewell Site. The dose rate for the Minsmere to Walberswick SPA is approximately an order of magnitude below that arising from Sizewell Site discharges.

112. Table 7-11 below presents a summary of the assessed dose rates and the corresponding RQs for scrape organisms.

Table 7-11 Dose Rates to Habitat 5 (Marshland) Organisms due to the Combined Discharges of Gaseous Effluent from Sizewell B and C at Annual Limits

Organism	Total Dose Rate per organism [µGy/h]	Risk Quotient (expected value) [unitless]
Amphibian	5.3E-02	1.3E-03
Benthic fish	1.2E+00	3.1E-02
Bird	5.4E-02	1.4E-03
Crustacean	1.4E+00	3.4E-02
Insect larvae	2.7E+00	6.7E-02
Mammal	5.3E-02	1.3E-03
Mollusc - bivalve	1.3E+00	3.3E-02
Mollusc - gastropod	1.3E+00	3.4E-02
Pelagic fish	5.3E-02	1.3E-03
Phytoplankton	5.0E-02	1.2E-03
Reptile	1.2E+00	3.1E-02
Vascular plant	1.4E+00	3.4E-02
Zooplankton	5.1E-02	1.3E-03

113. The previous Environment Agency assessment generally predicted higher doses, but was based on much simpler (and more pessimistic) modelling and earlier assessment approaches which have been largely superseded.

8 CONCLUSION

114. The potential impact of routine operational aqueous and gaseous discharges from the proposed SZC nuclear power plant on a range of organisms representative of those inhabiting the areas close to the facility has been assessed. The assessment was based on the proposed annual discharge limits for SZC,

and the permitted discharge limits for the neighbouring SZB facility were used in the assessment of in-combination effects.

115. For all of the organisms evaluated, dose rates (biological impacts of ionising radiation) remained substantially lower than the current Environment Agency assessment threshold of 40 µGy/h. The dose rates were also lower than broader internationally considered thresholds. These included the:

- ERICA screening value that is considered protective of populations of NHB across all ecosystems (10 µGy/h); and
- Derived consideration reference levels, the most stringent of which is 4 µGy/h (for the duck, rat, deer and pine tree RAPs), applicable to planned exposure situations [Ref 41] [Ref 42].

116. The assessment results have shown the dose rate from SZC discharges to the worst affected organism (polychaete worm occupying a marine habitat) to be 0.80 µGy/h, with a RQ value of 0.020. The worst affected organism from the combined discharges of radioactive effluent from the SZB and SZC facilities (insect larvae occupying a marshland habitat) was 2.7 µGy/h, with a RQ value of 0.067. This dose rate is more than one order of magnitude below the current threshold dose rate of 40 µGy/h.

117. The impacts of radioactive effluent discharges on NHB from the proposed SZC nuclear power plant alone and in combination with SZB are therefore predicted to be very low. As such, based on the international recognised models used in this assessment, the output of which are well below regulatory threshold levels and furthermore comparable to or below previous assessments undertaken by the Environment Agency for the Natura 2000 sites, it can be concluded that there would be no significant effects on any Natura 2000 site and hence radiological effects are screened out of the Shadow Habitats Regulations Assessment. Likewise, no significant effects are predicted on any other ecological receptor or designated site, such as SSSIs.

