Generation Environment Management

Report

Assessment of Dose from Increased Discharges of Carbon-14 from Sizewell B

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Report Summary

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Summary

Radiation dose assessments have been made in support of an application to increase the numerical limit on discharge of carbon-14 to air from Sizewell B. The assessment of dose to the representative person from Sizewell B includes the impact of discharges to air, discharges to sea (both at the numerical limits for discharge) and direct radiation. Direct radiation is the dominant pathway, followed by discharges to sea and discharges to air. Assessment of dose to the representative person from Sizewell B and Sizewell A includes the impact of discharges to sea and discharges to air at the numerical limits for discharge. Dose from discharges is dominated by discharge to sea from Sizewell A. The assessment of collective dose from Sizewell B includes the joint impact of discharges to air and discharges to sea at the numerical limits. Collective dose is dominated by ^{14}C discharged to air. The assessment of dose to wildlife is presented for both discharge to air and discharges to sea. Dose to wildlife is dominated by discharges to sea.

Conclusions

The proposed increase in the discharge limit to ^{14}C results in:

- a dose to the representative person (adult member of a local fisherman's family) that is 10.8 μSv/y, only 4% of the constraint of 300 μSv/y,
- collective dose that is less than 1% of the collective dose from natural ^{14}C and
- risk to wildlife that is less than 6% of the no effect dose rate, the most effected organism being polychaete worms.

Therefore, there doses from the proposed increase in limit are broadly acceptable.

Report issue/amendment

Date	Author	Revision	Amendment
August 2020	Discharges & Dose Impact Lead	000	First issue

Glossary

Word, Phrase or Acronym	Description
Collective dose	Dose to a population assessed as a measure of harm, usually over an extended period (*e.g*. 500 years)
Contiguous sites	Adjacent sites, each covered by a separate permit to discharge radioactivity to the environment, such as Sizewell B and Sizewell A
ERICA	Computer package for the assessment of radiation dose to wildlife from discharges
First-pass	Collective dose from the initial spread of radioactivity from discharges to air
Global circulation pathway	Collective dose pathway from long-lived radionuclides that can mix into the atmosphere (*e.g*. tritium and carbon-14)
Magnox reactor	CO_2-cooled reactor powered by native uranium metal clad in Magnox alloy, now decommissioning
MDA	Minimum detectable activity
Natura 2000	World's largest network of breeding and resting sites for rare and threatened species, Europe-based
ONR	Office for Nuclear Regulation
Pathway	Route by which a member of the public recieves radiation dose
PC-CREAM 08	Computer package for assessment of dose to human populations from discharges
PWR	Pressurised water-cooled reactor
Ramsar site	A wetland site designated to be of international importance under the Ramsar Convention
RAP	Reference animal or plant for wildlife dose assessment
Representative person	The individual representative of the member of the public receiving the highest radiation dose
SAC	Special area of conservation
Single source	A facility covered under a single permit to discharge radioactivity to the environment, such as Sizewell B
SPA	Special protection area
SSSI	Site of special scientific interest
Terrestrial Ecosystem SCK-CEN	Computer package for the assessment of dose to wildlife including noble gases (not covered by ERICA)
Top 2 approach	Assessment of dose to the representative person assuming that the 2 foods contributing the highest dose are consumed at the high (critical) rate, with all others consumed at an average rate
WCBA	Women of child bearing age; a group whose habits are used for the assessment of potential dose to the foetus

Verification Certificate

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1 Introduction

Since the start of fuel cycle 17, and more specifically since January 2020 an anomalous increasing trend has been noted in discharges of carbon-14 to air resulting in carbon-14 discharges in excess of the Quarterly Notification Level. If unabated, the current trend in carbon-14 may threaten the annual discharge limit, so an application is being made to increase the limit by 20%. The application requires assessments of radiation dose to both the public and local wildlife that might result from such an increase.

This report details those dose assessments.

2 Assessment Methods

The assessments covered dose to the representative person, collective dose and dose to local wildlife.

2.1 Dose to the Representative Person

All pathways (discharges to air, discharges to sea and direct radiation) should be considered to determine dose to the representative person for comparison against the constraint of 300 µSv/y for dose from a single source (Reference 1). An additional constraint of 500 µSv/y should be considered for dose from contiguous sites (*e.g*. Sizewell B and Sizewell A), although this applies to discharges only (Reference 1). Therefore dose from discharges from Sizewell A have also been considered.

The following radionuclides discharged to air from Sizewell B were considered:

- tritium (^{3}H, subject to a numerical limit),
- carbon-14 (^{14}C, subject to a numerical limit),
- krypton-88 (^{88}Kr, representing noble gases – see below, which are subject to a numerical limit),
- iodine-131 (^{131}I, subject to a numerical limit) and
- cobalt-60 (^{60}Co, representing beta particulate, which is subject to a numerical limit).

Noble gases discharged from Sizewell B are dominated by xenon-133 (^{133}Xe, 40%), xenon-135 (^{135}Xe, 25%) and ^{88}Kr (10%). The dose per unit discharge for ^{88}Kr is 7 times higher than that for ^{135}Xe and 40 times higher than that for ^{133}Xe-133, so ^{88}Kr was chosen as being reasonably conservative for noble gas discharges from Sizewell B. Beta particulate is represented as ^{60}Co to provide a conservative estimate of dose. Both approaches are consistent with the approach taken in Reference 2.