APPENDIX A HABITAT SURVEY AREA

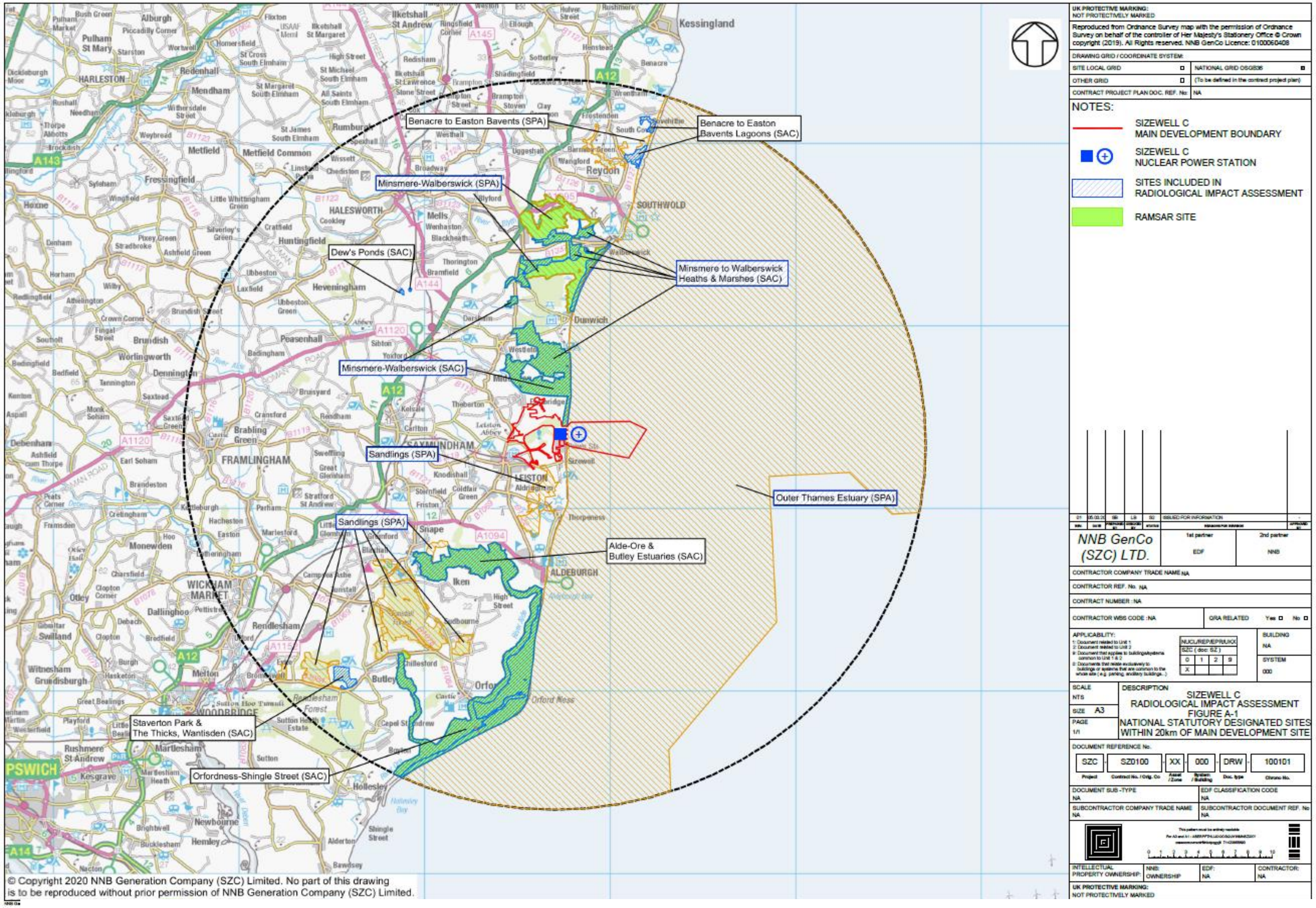

Figure A-1 National Statutory Designated Sites selected for Sizewell C RIA

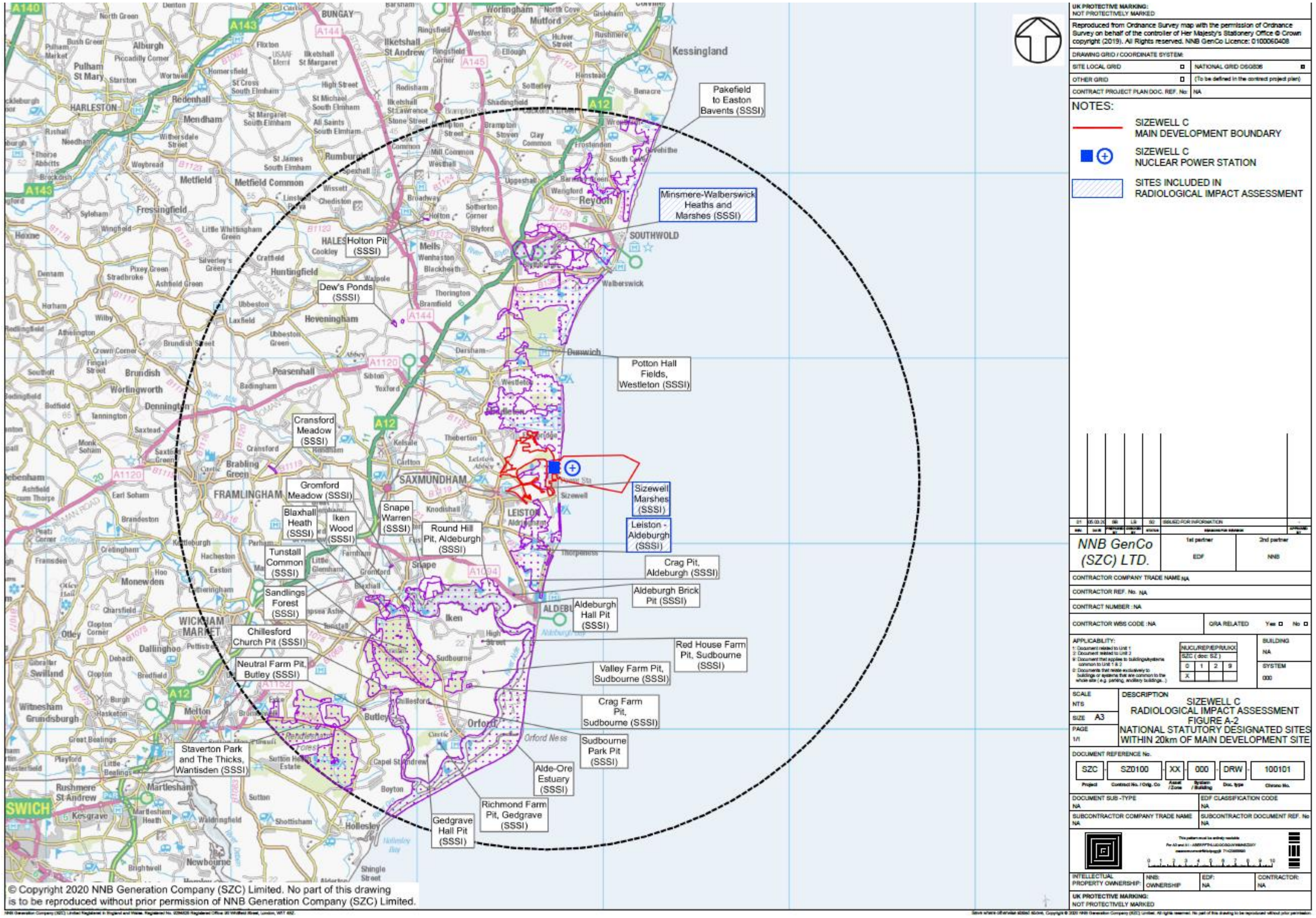

Figure A-2 International Statutory Designated Sites selected for Sizewell C RIA

APPENDIX B METEOROLOGICAL DATA

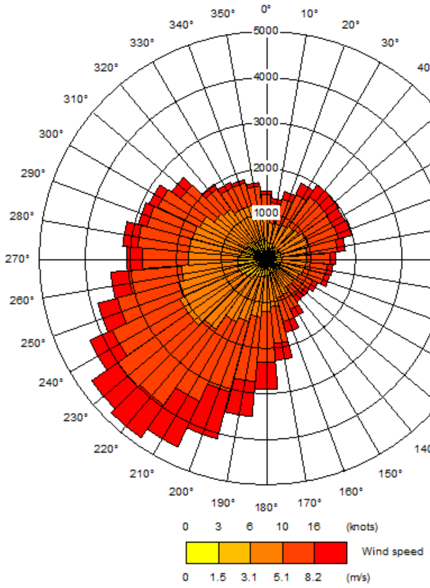

Figure B-3 Sizewell C Centred Windrose

Table B-1 10 Year (2003-2013) Meteorological Data in PC-CREAM 08 Format

Stability Category	Wind Angle (°)											
	15-45	45-75	75-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	345-15
A,	0	1.14E-5	1.14E-5	2.28E-5	1.14E-5	1.14E-5	1.14E-5	0	1.14E-5	1.14E-5	0	3.42E-5
B,	2.28E-4	2.40E-4	4.22E-4	3.99E-4	2.05E-4	2.05E-4	3.08E-4	1.59E-3	1.94E-3	1.90E-3	1.03E-3	4.56E-4
C,	6.98E-3	8.08E-3	8.89E-3	1.01E-2	5.74E-3	4.25E-3	6.98E-3	1.14E-2	8.81E-3	7.85E-3	8.69E-3	1.35E-2
D,	6.57E-2	6.87E-2	5.13E-2	4.31E-2	2.32E-2	1.67E-2	2.10E-2	2.34E-2	1.84E-2	1.42E-2	1.33E-2	3.49E-2
E,	3.21E-2	3.56E-2	2.54E-2	1.68E-2	1.02E-2	8.16E-3	8.73E-3	1.04E-2	1.11E-2	8.70E-3	9.78E-3	1.69E-2
F,	3.56E-3	4.35E-3	3.97E-3	3.05E-3	2.28E-3	2.25E-3	2.42E-3	2.26E-3	2.43E-3	2.67E-3	3.03E-3	3.07E-3
C+Rain,	1.64E-3	2.01E-3	1.73E-3	1.90E-3	1.76E-3	1.51E-3	1.53E-3	1.69E-3	1.09E-3	8.44E-4	1.00E-3	1.94E-3
D+Rain	4.44E-2	2.75E-2	1.85E-2	1.95E-2	2.16E-2	1.88E-2	2.01E-2	1.64E-2	1.12E-2	8.78E-3	1.27E-2	2.84E-2

APPENDIX C NHB ENVIRONMENTAL CONCENTRATION DATA

118. The tables below present the PC-CREAM 08 derived environmental concentration data used to assess the dose rates to NHB. All the data presented are based on a 60 year integration time.

C.1 Sizewell C Discharges

Table C-2 Radionuclide Concentrations in Unfiltered Seawater and Seabed Sediment (Local Compartment) from Sizewell C Discharges

Isotope	Activity concentration in water (Bq/l)	Activity concentration in seabed sediment (Bq/kg)
Ag-110m	9.78E-05	4.85E-03
C-14	1.74E-02	2.81E+01
Co-58	2.91E-04	4.88E-02
Co-60	4.93E-04	1.63E+00
Cr-51	7.38E-06	4.15E-04
Cs-134	9.72E-05	3.23E-02
Cs-137	1.73E-04	2.85E-01
H-3	1.84E+01	3.16E+01
I-131	4.17E-06	9.15E-07
Mn-54	4.15E-05	2.92E-02
Ni-63	1.68E-04	1.58E+00
Sb-124	7.54E-05	9.43E-04
Sb-125	1.44E-04	2.47E-02
Te-125m (Sb-125)*	2.07E-05	2.47E-02
Te-123m	4.29E-05	1.05E-03
Te-123 (Te-123m)*	1.33E-19	1.27E-15

* Progeny of the radionuclide shown in brackets

Table C-3 Radionuclide Concentration in Soil from Sizewell C Discharges at the Location of Habitat 1

Radionuclides	Dep. rates (Bq/m^2 per s) for annual discharge	Soil Concentration (Bq/kg)
Co-58	1.98E-09	4.82E-05
Co-60	2.33E-09	1.25E-03
Cs-134	1.82E-09	4.18E-04
Cs-137	1.63E-09	3.18E-03
I-131	3.56E-07	8.20E-04
I-133	6.89E-08	1.66E-05
Ba-137m (Cs-137)*	4.97E-10	2.44E-10
Cs-135 (Xe-135)*	1.26E-15	4.29E-09

*Progeny of the radionuclide in shown brackets

Table C-4 Radionuclide Concentration in Air from Sizewell C Discharges at the Location of Habitat 1

Radionuclide	Air Concentration (Bq/m^3)
C-14	1.11E-01
H-3	4.75E-01

Table C-5 Discharge rates of Radionuclides to the Freshwater Scrape and Marshland from Sizewell C Discharges