Although not measured routinely, it is understood that about 90% of ^{14}C discharged to air is in the form of methane, so assessment of dose by inhalation (dose to the representative person and first-pass collective dose) was adjusted to take into account the chemistry of the discharge, using the ratio of effective dose coefficients for inhalation by workers (Reference 3) of ^{14}C as methane (2.9E-12 Sv/Bq) to that for inhalation of ^{14}C as CO_2 (6.5E-12 Sv/Bq). This was applied to the inhalation pathways only, as there is no information available to quantify plant uptake rates of methane compared with plant uptake rates of CO_2.

Sizewell A has numerical limits on discharge to air of ^{3}H, ^{14}C and beta particulate activity, also represented by ^{60}Co in this assessment. Discharges at the relevant limits are shown in Table 1.

The following radionuclides discharged to sea from Sizewell B were considered:

- ^{3}H (subject to a numerical limit),
- caesium-137 (^{137}Cs, subject to a numerical limit) and

- other activity (subject to numerical limit – see below for radionuclide composition).

The composition of ‘other activity’ was considered as follows:

- a conservative assessment of 1% of the ^{14}C generated is discharged to sea (this is impacted directly by the proposed increase in the limit on discharge of ^{14}C to air),
- the remainder of the ‘other activity’ limit was split according to the averaged results from the most recent 10 years of results from the analyses of the annual bulked sample of liquid effluent:
- any radionuclide for which the results were consistently below the MDA were discounted,
- the following radionuclides were added from the station waste fingerprint (Reference 4):
    - o chromium -51 (^{51}Cr, too short lived to appear in the annual bulk, but has a high gamma decay energy) and
    - o nickel-63 (^{63}Ni, pure beta emitter of low radiological impact, but can represent a significant proportion of ‘other activity’ from European PWRs).

Sizewell A has numerical limits on the same radionuclides. However, the composition of ‘other activity’ from a decommissioning Magnox station is different to that from a generating PWR:

- the ‘other activity’ limit was split according to the averaged results from the results from the analyses of the annual bulked sample of liquid effluent for the years 2000 to 2004:
- any radionuclide for which the results were consistently below the MDA were discounted and
- decay correction was applied to the remaining radionuclides to derive their relative proportions in 2020.

The ‘other activity’ assessments for both stations were scaled to the relevant numerical limit to derive the discharges in Table 2.

The most conservative assessment of direct radiation dose from Sizewell B was assessed through the method described in Reference 5. Direct radiation from Sizewell A is not relevant to this assessment (Reference 1).

Dose to the representative person from discharges was assessed using PC-CREAM 08 (Reference 6). For discharges to air, a uniform windrose is used for EDF sites with 70% category D and 10% rain in C and D, as this has been found to provide a good fit to localised meteorology conditions (Reference 7). However, to examine the effects of localised meteorology, a second assessment was made with a localised file based on 10 years annual observations at RAF Wattisham.

Six candidate representative persons were identified:

- Magnox employees at the adjacent Sizewell A decommissioning site,
- people living at the nearest residence:
    - o adult age group,
    - o child age group,
    - o infant age group and
    - o foetus age group,
- commercial fishermen maintaining boats and fishing equipment on the shore to the south of the station and their families:
    - o adult age group,
    - o child age group,
    - o infant age group and

- o foetus age group.

The precise locations used for each candidate representative person are held in a separate file with a higher security classification, so cannot be included here. The habits data in Tables 3 and 4 were taken from the most recent habits survey report (Reference 8). Dose to the foetus age group is based on the habits of women of child-bearing age (WCBA). An factor of 0.75 is applied to the annual occupancy and ingestion rates to allow for a 9 month gestation period.

The assessment for dose from discharges to air used the “Top 2” approach, in which the two foodstuffs contributing the highest dose are consumed at the high rate and all other foodstuffs are consumed at the average rate. Previous assessments have assumed that all vegetables and fruit are grown in the garden of the critical habitation. However, typical domestic gardens are not large enough to accommodate this, so it was assumed that the top 2 were grown at the critical habitation, vegetables consumed at the average rate were grown at the nearest allotment and fruit consumed at the average rate was grown at the nearest farm (allotments do not usually accommodate fruit trees). It was assumed that all meat was raised at the nearest farm. There is no local production of milk (Reference 8). PC-CREAM provides results for green vegetables and root vegetables, but no separate results for potatoes or other vegetables, so it was assumed that the radionuclide concentrations in “Other vegetables” (Table 3) were the same as those in “Green vegetables” and the radionuclide concentration in “Potatoes” was the same as those in “Root vegetables”.

Equations used for the assessment can be found in Reference 9.

PC-CREAM does not calculate dose to the foetus age group. This was derived from the adult dose results (dose per unit discharge and habit) as follows.

- External gamma dose rates were assumed to be the same as the adult dose rate.
- External beta dose rates were assumed to be zero, as the foetus is effectively shielded from external beta radiation by the mother’s abdomen.
- Internal dose rates were derived from the adult dose rate by ratio to the foetus dose per unit intake (Reference 9) divided by the adult dose per unit intake (Reference 3). Note that foetus dose per unit intake refers to unit intake by the mother. Reference 9 contains no data for ^{88}Rb (daughter product of ^{88}Kr), so the foetus dose rate from intake of ^{88}Rb was derived with reference to ^{137}Cs, as caesium and rubidium are both alkali metals.