Radionuclide	Deposition rate (Bq/m^2 per s) for annual discharge	Radionuclide discharge rate to scrape (Bq/s)	Radionuclide discharge rate to marshland (Bq/s)
C-14	0.00E+00	0.00E+00	0.00E+00
Co-58	1.94E-10	2.35E-05	1.08E-03
Co-60	2.28E-10	2.76E-05	1.27E-03
Cs-134	1.78E-10	2.16E-05	9.92E-04
Cs-137	1.59E-10	1.93E-05	8.90E-04
H-3	2.44E-04	2.96E+01	1.36E+03
I-131	2.67E-08	3.24E-03	1.49E-01
I-133	5.14E-09	6.24E-04	2.87E-02
Ba137m (Cs-137)*	1.39E-10	1.68E-05	7.75E-04
Cs-135 (Xe-135)*	7.37E-16	8.94E-11	4.11E-09

*Progeny of the radionuclide in shown brackets

C.2 Combined Sizewell B and C Discharges

Table C-6 Concentration of Radionuclides in Unfiltered Seawater and Seabed Sediment from Sizewell B and C Discharges

Radionuclide	Unfiltered seawater (Bq/l)	Seabed sediment (Bq/kg)
Ag-110m	9.78E-05	4.85E-03
C-14	1.74E-02	2.81E+01
Co-58	2.91E-04	4.88E-02
Co-60	4.93E-04	1.63E+00
Cr-51	7.38E-06	4.15E-04
Cs-134	1.16E-02	3.84E+00
Cs-137	1.99E-03	3.29E+00
H-3	2.57E+01	4.42E+01
I-131	4.17E-06	9.15E-07
Mn-54	4.15E-05	2.92E-02
Ni-63	1.68E-04	1.58E+00
Sb-124	7.54E-05	9.43E-04
Sb-125	1.44E-04	2.47E-02
Te-125m (Sb-125)*	2.07E-05	2.47E-02
Te-123m	4.29E-05	1.05E-03
Te-123 (Te-123m)*	1.33E-19	1.27E-15

*Progeny of the radionuclide shown in brackets

Table C-7 Concentration of Radionuclides in Soil from Sizewell B and C Discharges at the Location of Habitat 1

Radionuclides	Dep. rates ($Bq/m^2/s$)	Soil Concentration (Bq/kg)
Co-58	1.98E-09	4.82E-05
Co-60	2.05E-08	1.10E-02
Cs-134	1.82E-09	4.18E-04
Cs-137	1.63E-09	3.18E-03
I-131	8.02E-07	1.84E-03
I-133	6.89E-08	1.66E-05
Ba-137m (Cs-137)*	4.97E-10	2.44E-10
Cs-135 (Xe-135)*	1.26E-15	4.29E-09

*Progeny of the radionuclide in shown brackets

Table C-8 Radionuclide Concentration in Air from Sizewell B and C Discharges at the Location of Habitat 1

Radionuclide	Air Concentration (Bq/m^3)
C-14	1.51E-01
H-3	7.12E-01

Table C-9 Discharge rates of Radionuclides to the Freshwater Scrape and Marshland from Sizewell B and C Discharges

Radionuclide	Deposition rate (Bq/m2/s) for annual discharge	Radionuclide discharge rate to scrape	Radionuclide discharge rate to marshland
C-14	0.00E+00	0.00E+00	0.00E+00
Co-58	1.94E-10	2.35E-05	1.08E-03
Co-60	2.01E-09	2.44E-04	1.12E-02
Cs-134	1.78E-10	2.16E-05	9.92E-04
Cs-137	1.59E-10	1.93E-05	8.90E-04
H-3	3.66E-04	4.45E+01	2.05E+03
I-131	6.00E-08	7.28E-03	3.35E-01
I-133	5.14E-09	6.24E-04	2.87E-02
Ba137m (Cs-137)*	1.39E-10	1.68E-05	7.75E-04
Cs-135 (Xe-135)*	7.37E-16	8.94E-11	4.11E-09

*Progeny of the radionuclide in shown brackets

APPENDIX D NHB BREAKDOWN OF TOTAL DOSE RATES BY RADIONUCLIDE

Table D-10 Total Dose Rate (µGy/h) to Habitat 1 (Terrestrial) Organisms due to Gaseous Discharges from Sizewell C

Isotope	Amphibian	Annelid	Arthropod - detritivorous	Bat	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree	Badger
C-14	4.2E-03	1.4E-03	1.4E-03	4.3E-03	4.4E-03	1.4E-03	2.8E-03	2.9E-03	4.4E-03	4.4E-03	1.4E-03	4.4E-03	2.8E-03	4.3E-03	4.4E-03
Co-58	2.5E-08	2.5E-08	2.5E-08	9.9E-09	9.7E-09	9.7E-09	9.2E-09	9.7E-09	8.1E-09	2.4E-08	9.7E-09	2.3E-08	8.7E-09	7.8E-09	1.4E-08
Co-60	1.7E-06	1.6E-06	1.6E-06	6.4E-07	6.2E-07	6.3E-07	6.0E-07	6.3E-07	5.3E-07	1.5E-06	6.3E-07	1.5E-06	5.6E-07	4.9E-07	9.4E-07
Cs-134	3.7E-07	3.5E-07	3.6E-07	2.9E-07	1.8E-07	1.4E-07	1.8E-07	2.7E-07	9.7E-07	5.7E-07	1.4E-07	3.5E-07	2.0E-07	1.4E-07	6.2E-07
Cs-137	1.2E-06	9.9E-07	1.0E-06	2.0E-06	6.9E-07	4.3E-07	8.5E-07	1.8E-06	3.9E-06	2.7E-06	4.0E-07	1.2E-06	1.2E-06	4.2E-07	2.9E-06
H-3	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.5E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04	5.9E-04
I-131	2.0E-07	1.7E-07	1.8E-07	1.0E-07	1.1E-07	8.9E-08	7.6E-08	7.5E-08	1.1E-07	1.9E-07	8.0E-08	1.8E-07	5.9E-08	7.9E-08	1.4E-07
Ba-137m (Cs-137)*	7.7E-14	7.8E-14	7.9E-14	3.0E-14	2.9E-13	3.0E-14	2.9E-14	3.0E-14	1.6E-14	7.4E-14	3.0E-14	7.1E-14	3.3E-14	2.9E-14	4.0E-14
Cs-135 (Xe-135)*	7.8E-14	1.4E-14	1.8E-14	5.8E-13	9.6E-14	1.8E-14	1.9E-13	6.2E-13	5.8E-13	5.8E-13	6.9E-15	9.8E-14	3.3E-13	2.3E-14	5.8E-13
I-133	6.9E-09	5.9E-09	6.2E-09	3.6E-09	3.9E-09	3.0E-09	2.5E-09	2.5E-09	4.0E-09	6.7E-09	2.6E-09	6.5E-09	2.0E-09	2.6E-09	4.8E-09
Total	4.8E-03	2.0E-03	2.0E-03	4.9E-03	5.0E-03	1.9E-03	3.4E-03	3.4E-03	5.0E-03	5.0E-03	2.0E-03	5.0E-03	3.4E-03	4.9E-03	4.9E-03

*Progeny of the radionuclide in shown brackets

Table D-11 Total Dose Rate (µGy/ h) to Habitat 2 (Marine) Organisms due to Aqueous Discharges from Sizewell C

Isotope	Bird	Benthic fish	Crustacean	Macroalgae	Mammal	Mollusc - bivalve	Pelagic fish	Phytoplankton	Polychaete worm	Sea anemones & True coral	Vascular plant	Zooplankton
Ag-110m	5.6E-04	2.1E-03	2.6E-03	2.1E-03	1.9E-03	2.3E-03	2.3E-04	2.1E-04	4.4E-03	2.1E-03	2.0E-03	2.8E-05
C-14	8.7E-04	8.8E-04	7.2E-04	6.6E-04	8.7E-04	3.2E-04	8.7E-04	1.2E-04	5.0E-03	8.5E-04	6.5E-04	5.0E-03
Co-58	1.5E-05	5.9E-02	5.8E-02	6.4E-02	4.9E-05	6.3E-02	1.3E-04	1.6E-05	1.3E-01	6.4E-02	6.3E-02	3.5E-05
Co-60	6.0E-05	2.6E-01	2.6E-01	2.8E-01	1.9E-04	2.8E-01	5.0E-04	7.1E-05	5.5E-01	2.8E-01	2.8E-01	1.3E-04
Cr-51	1.5E-07	8.1E-06	7.8E-06	9.0E-06	2.7E-07	8.7E-06	1.4E-08	2.6E-07	1.8E-05	8.9E-06	8.9E-06	5.3E-08
Cs-134	1.0E-05	4.3E-04	4.1E-04	4.6E-04	1.3E-05	4.5E-04	1.6E-06	1.3E-07	9.1E-04	4.6E-04	4.5E-04	1.1E-06
Cs-137	1.6E-05	2.8E-04	2.7E-04	3.1E-04	1.3E-05	3.0E-04	2.7E-06	1.7E-07	6.1E-04	3.1E-04	3.0E-04	2.8E-06
H-3	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04
I-131	1.2E-09	8.3E-08	9.7E-08	2.0E-06	1.1E-09	4.5E-06	5.7E-09	2.5E-07	4.2E-06	4.1E-06	9.4E-08	1.3E-06
Mn-54	1.4E-05	4.9E-02	4.8E-02	5.2E-02	5.0E-05	5.2E-02	6.1E-06	1.1E-06	1.0E-01	5.2E-02	5.1E-02	1.0E-06
Ni-63	1.0E-06	5.2E-07	2.6E-06	2.0E-06	1.0E-06	1.3E-05	5.2E-07	1.2E-06	8.7E-06	1.3E-05	2.0E-06	1.0E-06
Sb-124	2.2E-04	2.1E-04	2.0E-04	2.2E-04	4.7E-04	2.1E-04	1.4E-05	4.4E-06	5.2E-04	2.2E-04	2.0E-04	1.3E-05
Sb-125	1.2E-04	9.2E-05	8.5E-05	9.5E-05	2.4E-04	9.7E-05	8.0E-06	7.1E-06	2.3E-04	9.3E-05	9.4E-05	1.1E-05
Te-123 (Te-123m)*	1.6E-20	2.3E-21	2.8E-21	2.2E-21	2.0E-20	3.7E-21	1.3E-21	1.4E-20	9.3E-21	1.8E-21	2.2E-21	1.1E-21
Te-123m	2.8E-05	6.4E-06	7.3E-06	5.9E-06	4.3E-05	8.9E-06	2.2E-06	3.3E-05	2.2E-05	4.8E-06	5.8E-06	2.7E-06
Te-125m (Sb-125)*	1.5E-05	1.5E-06	2.0E-06	1.2E-06	1.6E-05	2.9E-06	1.2E-06	1.9E-05	8.2E-06	5.4E-07	1.1E-06	1.5E-06
Total	2.1E-03	3.7E-01	3.7E-01	4.0E-01	4.0E-03	3.9E-01	1.9E-03	6.3E-04	8.0E-01	4.0E-01	3.9E-01	5.4E-03

*Progeny of the radionuclide in shown brackets

Table D-12 Total Dose Rate (µGy/h) to Habitat 4 (Scrape) Organisms due to Gaseous Discharges from Sizewell C

Isotope	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
C-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-58	3.0E-08	7.0E-05	1.9E-07	8.0E-05	1.6E-04	8.8E-08	7.6E-05	7.8E-05	5.7E-08	3.1E-08	7.0E-05	8.0E-05	9.3E-08
Co-60	2.2E-06	5.9E-03	1.4E-05	6.4E-03	1.3E-02	6.3E-06	6.4E-03	6.4E-03	4.1E-06	2.6E-06	5.8E-03	6.4E-03	7.4E-06
Cs-134	1.3E-05	1.4E-03	1.3E-05	1.6E-03	3.2E-03	1.6E-05	1.5E-03	1.5E-03	1.8E-05	2.0E-07	1.4E-03	1.6E-03	1.5E-07
Cs-137	1.5E-04	5.0E-03	1.1E-04	6.4E-03	1.3E-02	1.2E-04	5.3E-03	5.7E-03	1.5E-04	2.4E-06	5.0E-03	6.3E-03	1.8E-06
H-3	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03	1.6E-03
I-131	1.5E-06	5.5E-04	2.3E-07	7.2E-04	1.4E-03	2.0E-06	6.0E-04	6.3E-04	1.8E-06	1.5E-07	5.4E-04	7.2E-04	2.5E-07
I-133	6.4E-08	1.9E-05	9.4E-09	2.8E-05	5.6E-05	8.3E-08	2.0E-05	2.2E-05	7.5E-08	3.2E-09	1.8E-05	2.7E-05	5.8E-09
Ba-137m (Cs-137)*	4.2E-13	3.2E-11	1.4E-11	3.9E-11	7.7E-11	9.0E-13	3.7E-11	3.8E-11	6.6E-13	3.2E-14	3.2E-11	3.8E-11	5.2E-13
Cs-135 (Xe-135)*	3.3E-10	2.9E-10	1.9E-10	4.7E-10	7.4E-10	1.9E-10	2.5E-11	5.0E-11	2.8E-10	1.1E-11	3.3E-10	4.2E-10	6.9E-12
Total	1.8E-03	1.5E-02	1.8E-03	1.7E-02	3.2E-02	1.8E-03	1.6E-02	1.6E-02	1.8E-03	1.6E-03	1.4E-02	1.7E-02	1.6E-03

*Progeny of the radionuclide in shown brackets

Table D-13 Total Dose Rate (µGy/ h) to Habitat 5 (Marshland) Organisms due to Gaseous Discharges from Sizewell C

Isotope	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
C-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-58	6.0E-07	1.4E-03	3.7E-06	1.6E-03	3.2E-03	1.7E-06	1.5E-03	1.6E-03	1.1E-06	6.2E-07	1.4E-03	1.6E-03	1.9E-06
Co-60	4.4E-05	1.2E-01	2.8E-04	1.3E-01	2.5E-01	1.3E-04	1.3E-01	1.3E-01	8.2E-05	5.1E-05	1.2E-01	1.3E-01	1.5E-04
Cs-134	2.6E-04	2.8E-02	2.5E-04	3.2E-02	6.5E-02	3.2E-04	3.0E-02	3.1E-02	3.6E-04	4.1E-06	2.8E-02	3.2E-02	3.1E-06
Cs-137	2.9E-03	9.9E-02	2.1E-03	1.3E-01	2.6E-01	2.3E-03	1.1E-01	1.1E-01	3.0E-03	4.9E-05	1.0E-01	1.3E-01	3.5E-05
H-3	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02	3.3E-02
I-131	3.1E-05	1.1E-02	4.5E-06	1.4E-02	2.7E-02	4.1E-05	1.2E-02	1.3E-02	3.6E-05	3.0E-06	1.1E-02	1.4E-02	5.0E-06
I-133	1.3E-06	3.7E-04	1.9E-07	5.6E-04	1.1E-03	1.6E-06	4.1E-04	4.4E-04	1.5E-06	6.4E-08	3.7E-04	5.4E-04	1.2E-07
Ba-137m (Cs-137)*	8.4E-12	6.4E-10	2.8E-10	7.8E-10	1.5E-09	1.8E-11	7.4E-10	7.6E-10	1.3E-11	6.5E-13	6.3E-10	7.6E-10	1.0E-11
Cs-135 (Xe-135)*	6.6E-09	5.7E-09	3.8E-09	9.3E-09	1.5E-08	3.8E-09	5.1E-10	1.0E-09	5.6E-09	2.1E-10	6.7E-09	8.5E-09	1.4E-10
Total	3.6E-02	2.9E-01	3.5E-02	3.4E-01	6.4E-01	3.5E-02	3.1E-01	3.2E-01	3.6E-02	3.3E-02	2.9E-01	3.4E-01	3.3E-02

*Progeny of the radionuclide in shown brackets

Table D-14 Total Dose Rate (µGy/ h) to Habitat 1 (Terrestrial) Organisms due to Gaseous Discharges from Sizewell B and C