2.2 Collective Dose

Collective dose from the proposed increase in discharge limit was also assessed using PC-CREAM 08 for the discharges in Table 1 and 2, the number of years that discharges would continue (end of generation is assumed to be 2055) and the availability of the reactor (90%, assuming a refuelling outage every 18 months). As with the assessment of individual dose, an additional assessment was made with a localised file based on 10 years annual observations at RAF Wattisham.

2.3 Dose to Wildlife

Implementation of the European Union Wild Birds and Habitat Directives has led to the creation of a number of conservation areas collectively referred as Natura 2000 sites:

- Sites of Special Scientific Interest (SSSI),
- Special Areas of Conservation (SAC),
- Special Protection Areas (SPA) and
- Ramsar Sites.

Two Natura 2000 sites were identified in the vicinity of Sizewell B: a Ramsar site to the north of the site (nearest point at 780 m on a bearing of 010°) and an SSSI to the west of the site (nearest point at 350 m on a bearing of 295°).

Radiation impact on wildlife at these sites was considered for depositing radionuclides using the ERICA dose assessment tool version 1.3 (Reference 10). ERICA can be used only to assess the impact of depositing radionuclides, so the impact of ^{88}Kr and ^{131m}Xe (^{131}I daughter) were assessed using the Terrestrial Ecosystem SCK-CEN version 2 spreadsheet, a development of the Environment Agency's R&D Publication 128 (Reference 11) that has been extended to include a range of reference animals and plants (RAPs) that are compatible with ERICA. This allows simple addition of the results from the tools to derive an overall dose rate for each RAP. Therefore, assessments were carried out for those RAPs that are common to both tools.

Wildlife doses from discharges to sea were assessed for the discharges from Sizewell B listed in Table 2.

3 Results

3.1 Dose to the Representative Person

Doses to each of the candidate representative persons by pathway are presented in Table 5. The representative person is an adult member of the fisherman family who receives 10.8 μSv/y from discharges at the proposed limits and direct radiation, only 4% of the constraint of 300 μSv/y. Dose is dominated by direct radiation (79%), then discharges to sea (19%), while discharges to air account for only 2% of the dose. The direct radiation is dose is the most conservative of those submitted to the ONR for 2019 (Reference 12), which assumes the dry fuel store is the primary radiation source, so the assessment is independent of reactor power. This figure is an upper bound, as dose rates measured on-site for the assessment are not statistically distinguishable from the local background. Carbon-14 accounts for around only 1% of the total dose.

Doses from discharges to each of the candidate representative persons by radionuclide are presented in Table 6. Carbon-14 accounts for only about 5% of the dose to the representative person from discharges, with the proposed increase in the discharge limit of ^{14}C resulting in an increase of 0.01 μSv/y over dose from discharges at the current limits.

Dose from combined discharges with Sizewell A at the proposed limits (current limits for Sizewell A) are presented in Table 7. Again, the most exposed person is an adult member of the local fisherman family, who receives 16.6 μSv/y, only 3% of the constraint of 500 μSv/y. This is dominated by discharges of ^{137}Cs from Sizewell A (85%). Discharges of ^{14}C to air from Sizewell B accounts for only 0.2% of this total.

The proposed increase in limit is more significant for local residents consuming locally grown food, for whom the proposed increase results in an increased dose of 0.12 μSv/y (adult resident). Dose to the adult resident is dominated by ^{14}C (72% for discharges at the proposed limits), followed by noble gases (represented by ^{88}Kr, 24%) and ^{3}H (3%). Doses from ^{131}I and particulate discharges (represented by ^{60}Co) are insignificant. The top 2 pathways were consumption of potatoes (36% of the dose) and root vegetables (24% of the dose).

Comparisons were made for dose to an adult resident (the most exposed individual from discharges to air) assuming all ^{14}C was discharges as CO_2 and using the local meteorology (Wattisham data set). The comparisons are presented in Table 8. The assumption that all ^{14}C is discharged as CO_2 adds only another 0.09 μSv/y to the dose to the adult resident. Adopting local (Wattisham) meteorology reduces dose to the adult resident by 7%.

3.2 Collective Dose

Collective dose to the UK, European and World populations are presented in Tables 9 to 11. Due to its very long half-life, collective dose from ^{14}C is dominated by the global circulation pathway; it accounts for over 99% of the collective dose to the UK population, European and World populations. The proposed increase in limits adds 11 manSv to the UK population, 82 manSv to the European population and about 1750 manSv to the World population, assuming that discharges continue at the proposed limits with 90% station availability to the end of generation. These are modest increases in collective dose. To put them into context, the collective dose to the UK population alone (in a *single* year) just from naturally occurring ^{14}C is 700 manSv (Reference 2), so will be about 24,500 manSv over the same period as considered for discharges in this report. Therefore, collective dose from discharges at the proposed limits is 0.3% of the collective dose from natural ^{14}C.

3.3 Dose to Wildlife

Dose rates to wildlife at the SSSI to the west of the site and the Ramsar site to the north of the site at the proposed limits are shown in Tables 12 and 13, both assuming a uniform wind rose. Comparisons with dose rates at the current limits and with use of local meteorology are shown in Table 14.