Isotope	Amphibian	Annelid	Arthropod - detritivorous	Bat	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree	Badger
C-14	5.8E-03	1.9E-03	1.9E-03	5.9E-03	6.0E-03	1.9E-03	3.8E-03	3.9E-03	6.0E-03	6.0E-03	1.9E-03	6.0E-03	3.8E-03	5.8E-03	5.9E-03
Co-58	2.5E-08	2.5E-08	2.5E-08	9.9E-09	9.7E-09	9.7E-09	9.2E-09	9.7E-09	8.1E-09	2.4E-08	9.7E-09	2.3E-08	8.7E-09	7.8E-09	1.4E-08
Co-60	1.5E-05	1.4E-05	1.4E-05	5.6E-06	5.4E-06	5.5E-06	5.3E-06	5.5E-06	4.6E-06	1.4E-05	5.5E-06	1.4E-05	5.0E-06	4.3E-06	8.3E-06
Cs-134	3.7E-07	3.5E-07	3.6E-07	2.9E-07	1.8E-07	1.4E-07	1.8E-07	2.7E-07	9.7E-07	5.7E-07	1.4E-07	3.5E-07	2.0E-07	1.4E-07	6.2E-07
Cs-137	1.2E-06	9.9E-07	1.0E-06	2.0E-06	6.9E-07	4.3E-07	8.5E-07	1.8E-06	3.9E-06	2.7E-06	4.0E-07	1.2E-06	1.2E-06	4.2E-07	2.9E-06
H-3	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.2E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04	8.8E-04
I-131	4.4E-07	3.8E-07	4.1E-07	2.3E-07	2.4E-07	2.0E-07	1.7E-07	1.7E-07	2.5E-07	4.3E-07	1.8E-07	4.1E-07	1.3E-07	1.8E-07	3.0E-07
Ba-137m (Cs-137)*	7.7E-14	7.8E-14	7.9E-14	3.0E-14	2.9E-13	3.0E-14	2.9E-14	3.0E-14	1.6E-14	7.4E-14	3.0E-14	7.1E-14	3.3E-14	2.9E-14	4.0E-14
Cs-135 (Xe-135)*	7.8E-14	1.4E-14	1.8E-14	5.8E-13	9.6E-14	1.8E-14	1.9E-13	6.2E-13	5.8E-13	5.8E-13	6.9E-15	9.8E-14	3.3E-13	2.3E-14	5.8E-13
I-133	6.9E-09	5.9E-09	6.2E-09	3.6E-09	3.9E-09	3.0E-09	2.5E-09	2.5E-09	4.0E-09	6.7E-09	2.6E-09	6.5E-09	2.0E-09	2.6E-09	4.8E-09
Total	6.7E-03	2.7E-03	2.8E-03	6.8E-03	6.9E-03	2.7E-03	4.7E-03	4.8E-03	6.9E-03	6.9E-03	2.7E-03	6.9E-03	4.7E-03	6.7E-03	6.8E-03

*Progeny of the radionuclide in shown brackets

Table D-15 Total Dose Rate (µGy/ h) to Habitat 2 (Marine) Organisms due to Aqueous Discharges from Sizewell B and C

Isotope	Bird	Benthic fish	Crustacean	Macroalgae	Mammal	Mollusc - bivalve	Pelagic fish	Phytoplankton	Polychaete worm	Sea anemones & True coral	Vascular plant	Zooplankton
Ag-110m	5.6E-04	2.1E-03	2.6E-03	2.1E-03	1.9E-03	2.3E-03	2.3E-04	2.1E-04	4.4E-03	2.1E-03	2.0E-03	2.8E-05
C-14	8.7E-04	8.8E-04	7.2E-04	6.6E-04	8.7E-04	3.2E-04	8.7E-04	1.2E-04	5.0E-03	8.5E-04	6.5E-04	5.0E-03
Co-58	1.5E-05	5.9E-02	5.8E-02	6.4E-02	4.9E-05	6.3E-02	1.3E-04	1.6E-05	1.3E-01	6.4E-02	6.3E-02	3.5E-05
Co-60	6.0E-05	2.6E-01	2.6E-01	2.8E-01	1.9E-04	2.8E-01	5.0E-04	7.1E-05	5.5E-01	2.8E-01	2.8E-01	1.3E-04
Cr-51	1.5E-07	8.1E-06	7.8E-06	9.0E-06	2.7E-07	8.7E-06	1.4E-08	2.6E-07	1.8E-05	8.9E-06	8.9E-06	5.3E-08
Cs-134	1.2E-03	5.1E-02	4.9E-02	5.5E-02	1.5E-03	5.4E-02	1.9E-04	1.6E-05	1.1E-01	5.5E-02	5.4E-02	1.4E-04
Cs-137	1.8E-04	3.2E-03	3.1E-03	3.5E-03	1.4E-04	3.4E-03	3.1E-05	1.9E-06	7.0E-03	3.6E-03	3.4E-03	3.2E-05
H-3	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04	2.1E-04
I-131	1.2E-09	8.3E-08	9.7E-08	2.0E-06	1.1E-09	4.5E-06	5.7E-09	2.5E-07	4.2E-06	4.1E-06	9.4E-08	1.3E-06
Mn-54	1.4E-05	4.9E-02	4.8E-02	5.2E-02	5.0E-05	5.2E-02	6.1E-06	1.1E-06	1.0E-01	5.2E-02	5.1E-02	1.0E-06
Ni-63	1.0E-06	5.2E-07	2.6E-06	2.0E-06	1.0E-06	1.3E-05	5.2E-07	1.2E-06	8.7E-06	1.3E-05	2.0E-06	1.0E-06
Sb-124	2.2E-04	2.1E-04	2.0E-04	2.2E-04	4.7E-04	2.1E-04	1.4E-05	4.4E-06	5.2E-04	2.2E-04	2.0E-04	1.3E-05
Sb-125	1.2E-04	9.2E-05	8.5E-05	9.5E-05	2.4E-04	9.7E-05	8.0E-06	7.1E-06	2.3E-04	9.3E-05	9.4E-05	1.1E-05
Te-123 (Te-123m)*	1.6E-20	2.3E-21	2.8E-21	2.2E-21	2.0E-20	3.7E-21	1.3E-21	1.4E-20	9.3E-21	1.8E-21	2.2E-21	1.1E-21
Te-123m	2.8E-05	6.4E-06	7.3E-06	5.9E-06	4.3E-05	8.9E-06	2.2E-06	3.3E-05	2.2E-05	4.8E-06	5.8E-06	2.7E-06
Te-125m (Sb-125)*	1.5E-05	1.5E-06	2.0E-06	1.2E-06	1.6E-05	2.9E-06	1.2E-06	1.9E-05	8.2E-06	5.4E-07	1.1E-06	1.5E-06
Total	3.5E-03	4.2E-01	4.2E-01	4.6E-01	5.7E-03	4.5E-01	2.2E-03	7.1E-04	9.1E-01	4.5E-01	4.5E-01	5.6E-03

*Progeny of the radionuclide in shown brackets

Table D-16 Total Dose Rate (µGy/ h) to Habitat 4 (Scrape) Organisms due to Gaseous Discharges from Sizewell B and C

Isotope	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
C-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-58	3.0E-08	7.0E-05	1.9E-07	8.0E-05	1.6E-04	8.8E-08	7.6E-05	7.8E-05	5.7E-08	3.1E-08	7.0E-05	8.0E-05	9.3E-08
Co-60	1.9E-05	5.2E-02	1.2E-04	5.6E-02	1.1E-01	5.6E-05	5.6E-02	5.6E-02	3.6E-05	2.3E-05	5.1E-02	5.6E-02	6.5E-05
Cs-134	1.3E-05	1.4E-03	1.3E-05	1.6E-03	3.2E-03	1.6E-05	1.5E-03	1.5E-03	1.8E-05	2.0E-07	1.4E-03	1.6E-03	1.5E-07
Cs-137	1.5E-04	5.0E-03	1.1E-04	6.4E-03	1.3E-02	1.2E-04	5.3E-03	5.7E-03	1.5E-04	2.4E-06	5.0E-03	6.3E-03	1.8E-06
H-3	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03	2.5E-03
I-131	3.5E-06	1.2E-03	5.1E-07	1.6E-03	3.1E-03	4.6E-06	1.4E-03	1.4E-03	4.0E-06	3.4E-07	1.2E-03	1.6E-03	5.6E-07
I-133	6.4E-08	1.9E-05	9.4E-09	2.8E-05	5.6E-05	8.3E-08	2.0E-05	2.2E-05	7.5E-08	3.2E-09	1.8E-05	2.7E-05	5.8E-09
Ba-137m (Cs-137)*	4.2E-13	3.2E-11	1.4E-11	3.9E-11	7.7E-11	9.0E-13	3.7E-11	3.8E-11	6.6E-13	3.2E-14	3.2E-11	3.8E-11	5.2E-13
Cs-135 (Xe-135)*	3.3E-10	2.9E-10	1.9E-10	4.7E-10	7.4E-10	1.9E-10	2.5E-11	5.0E-11	2.8E-10	1.1E-11	3.3E-10	4.2E-10	6.9E-12
Total	2.6E-03	6.2E-02	2.7E-03	6.9E-02	1.3E-01	2.7E-03	6.7E-02	6.8E-02	2.7E-03	2.5E-03	6.1E-02	6.8E-02	2.5E-03