The highest dose rate from discharges to air is received by grasses and herbs at both locations, the maximum being received at the SSSI to the west of the site, 0.005 µGy/hr. The critical radionuclide for these organisms is ^{88}Kr, with ^{14}C as the next-most significant, contributing 17% of the dose. The proposed increase in discharge limit increases dose to the most exposed organism by only 3%. Use of local meteorology reduces dose at the SSSI by 28%, but reduces dose rates by only 4% at the Ramsar site.

The highest dose rate to wildlife overall is from discharges to sea (Table 15), the maximum being 0.19 µGy/hr to polychaete worms. The main contribution to dose for polychaete worms is ^{54}Mn (a component of “Other activity”), which accounts for over 40% of the total dose; ^{14}C accounts for less than 0.1%. The marine organism most effected by dose from ^{14}C is zooplankton, which receives almost 30% of its total dose from ^{14}C.

The risk quotients (observed dose rate over “no effect” dose rate) for each organism are shown in Table 16. Those for discharges to air are the ERICA risk quotients adjusted to include the risk from the noble gases. The risk quotient to the most exposed organism from discharges to air (grasses and herbs), even allowing for a conservative screening value, is only 1.6×10^{-3}, while the maximum (allowing for a conservative screening value) is only 5.7×10^{-2} to polychaete worms. Therefore, there is no significant risk to local wildlife from discharges at the proposed limits.

4 Conclusions

The proposed increase in the discharge limit to ^{14}C results in:

- a dose to the representative person (adult member of a local fisherman’s family) that is 10.8 µSv/y, only 4% of the constraint of 300 µSv/y (Reference 1),
- collective dose that is less than 1% of the collective dose from natural ^{14}C and
- risk to wildlife that is less than 6% of the no effect dose rate, the most effected organism being polychaete worms.

Therefore, there doses from the proposed increase in limit are broadly acceptable.

5 References

Ref. No.	Document Number	Document Title
1	Environment Agency (2010) Radioactive Substances Regulation– Environmental Principles, Regulatory Guidance Series, No RSR 1	
2	SZB/THR/042	Review of the Control and Impact of the Discharge and Disposal of Radioactive Waste at Sizewell B Power Station (Information provided by British Energy Generation Limited for the review by the Environment Agency of authorisations under RSA 93), 2005
3	ICRP (2012) Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119. Ann. ICRP 41(Suppl.).	
4	SZB/THR/009	Sizewell B Power Station, Wastestream Characterisation Report, Radioactive waste for disposal at the Low Level Waste Repository, Rev 007, 2010
5	ERO/REP/0197/GEN	Direct Radiation Dose to the Public from EDF Energy Nuclear Power Stations, 2015 to 2017
6	h J.G. and Simmonds J. R. (Eds) (2009) The Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment Used in PC-CREAM 08. HPA-RPD-058, Health Protection Agency, Radiation Protection Division, Chilcott	
7	E/EAN/BBEB/0031/GEN/05	A Eslava-Gomez & A C Ponting, Site Specific and Other Data for Use with PC-CREAM to Assess Public Doses from Gaseous and Liquid Discharges, 2005
8	Garrod C.J., Clyne F.J. and Rumney P. (2016) Radiological Habits Survey: Sizewell, 2015. RL 01/16. CEFAS, Lowestoft	
9	BEG/SPEC/SHE/ENVI/032	The Retrospective Assessment of Public Radiation Dose in the Vicinity of EDF Energy Nuclear Power Stations, Rev 0003, 2018
10	Brown J.E., Alfonso B. , Avila R. , Beresford N.A. , Copplestone D. and Hosseini A. (2016) A new version of the ERICA tool to facilitate impact assessments of radioactivity on wild plants and animals. Journal of Environmental Radioactivity, **153**, 141-148.	
11	Copplestone D., Bielby S., Jones SR., Patton D., Daniel P. and Gize I. (2001) Impact Assesment of Ionising Radiation on Wildlife, R&D Publication 128. Environment Agency.	
12	NSL_GEN_32717_N	Reply to Request for Public Dose Information for the 2019 Calendar Year

6 Tables

Table 1: Discharges to Air at Numerical Limits

Limited Nuclide	Discharge, Bq/y		
	Current	Proposed	Sizewell A
Tritium	3.0E+12	3.0E+12	3.5E+12
Carbon-14	5.0E+11	6.0E+11	1.0E+11
Noble gases[a]	3.0E+13	3.0E+13	N/A
Iodine-131	5.0E+08	5.0E+08	N/A
Beta particulate[b]	1.0E+08	1.0E+08	8.5E+08

a: Treated as ^{88}Kr for dose assessment.
b: Treated as ^{60}Co for dose assessment.

Table 2: Discharges to Sea at Numerical Limits

Nuclide	Discharge, Bq/y	
	Sizewell B	Sizewell A
Subject to numerical limit:		
Tritium	8.0E+13	5.0E+12
Caesium-137	2.0E+10	1.0E+12
Other activity	1.3E+11	7.0E+11
Component of "Other activity" for dose assessment[a]:		
C-14[b]	6.0E+09	
Cr-51	3.5E+10	
Mn-54	6.3E+09	
Fe-55	1.1E+10	2.5E+07
Co-58	4.3E+09	
Co-60	1.3E+10	9.7E+07
Ni-63	5.6E+09	
Sr-90		3.5E+11
Y-90		3.5E+11
Sb-124	2.1E+09	
Sb-125	7.2E+09	
Te-125m	1.6E+09	
Cs-134	3.5E+10	2.5E+09
Pu-238	1.9E+07	4.0E+06
Pu-239	3.0E+07	1.4E+08
Pu-241	2.8E+09	1.4E+09
Am-241	3.8E+07	2.0E+08
Cm-242	2.5E+07	
Cm-243		5.8E+06

a: Blank (greyed-out) cells indicated consistently below the MDA or below 1 Bq after decay correction.
b: At proposed limit