*Progeny of the radionuclide in shown brackets

Table D-17 Total Dose Rate (µGy/ h) to Habitat 5 (Marshland) Organisms due to Gaseous Discharges from Sizewell B and C

Isotope	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
C-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Co-58	6.0E-07	1.4E-03	3.7E-06	1.6E-03	3.2E-03	1.7E-06	1.5E-03	1.6E-03	1.1E-06	6.2E-07	1.4E-03	1.6E-03	1.9E-06
Co-60	3.9E-04	1.0E+00	2.4E-03	1.1E+00	2.2E+00	1.1E-03	1.1E+00	1.1E+00	7.2E-04	4.5E-04	1.0E+00	1.1E+00	1.3E-03
Cs-134	2.6E-04	2.8E-02	2.5E-04	3.2E-02	6.5E-02	3.2E-04	3.0E-02	3.1E-02	3.6E-04	4.1E-06	2.8E-02	3.2E-02	3.1E-06
Cs-137	2.9E-03	9.9E-02	2.1E-03	1.3E-01	2.6E-01	2.3E-03	1.1E-01	1.1E-01	3.0E-03	4.9E-05	1.0E-01	1.3E-01	3.5E-05
H-3	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02	4.9E-02
I-131	6.9E-05	2.5E-02	1.0E-05	3.2E-02	6.2E-02	9.2E-05	2.7E-02	2.8E-02	8.1E-05	6.7E-06	2.4E-02	3.2E-02	1.1E-05
I-133	1.3E-06	3.7E-04	1.9E-07	5.6E-04	1.1E-03	1.6E-06	4.1E-04	4.4E-04	1.5E-06	6.4E-08	3.7E-04	5.4E-04	1.2E-07
Ba-137m (Cs-137)*	8.4E-12	6.4E-10	2.8E-10	7.8E-10	1.5E-09	1.8E-11	7.4E-10	7.6E-10	1.3E-11	6.5E-13	6.3E-10	7.6E-10	1.0E-11
Cs-135 (Xe-135)*	6.6E-09	5.7E-09	3.8E-09	9.3E-09	1.5E-08	3.8E-09	5.1E-10	1.0E-09	5.6E-09	2.1E-10	6.7E-09	8.5E-09	1.4E-10
Total	5.3E-02	1.2E+00	5.4E-02	1.4E+00	2.7E+00	5.3E-02	1.3E+00	1.3E+00	5.3E-02	5.0E-02	1.2E+00	1.4E+00	5.1E-02

*Progeny of the radionuclide in shown brackets

Table D-18 Total Dose Rate (µGy/ h) to Habitat 1 (Terrestrial) Organisms due to Discharges of Noble Gases from Sizewell C and from the Combined Sizewell Site Discharges

Organism	SZC Discharges			Combined Sizewell B and C Discharges		
	Ar-41 Dose Rate	Kr-85 Dose Rate	Total Dose Rate per organism	Ar-41 Dose Rate	Kr-85 Dose Rate	Total Dose Rate per organism
Bacteria	2.8E-7	6.6E-9	2.9E-7	5.0E-7	6.6E-9	5.1E-7
Lichen	9.5E-4	3.9E-6	9.5E-4	1.7E-3	3.9E-6	1.7E-3
Tree	1.0E-3	8.7E-6	1.0E-3	1.8E-3	8.7E-6	1.8E-3
Shrub	1.0E-3	8.7E-6	1.0E-03	1.8E-3	8.7E-6	1.8E-3
Herb	1.0E-3	8.7E-6	1.0E-3	1.8E-3	8.7E-6	1.8E-3
Seed	1.1E-3	1.4E-5	1.1E-3	1.9E-3	1.4E-5	2.0E-3
Fungi	1.2E-3	2.7E-5	1.2E-3	2.1E-3	2.7E-5	2.1E-3
Caterpillar	1.8E-3	5.4E-6	1.8E-3	3.3E-3	5.4E-6	3.3E-3
Ant	7.0E-4	4.8E-6	7.1E-4	1.2E-3	4.8E-6	1.2E-3
Bee	1.7E-3	3.0E-6	1.7E-3	3.0E-3	3.0E-6	3.0E-3
Woodlouse	9.6E-4	4.6E-6	9.6E-4	1.7E-3	4.6E-6	1.7E-3
Earthworm	2.2E-7	6.3E-10	2.2E-7	3.9E-7	6.3E-10	3.9E-7
Herb. Mammal	3.7E-4	1.7E-7	3.7E-4	6.6E-4	1.7E-7	6.6E-4
Car. Mammal	4.4E-4	1.9E-7	4.4E-4	7.7E-4	1.9E-7	7.7E-4
Rodent	3.5E-4	4.0E-7	3.5E-4	6.1E-4	4.0E-7	6.1E-4
Bird	1.2E-3	5.0E-7	1.2E-3	2.1E-3	5.0E-7	2.1E-3
Bird egg	8.6E-4	9.2E-7	8.6E-4	1.5E-3	9.2E-7	1.5E-3
Reptile	4.8E-4	2.9E-7	4.8E-4	8.4E-4	2.9E-7	8.4E-4

APPENDIX E MODEL PARAMETERS

E.1 Habitat 1 input parameters

Table E-19 Terrestrial Concentration Ratio (Bq kg-1 (f.w.) per Bq kg-1 soil (d.w.) or Bq m-3 air for H and C)

Nuclide	Amphibian	Annelid	Arthropod - detritivorous	Bat	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree	Badger
C	1.34E+03	4.29E+02	4.30E+02	1.34E+03	1.34E+03	4.30E+02	8.90E+02	8.90E+02	1.34E+03	1.34E+03	4.30E+02	1.34E+03	8.90E+02	1.30E+03	1.34E+03
Co	1.91E-01	1.88E-02	7.07E-03	1.91E-01	1.30E-02	7.07E-03	1.93E-02	8.40E-02	1.91E-01	1.91E-01	1.88E-02	1.91E-01	1.30E-02	5.43E-03	1.91E-01
Cs	4.57E-01	8.10E-02	1.06E-01	3.41E+00	5.63E-01	1.06E-01	1.12E+00	3.78E+00	3.41E+00	3.41E+00	4.05E-02	5.74E-01	1.96E+00	1.36E-01	3.41E+00
H	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02	1.50E+02
I	4.00E-01	1.56E-01	3.01E-01	4.00E-01	4.00E-01	3.01E-01	1.40E-01	1.40E-01	4.00E-01	4.00E-01	1.80E-01	4.00E-01	7.03E-04	1.40E-01	4.00E-01

Table E-20 Terrestrial Occupancy Factor (unitless)

Habitat	Amphibian	Annelid	Arthropod - detritivorous	Bat	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree	Badger
On-soil	0	0	0	1	1	1	1	1	1	0	1	0	1	1	0.5
In-soil	1	1	1	0	0	0	0	0	0	1	0	1	0	0	0.5
In-air	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E-21 Reference Organism Specific Data (Terrestrial Ecosystem)

Organism	Mass	Default Geometries		
	(kg)	Length (cm)	Height (cm)	Width (cm)
Amphibian (ICRP Frog)	3.14E-02	7.99E+00	3.00E+00	2.50E+00
Annelid (ICRP Earthworm)	5.24E-03	1.00E+01	1.00E+00	1.00E+00
Arthropod - detritivorous (FASSET Woodlouse)	1.70E-04	1.74E+00	6.13E-01	3.05E-01
Bat[14]	7.00E-03	4.10E+00	1.20E+00	1.20E+00
Bird (ICRP Duck)	1.26E+00	3.00E+01	1.00E+01	8.02E+00
Flying insects (ICRP Bee)	5.89E-04	2.00E+00	7.50E-01	7.50E-01
Grasses & Herbs (ICRP Wild grass)	2.62E-03	5.00E+00	1.00E+00	1.00E+00
Lichen & Bryophytes (ICRP Bryophyte)	1.70E-04	4.01E+00	2.29E-01	2.29E-01
Mammal - large (ICRP Deer)	2.45E+02	1.30E+02	6.00E+01	6.00E+01
Mammal - small-burrowing (ICRP Rat)	3.14E-01	2.00E+01	6.00E+00	5.00E+00
Mollusc - gastropod (ICRP Snail)	1.40E-03	1.88E+00	1.54E+00	9.27E-01
Reptile (FASSET snake note this is an ellipsoid)	7.44E-01	1.16E+02	3.49E+00	3.49E+00
Shrub	2.62E-03	5.00E+00	1.00E+00	1.00E+00
Tree (ICRP Pine tree)	4.71E+02	1.00E+03	3.00E+01	3.00E+01
Badger[14]	6.60E+00	7.30E+01	3.00E+01	2.50E+01

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[14] Badger and bat from reference [16].

E.2 Habitat 2 input parameters

Table E-22 Marine Concentration Ratio (Bq kg-1 (f.w.) per Bq l-1)

Nuclide	Bird	Benthic fish	Crustacean	Macroalgae	Mammal	Mollusc - bivalve	Pelagic fish	Phytoplankton	Polychaete worm	Sea anemones & True coral	Vascular plant	Zooplankton
Ag	2.20E+04	1.10E+04	3.60E+04	3.90E+03	2.20E+04	3.60E+04	1.10E+04	6.90E+04	2.70E+04	1.30E+02	3.90E+03	6.00E+03
C	1.70E+03	1.70E+03	1.40E+03	1.30E+03	1.70E+03	6.50E+02	1.70E+03	2.50E+02	1.00E+04	1.70E+03	1.30E+03	1.00E+04
Co	5.00E+02	5.30E+03	3.50E+03	1.70E+03	5.00E+02	5.30E+03	5.30E+03	3.10E+03	8.03E+03	6.08E+02	3.28E+02	4.80E+03
Cr	2.00E+03	2.00E+02	1.00E+02	6.00E+03	2.00E+03	2.00E+03	2.00E+02	5.00E+03	2.00E+03	2.00E+03	6.00E+03	1.00E+03
Cs	4.80E+02	8.40E+01	5.30E+01	9.60E+01	2.20E+02	5.00E+01	8.40E+01	8.50E+00	1.80E+02	2.30E+02	1.00E+01	1.30E+02
H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
I	6.80E-01	9.00E+00	3.92E+01	4.20E+03	6.80E-01	8.80E+03	9.00E+00	9.50E+02	8.80E+03	8.80E+03	2.40E+01	3.10E+03
Mn	4.50E+03	2.60E+03	4.50E+04	8.60E+03	4.50E+03	1.20E+04	2.60E+03	3.50E+03	3.20E+03	1.00E+01	3.00E+04	2.50E+03
Ni	5.00E+02	2.50E+02	1.27E+03	9.50E+02	5.00E+02	6.40E+03	2.50E+02	5.70E+02	4.20E+03	6.40E+03	9.50E+02	5.00E+02
Sb	8.30E+03	6.00E+02	3.00E+02	2.25E+02	8.30E+03	4.70E+02	6.00E+02	1.00E+03	4.50E+03	9.00E+01	2.25E+02	1.31E+03
Te	8.30E+03	6.90E+02	1.00E+03	4.25E+02	8.30E+03	1.50E+03	6.90E+02	1.31E+04	4.50E+03	1.00E+01	4.25E+02	1.00E+03

Table E-23 Marine Occupancy Factor (unitless)

Habitat	Bird	Benthic fish	Crustacean	Macroalgae	Mammal	Mollusc - bivalve	Pelagic fish	Phytoplankton	Polychaete worm	Sea anemones & True coral	Vascular plant	Zooplankton
Water-surface	0	0	0	0	0	0	0	0	0	0	0	0
Water	1	0	0	0	1	0	1	1	0	0	0	1
Sediment-surface	0	1	1	1	0	1	0	0	0	1	1	0
Sediment	0	0	0	0	0	0	0	0	1	0	0	0

Table E-24 Reference Organism Specific Data (Marine Ecosystem)

Organism	Mass	Default Geometries		
	(kg)	Length (cm)	Height (cm)	Width (cm)
Benthic fish (ICRP Flat fish)	1.31E+00	3.99E+01	2.49E+01	2.51E+00
Bird (ICRP Duck, Wading bird)	1.26E+00	3.00E+01	1.00E+01	8.02E+00
Crustacean (ICRP Crab)	7.54E-01	2.00E+01	1.20E+01	6.00E+00
Macroalgae (ICRP Brown seaweed)	6.52E-01	5.00E+01	5.00E-01	5.00E-01
Mammal (FASSET Mammal)	1.82E+02	1.80E+02	4.39E+01	4.39E+01
Mollusc - bivalve (FASSET Benthic mollusc)	1.64E-02	5.00E+00	2.50E+00	2.50E+00
Pelagic fish (FASSET Pelagic fish)	5.65E-01	3.00E+01	6.00E+00	6.00E+00

Phytoplankton (ERICA Phytoplankton)[15]	1.00E-06	5.00E-03	5.00E-03	5.00E-03
Polychaete worm (FASSET Benthic worm)	1.73E-02	2.30E+01	1.20E+00	1.20E+00
Sea anemones & True coral (ICRP Polyp)	1.77E-03	1.50E+00	1.50E+00	1.50E+00
Vascular plant (FASSET Vascular plant)	2.62E-02	9.29E+00	2.32E+00	2.32E+00
Zooplankton (FASSET Zooplankton)	6.14E-05	6.20E-01	6.10E-01	3.10E-01

E.3 Habitats 4 and 5 input parameters

Table E-25 Scrape and Marshland Concentration Ratios [Bq/kg(f.w.) per Bq/l]

Nuclide	**Amphibian**	**Benthic fish**	**Bird**	**Crustacean**	**Insect larvae**	**Mammal**	**Mollusc - bivalve**	**Mollusc - gastropod**	**Pelagic fish**	**Phytoplankton**	**Reptile**	**Vascular plant**	**Zooplankton**
C	1.80E+05	1.80E+05	1.80E+05	1.80E+05	1.80E+05	1.80E+05	1.80E+05	1.80E+05	1.80E+05	4.00E+03	1.80E+05	8.80E+03	1.80E+05
Co	2.31E+02	2.31E+02	7.00E+02	1.85E+03	1.85E+03	2.31E+02	1.05E+03	1.05E+03	2.31E+02	6.46E+02	1.22E+01	9.28E+02	1.85E+03
Cs	3.95E+03	3.37E+03	2.27E+03	1.81E+03	1.99E+03	2.27E+03	1.29E+02	1.29E+02	3.37E+03	1.42E+02	3.95E+03	3.59E+02	8.97E+01
H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
I	3.19E+02	3.19E+02	3.91E+01	8.31E+01	8.31E+01	3.19E+02	8.31E+01	8.31E+01	3.19E+02	5.41E+01	3.19E+02	5.41E+01	8.31E+01

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[15] For technical reasons the default mass of both marine and freshwater phytoplankton in ERICA has been set to 1.00E-06 Kg replacing the old values of 6.54E-11 kg and 2.05E-12 kg for FASSET marine and freshwater phytoplankton respectively. This is a relatively small geometry and can be considered to represent an accreted mass of phytoplankton cells.