Table 3: Consumption Data

Group		Consumption, Kg/y												
		Fish	Crusta-ceans	Molluscs	Seaweed	Green veg	Root veg.	Potatoes	Other veg	Fruit	Cow meat	Cow liver	Sheep meat	Sheep liver
Fishermen family	Adult	23.5	10.4	3.2	0.6									
	Child	14.0	1.4	0.8	0.0									
	Infant	7.4	0.5	0.2	0.0									
	WCBAa	13.5	12.1	0.4	0.0									
Adult residents	High rate					46.6	50.9	77.5	41.7	36.9	19.2	5.5	7.2	2.1
	Average rate					15.5	12.7	32.3	16.7	9.8	6.4	1.5	2.3	0.6
Child residents	High rate					10.0	9.9	20.3	6.3	12.5	12.8	0.0	2.9	0.0
	Average rate					3.0	3.0	10.7	2.0	3.8	6.4	0.0	1.2	0.0
Infant residents	High rate					9.1	5.3	7.5	2.7	3.1	4.3	0.0	0.9	0.0
	Average rate					3.2	1.8	2.1	0.8	0.8	1.3	0.0	0.2	0.0
WCBA[a] residents	High rate					34.4	49.0	52.3	13.6	10.0	10.4	3.0	0.0	0.0
	Average rate					15.5	12.7	32.3	16.7	9.8	6.4	1.5	2.3	0.6

a: Women of child-bearing age for the foetus age group.

Table 4: Occupancy Data

Group		Occupancy, Hr/y		
		Indoors	Outdoors	Beach
Magnox employee		1150	490	
Fishermen family	Adult	0	2399	2399
	Child			659
	Infant			73
	WCBA[a]			319
Residents	Adult	5395	1146	
	Child	3497	874	
	Infant	3546	1460	
	WCBA[a]	3546	1460	

a: Women of child-bearing age for the foetus age group.

Table 5: Dose to Candidate Representative persons by Pathway

Pathway	Dose, µSv								
	Magnox employee	Local Resident				Local Fisherman's family			
		Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Discharges to air									
Inhalation	6.1E-02	1.1E-01	7.3E-02	7.0E-02	4.3E-03	3.3E-02			
Plume γ	1.7E-01	2.3E-01	1.7E-01	2.3E-01	1.7E-01	2.1E-01			
Plume β	1.0E-03	1.6E-03	1.2E-03	1.7E-03	0.0E+00	2.0E-03			
Ground γ	1.2E-03	1.5E-03	1.1E-03	1.7E-03	1.2E-03	1.8E-03			
Ground β	7.8E-05	1.8E-04	1.3E-04	1.9E-04	0.0E+00	2.4E-04			
Resuspension (inhaled)	1.1E-06	1.9E-06	2.2E-06	3.1E-06	1.1E-06	5.8E-07			
Green vegetables		1.4E-02	3.8E-03	1.3E-01	1.5E-02				
Other vegetables		1.5E-02	2.6E-03	2.1E-03	1.6E-02				
Root vegetables		2.4E-01	3.7E-03	4.4E-03	2.4E-01				
Potato		3.7E-01	1.3E-01	9.9E-02	2.6E-01				
Domestic fruit		8.8E-03	8.3E-02	2.0E-03	9.2E-03				
Cattle meat		8.4E-03	1.2E-02	4.7E-03	8.7E-03				
Sheep meat		3.0E-03	2.1E-03	8.5E-04	3.1E-03				
Cow liver		2.0E-03	0.0E+00	0.0E+00	2.1E-03				
Sheep liver		7.3E-04	0.0E+00	0.0E+00	7.5E-04				

Table 5: Continued

Pathway	Dose, µSv								
	Magnox employee	Local Resident				Local Fisherman's family			
		Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Discharges to Sea									
External **γ**						1.8E+00	7.5E-01	8.3E-02	6.2E-02
External **β**						6.1E-03	2.6E-03	2.9E-04	0.0E+00
Sea spray						2.9E-05	8.1E-06	4.5E-07	4.4E-06
Handling Fishing Gear **γ**						1.3E-02	0.0E+00	0.0E+00	1.3E-04
Handling Fishing Gear **β**						1.3E-03	0.0E+00	0.0E+00	0.0E+00
Local Fish						1.0E-01	6.7E-02	6.4E-02	3.7E-02
Regional Fish						8.6E-04	6.0E-04	6.0E-04	3.2E-04
Crustaceans						1.1E-01	2.5E-02	2.0E-02	9.3E-02
Molluscs						4.1E-02	1.8E-02	7.5E-03	3.3E-03
Seaweed						7.7E-03	0.0E+00	0.0E+00	0.0E+00
Direct radiation	9.0E+00	7.9E+00	8.9E+00	7.7E+00	5.8E+00	8.5E+00			
TOTAL	**9.2**	**8.9**	**9.4**	**8.3**	**6.5**	**10.8**	**0.9**	**0.2**	**0.2**

Table 6: Dose to Candidate Representative Persons by Nuclide (Discharges only)

Radiation source	Dose, µSv								
	Magnox employee	Local Resident				Local Fisherman's family			
		Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
C-14 discharged to air	5.1E-02	7.3E-01	2.9E-01	2.8E-01	5.3E-01	2.7E-02			
Co-60 discharged to air	1.3E-03	1.7E-03	1.2E-03	1.8E-03	1.2E-03	1.8E-03			
H-3 discharged to air	6.9E-03	3.0E-02	1.3E-02	1.2E-02	1.9E-02	3.6E-03			
I-131 discharged to air	3.6E-04	4.5E-03	4.6E-03	1.1E-02	3.0E-03	2.2E-04			
Kr-88 discharged to air	1.7E-01	2.4E-01	1.7E-01	2.4E-01	1.7E-01	2.2E-01			
H-3 discharged to sea						2.9E-03	1.1E-03	1.1E-03	2.9E-03
Cs-137 discharged to sea						2.8E-01	1.2E-01	1.7E-02	2.2E-02
Other activity discharged to sea						1.8E+00	7.4E-01	1.6E-01	1.7E-01
Total Discharges Dose	**0.23**	**1.0**	**0.48**	**0.54**	**0.73**	**2.3**	**0.86**	**0.18**	**0.20**

Table 7: Dose to the Representative Person from Discharges from Sizewell A and B

Radiation source	Dose, µSv							
	Local Resident				Local Fisherman's family			
	Adult	Child	Infant	Foetus	Adult	Child	Infant	Foetus
Discharges to Air								
Sizewell B								
C-14 discharged to air	7.3E-01	2.9E-01	2.8E-01	5.3E-01	2.7E-02			
Co-60 discharged to air	1.7E-03	1.2E-03	1.8E-03	1.2E-03	1.8E-03			
H-3 discharged to air	3.0E-02	1.3E-02	1.2E-02	1.9E-02	3.6E-03			
I-131 discharged to air	4.5E-03	4.6E-03	1.1E-02	3.0E-03	2.2E-04			
Kr-88 discharged to air	2.4E-01	1.7E-01	2.4E-01	1.7E-01	2.2E-01			
Sizewell A								
C-14 discharged to air	1.4E-01	4.5E-02	5.5E-02	8.9E-02	7.5E-03			
Co-60 discharged to air	1.4E-02	9.7E-03	1.5E-02	1.0E-02	1.3E-02			
H-3 discharged to air	3.5E-02	1.0E-02	1.4E-02	2.3E-02	3.6E-03			
Discharges to Sea								
Sizewell B								
H-3 discharged to sea					2.9E-03	1.1E-03	1.1E-03	2.9E-03
Cs-137 discharged to sea					2.8E-01	1.2E-01	1.7E-02	2.2E-02
Other activity discharged to sea					1.8E+00	7.4E-01	1.6E-01	1.7E-01
Sizewell A								
H-3 discharged to sea					1.8E-04	7.2E-05	6.8E-05	1.8E-04
Cs-137 discharged to sea					1.4E+01	5.8E+00	8.3E-01	2.2E+00
Other activity discharged to sea					2.0E-01	8.7E-02	2.2E-02	3.6E-02
Totals	**1.2**	**0.5**	**0.9**	**0.9**	**16.6**	**6.7**	**1.0**	**2.4**

Table 8: Comparison with Other Scenarios

Scenario	Dose at New Limits µSv/y					
	Magnox	Fishermen	Residents			
			Adult	Child	Infant	Foetus
Uniform windrose	2.0E-01	2.5E-01	1.0E+00	4.8E-01	5.4E-01	7.3E-01
All ^{14}C as CO_2	2.9E-01	2.7E-01	1.1E+00	5.4E-01	5.9E-01	7.3E-01
Wattisham met	2.0E-01	2.1E-01	9.3E-01	4.8E-01	5.4E-01	7.2E-01

Table 9: Collective Dose (manSv) to the UK Population

Nuclide	Current			New		
	First Pass	Global	Total	First Pass	Global	Total
Discharges to air						
H-3	3.1E-02	5.8E-03	3.6E-02	3.1E-02	4.4E-02	7.5E-02
C-14	4.2E+00	5.2E+01	5.6E+01	5.0E+00	6.3E+01	6.8E+01
Co-60	6.3E-04	0.0E+00	6.3E-04	6.3E-04	0.0E+00	6.3E-04
Kr-88	6.6E-02	0.0E+00	6.6E-02	6.6E-02	0.0E+00	6.6E-02
I-131	1.3E-02	0.0E+00	1.3E-02	1.3E-02	0.0E+00	1.3E-02
Total	4.3E+00	5.2E+01	**5.6E+01**	5.1E+00	6.3E+01	**6.8E+01**
Discharges to Sea						
H-3	1.4E-05	1.6E-05	3.0E-05	1.4E-05	1.6E-05	3.0E-05
Cs-137	1.6E-04	0.0E+00	1.6E-04	1.6E-04	0.0E+00	1.6E-04
Other activity	1.2E-03	3.3E-04	1.6E-03	1.3E-03	4.0E-04	1.7E-03
Total	1.4E-03	3.5E-04	**1.8E-03**	1.5E-03	4.2E-04	**1.9E-03**
TOTAL	**4**	**52**	**56**	5	63	**68**