Table E-26 Scrape and Marshland Occupancy Factor (unitless)

Habitat	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phytoplankton	Reptile	Vascular plant	Zooplankton
Water-surface	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	1	0	1	0	0	1	0	0	1	1	0.5	0	1
Sediment-surface	0	1	0	1	0	0	1	1	0	0	0	1	0
Sediment	0	0	0	0	1	0	0	0	0	0	0.5	0	0

Table E-27 Scrape and Marshland Distribution Coefficients [l kg-1]

Nuclide	Distribution Coefficient (Kd)
C	13.31916464
Co	111087.5049
Cs	140123.4408
H	1
I	143153.336

Table E-28 Reference Organism Specific Data (Freshwater Ecosystem)

Organism	**Mass**	**Default Geometries**		
	(kg)	**Length (cm)**	**Height (cm)**	**Width (cm)**
Amphibian (ICRP – Frog)	3.14E-02	7.99E+00	3.00E+00	2.50E+00
Benthic fish (FASSET Benthic fish)	1.47E+00	5.00E+01	8.01E+00	7.01E+00
Bird (ICRP Duck)	1.26E+00	3.00E+01	1.00E+01	8.02E+00
Crustacean (FASSET Crustacean)	1.57E-05	1.00E+00	3.00E-01	1.00E-01
Insect larvae (FASSET Insect larvae)	1.77E-05	1.50E+00	1.50E-01	1.50E-01
Mammal (FASSET Mammal)	3.90E+00	3.30E+01	1.50E+01	1.50E+01
Mollusc - bivalve (FASSET Bivalve mollusc)	7.07E-02	1.00E+01	4.50E+00	3.00E+00
Mollusc - gastropod (FASSET Gastropod)	3.53E-03	3.00E+00	1.50E+00	1.50E+00
Pelagic fish (ICRP Salmonid/Trout)	1.26E+00	5.00E+01	8.01E+00	6.01E+00
Phytoplankton (ERICA Phytoplankton)[15]	1.00E-06	7.97E-03	7.01E-04	7.01E-04
Reptile (ERICA Freshwater reptile) [16]	1.00E+00	1.80E+01	1.20E+01	6.00E+00
Vascular plant (FASSET Vascular plant)	1.05E-03	1.00E+02	1.00E-01	2.00E-01
Zooplankton (FASSET Zooplankton)	2.35E-06	2.00E-01	1.40E-01	1.60E-01

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[16] Representative of adult female European pond turtle (*Emys orbicularis*).

APPENDIX F REPRESENTATION OF LOCAL SPECIES

Table F-29 Representation of Local Species by ERICA Reference Organisms.

ERICA Reference Organism	Local Species Examples [Ref 1]
Terrestrial ecosystem	
Amphibian (ICRP Frog)	Natterjack toads (*Epidalea calamita*), Great crested newt *Triturus cristatus*
Annelid (ICRP Earthworm)	
Arthropod – detritivorous (FASSET Woodlouse)	
Bird (ICRP Duck)	Avocet (*Recurvirostra avosetta*), Barn owl (*Tyto alba*), Bittern (Botaurus stellaris), Black redstart (*Phoenicurus ochruros*), Cetti's warbler (*Cettia cetti*), Crossbill (*Loxia curvirostra*), Gadwall (Anas strepera), Hobby (*Falco subbuteo*), Kingfisher (*Alcedo atthis*), Lesser black-backed gull (Larus fuscus), Little tern (*Sterna albifrons*), Marsh Harrier (*Circus aeruginosus*), Nightjar (*Caprimulgus europaeus*), Redshank (*Tringa tetanus*), Red-throated diver (*Gavia stellate*), Ruff (*Philomachus pugnax*), Sandwich tern (*Sterna sandvicensis*), Shoveler (*Anas clypeata*), Teal (*Anas crecca*), Whitefronted Goose (*Anser albifrons*), Woodlark (*Lullula arborea*)
Flying insects (ICRP Bee)	Norfolk hawker dragonfly (*Aeshna isosceles*), Soldier fly (*Odontomyia ornate*), Tachinid fly (*Subclytia rotundiventris*), White Admiral butterfly (*Limenitis camilla*)
Grasses & Herbs (ICRP Wild grass)	Sea sandwort (*Honckenya peploides*), Sea beet (*Beta vulgaris ssp. Maritime*), Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
Lichen & bryophytes (ERICA Bryophyte)	
Mammal - large (ICRP deer)	
Mammal – small burrowing (ICRP Rat)	Water vole (*Arvicola amphibious*)
Mollusc – gastropod (ERICA snail)	
Reptile (ERICA snake)	Adder (*Viper berus*), Common lizard (*Zootoca vivipara*), Grass snake (*Natrix natrix*), Slow worm (*Angulis fragilis*)
Shrub (ICRP Wild grass)	Bell heather (*Erica cinerea*), Heather (*Calluna vulgaris*), Western gorse (*Ulex gallii*)
Tree (ICRP Pine Tree)	Oak (*Quercus spp.*)
Freshwater Ecosystem	
Amphibian (ICRP Frog)	Natterjack toads (*Epidalea calamita*)
Benthic fish (FASSET Benthic fish)	Eel (*Anguilla anguilla*)
Bird (ICRP Duck)	Bittern (*Botaurus stellaris*), Gadwall (*Anas strepera*), Lesser black-backed gull (*Larus fuscus*), Redshank (*Tringa tetanus*), Ruff (*Philomachus pugnax*), Shoveler (*Anas clypeata*), Teal (*Anas crecca*), White fronted Goose (*Anser albifrons*), Red-throated diver (*Gavia stellate*)
Crustacean (FASSET Crustacean)	
Insect larvae (FASSET Insect larvae)	
Mammal (FASSET Mammal)	Otter (*Lutra lutra*), Water vole (*Arvicola amphibious*)
Mollusc – bivalve (FASSET Bivalve mollusc)	
Mollusc –gastropod (FASSET Gastropod)	
Pelagic fish (ICRP Salmonid/Trout)	
Phytoplankton (ERICA Phytoplankton)	
Reptile (ERICA Freshwater Reptile)	
Vascular plant (FASSET Vascular plant)	
Zooplankton (FASSET Zooplankton)	
Marine Ecosystem	
(Wading) bird (ICRP Duck)	Avocet (*Recurvirostra avosetta*), Bittern (*Botaurus stellaris*), Gadwall (*Anas strepera*), Lesser black-backed gull (*Larus fuscus*), Redshank (*Tringa tetanus*), Red-throated diver (*Gavia stellate*), Ruff (*Philomachus pugnax*), Sandwich tern (*Sterna sandvicensis*), Shoveler (*Anas clypeata*), Teal (*Anas crecca*), Whitefronted Goose (*Anser albifrons*)

ERICA Reference Organism	**Local Species Examples [Ref 1]**
Benthic fish (ICRP Flat fish)	Eel (*Anguilla anguilla*), Plaice (*Pleuronectes platessa*), Sandeel (Ammodytes tobianus), Sole (*Solea solea*)
Crustacean (ICRP Crab)	Brown (edible) crab (*Cancer pagurus*), Lobster (*Homarus gammarus*)
Macroalgae (ICRP Brown seaweed)	
Mammal (FASSET Mammal)	Harbour porpoise (*Phocoena phocoena*)
Mollusc – bivalve (FASSET Benthic mollusc)	*Clam (Nucula nitidosa), Clam (Nucula nucleus),* Whelk (*Buccinium undatum*), Whelk (*Buccinium undatum*)
Pelagic fish (FASSET Pelagic fish)	Bass (*Dicentrachus labrax*), Cod (*Gadus morhua*), Grey mullet (*Chelon labrosus*), Herring (*Clupea harengus*), Mackerel (*Scomber scombrus*), Sea trout (*Salmo trutta trutta*), Sprat (*Sprattus sprattus*), Whiting (Merlanguis *merlangus*)
Phytoplankton (ERICA Phytoplankton)	
Polychaete worm (FASSET Benthic worm)	Polychaete worm (*Nephtys hombergii*), Ross worm (*Sabellaria spinulosa*).
Sea anemones and true corals (ICRP Polyp)	
Vascular plant (FASSET Vascular plant)	
Zooplankton (FASSET Zooplankton)	