Table 10: Collective Dose (manSv) to the European Population

Nuclide	Current			New		
	First Pass	Global	Total	First Pass	Global	Total
Discharges to air						
H-3	1.3E-01	4.4E-02	1.8E-01	1.3E-01	4.4E-02	1.8E-01
C-14	1.2E+01	4.0E+02	4.1E+02	1.4E+01	4.8E+02	4.9E+02
Co-60	2.3E-03	0.0E+00	2.3E-03	2.3E-03	0.0E+00	2.3E-03
Kr-88	2.8E-01	0.0E+00	2.8E-01	2.8E-01	0.0E+00	2.8E-01
I-131	2.9E-02	0.0E+00	2.9E-02	2.9E-02	0.0E+00	2.9E-02
Total	1.2E+01	4.0E+02	**4.1E+02**	1.4E+01	4.8E+02	**4.9E+02**
Discharges to Sea						
H-3	8.3E-05	9.8E-05	1.8E-04	8.3E-05	9.8E-05	1.8E-04
Cs-137	8.7E-04	0.0E+00	8.7E-04	8.7E-04	0.0E+00	8.7E-04
Other	7.4E-03	2.0E-03	9.4E-03	8.1E-03	2.4E-03	1.1E-02
Total	8.4E-03	2.1E-03	**1.0E-02**	9.1E-03	2.5E-03	**1.2E-02**
TOTAL	**12**	**398**	**411**	14	478	**493**

Table 11: Collective Dose (manSv) to the World Population

Nuclide	Current			New		
	First Pass	Global	Total	First Pass	Global	Total
Discharges to air						
H-3	1.3E-01	9.7E-01	1.1E+00	1.3E-01	9.7E-01	1.1E+00
C-14	1.2E+01	8.7E+03	8.7E+03	1.4E+01	1.0E+04	1.0E+04
Co-60	2.3E-03	0.0E+00	2.3E-03	2.3E-03	0.0E+00	2.3E-03
Kr-88	2.8E-01	0.0E+00	2.8E-01	2.8E-01	0.0E+00	2.8E-01
I-131	2.9E-02	0.0E+00	2.9E-02	2.9E-02	0.0E+00	2.9E-02
Total	1.2E+01	8.7E+03	**8.7E+03**	1.4E+01	1.0E+04	**1.0E+04**
Discharges to Sea						
H-3	1.3E-04	2.7E-03	2.8E-03	1.3E-04	2.7E-03	2.8E-03
Cs-137	1.6E-03	0.0E+00	1.6E-03	1.6E-03	0.0E+00	1.6E-03
Other	1.1E-02	5.6E-02	6.7E-02	1.2E-02	6.7E-02	7.9E-02
Total	1.3E-02	5.8E-02	**7.1E-02**	1.4E-02	6.9E-02	**8.3E-02**
TOTAL	**12**	**8732**	**8744**	14	10478	**10493**

Table 12: Dose Rates to Terrestrial Wildlife in the SSSI to the West of the Site at the Proposed Limits

Nuclide[a]	Total Dose Rate, $\mu Gy\ h^{-1}$											
	Amphibian[b]	Annelid	Arthropod	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Tree
H-3	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.2E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04
C-14	1.5E-03	4.6E-04	4.7E-04	1.5E-03	4.7E-04	9.6E-04	9.7E-04	1.5E-03	1.5E-03	4.7E-04	1.5E-03	1.5E-03
Co-60	1.3E-06	1.3E-06	1.3E-06	2.7E-05	2.7E-05	2.6E-05	2.7E-05	2.3E-05	1.2E-06	2.7E-05	1.2E-06	2.1E-05
Kr-88 +	1.5E-03	4.3E-07	2.0E-03	1.2E-03	1.9E-03	3.6E-03	2.1E-03	7.1E-04	3.1E-07	1.8E-03	1.4E-03	1.7E-03
I-131 +	4.7E-10	4.1E-10	4.4E-10	3.4E-06	2.8E-06	2.4E-06	2.3E-06	3.5E-06	4.6E-10	2.5E-06	4.4E-10	2.4E-06
Total[c]	**3.2E-03**	**7.0E-04**	**2.7E-03**	**2.9E-03**	**2.6E-03**	**4.8E-03**	**3.3E-03**	**2.5E-03**	**1.7E-03**	**2.5E-03**	**3.1E-03**	**3.4E-03**

a: '+' symbol indicates that the dose from daughter radionuclides is included.
b: Pale amber heading indicates organism lives in soil, so bulk soil concentrations have been used; other organisms live on soil, so top-soil concentrations have been used.
c: Highest dose rate is highlighted in red.

Table 13: Dose Rates to Terrestrial Wildlife in the Ramsar Site to the North of the Site at the Proposed Limits

Nuclide[a]		Total Dose Rate, $\mu Gy\ h^{-1}$											
		Amphibian[b]	Annelid	Arthropod	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Tree
H-3		9.8E-05	9.8E-05	9.8E-05	9.8E-05	9.1E-05	9.8E-05	9.7E-05	9.8E-05	9.8E-05	9.8E-05	9.8E-05	9.8E-05
C-14		6.0E-04	1.9E-04	1.9E-04	6.3E-04	1.9E-04	4.0E-04	4.1E-04	6.3E-04	6.3E-04	1.9E-04	6.3E-04	6.1E-04
Co-60		5.5E-07	5.5E-07	5.5E-07	1.1E-05	1.1E-05	1.1E-05	1.1E-05	9.6E-06	5.2E-07	1.1E-05	5.2E-07	9.0E-06
Kr-88	+	6.1E-04	1.8E-07	8.2E-04	4.8E-04	7.7E-04	1.5E-03	8.8E-04	3.4E-04	1.3E-07	7.2E-04	5.7E-04	6.9E-04
I-131	+	1.9E-10	1.7E-10	1.8E-10	1.4E-06	1.1E-06	9.7E-07	9.6E-07	1.4E-06	1.9E-10	1.0E-06	1.8E-10	1.0E-06
Total[c]		**1.3E-03**	**2.9E-04**	**1.1E-03**	**1.2E-03**	**1.1E-03**	**2.0E-03**	**1.4E-03**	**1.1E-03**	**7.2E-04**	**1.0E-03**	**1.3E-03**	**1.4E-03**

a: '+' symbol indicates that the dose from daughter radionuclides is included.
b: Pale amber heading indicates organism lives in soil, so bulk soil concentrations have been used; other organisms live on soil, so top-soil concentrations have been used.
c: Highest dose rate is highlighted in red.

Table 14: Comparison with Other Scenarios

Scenario[a]	Total Dose Rate, µGy h^{-1}											
	Amphibian	Annelid	Arthropod	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Tree
SSSI Proposed	3.2E-03	7.0E-04	2.7E-03	2.9E-03	2.6E-03	**4.8E-03**	3.3E-03	2.5E-03	1.7E-03	2.5E-03	3.1E-03	3.4E-03
Ramsar Proposed	1.3E-03	2.9E-04	1.1E-03	1.2E-03	1.1E-03	2.0E-03	1.4E-03	1.1E-03	7.2E-04	1.0E-03	1.3E-03	1.4E-03
SSSI Current	2.9E-03	6.2E-04	2.6E-03	2.7E-03	2.5E-03	**4.6E-03**	3.2E-03	2.2E-03	1.5E-03	2.4E-03	2.9E-03	3.1E-03
Ramsar Current	1.2E-03	2.6E-04	1.1E-03	1.1E-03	1.0E-03	1.9E-03	1.3E-03	9.7E-04	6.2E-04	9.9E-04	1.2E-03	1.3E-03
SSSI Local Met	2.3E-03	5.0E-04	1.9E-03	2.1E-03	1.9E-03	**3.4E-03**	2.4E-03	1.8E-03	1.2E-03	1.8E-03	2.2E-03	2.4E-03
Ramsar Local Met	1.3E-03	2.8E-04	1.1E-03	1.2E-03	1.0E-03	1.9E-03	1.3E-03	1.0E-03	7.0E-04	9.9E-04	1.2E-03	1.3E-03

a: Highest dose rate for each scenario is highlighted in red.

Table 15: Dose Rates to Marine Wildlife at the Proposed Limits

Nuclide[a]	Total Dose Rate, µGy/h												
	Benthic fish	Bird	Crus-tacean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Poly-chaete worm	Reptile	Sea anemones & True coral	Vascular plant	Zoo-plankton
H-3	6.1E-05	6.1E-05	6.1E-05	6.0E-05	6.1E-05	6.1E-05	6.1E-05	6.0E-05	6.1E-05	6.1E-05	6.1E-05	6.1E-05	6.1E-05
C-14	2.4E-05	2.4E-05	2.0E-05	1.8E-05	2.4E-05	8.8E-06	2.4E-05	3.3E-06	1.4E-04	2.4E-05	2.3E-05	1.8E-05	1.4E-04
Cr-51	5.2E-04	9.6E-06	5.0E-04	5.8E-04	1.7E-05	5.6E-04	8.9E-07	1.7E-05	1.1E-03	1.7E-05	5.7E-04	5.8E-04	3.4E-06
Mn-54	3.5E-02	9.9E-06	3.5E-02	3.8E-02	3.6E-05	3.8E-02	4.4E-06	8.1E-07	7.5E-02	3.6E-05	3.8E-02	3.7E-02	7.3E-07
Fe-55	8.2E-07	1.5E-06	7.7E-06	4.6E-05	1.5E-06	4.6E-05	7.6E-07	4.3E-05	4.6E-05	1.5E-06	8.0E-06	4.6E-05	7.4E-06
Co-58	3.9E-03	9.9E-07	3.8E-03	4.2E-03	3.2E-06	4.1E-03	8.4E-06	1.1E-06	8.4E-03	3.1E-06	4.2E-03	4.1E-03	2.3E-06
Co-60	3.4E-02	7.8E-06	3.3E-02	3.6E-02	2.5E-05	3.6E-02	6.5E-05	9.3E-06	7.2E-02	2.5E-05	3.6E-02	3.6E-02	1.7E-05
Ni-63	1.7E-07	3.4E-07	8.6E-07	6.7E-07	3.4E-07	4.4E-06	1.7E-07	3.8E-07	2.9E-06	3.4E-07	4.4E-06	6.5E-07	3.4E-07
Sb-124	4.4E-04	4.6E-04	4.1E-04	4.6E-04	9.8E-04	4.4E-04	3.0E-05	9.3E-06	1.1E-03	9.7E-04	4.7E-04	4.3E-04	2.7E-05
Sb-125 +	4.3E-04	5.8E-04	4.0E-04	4.4E-04	1.1E-03	4.5E-04	3.7E-05	3.3E-05	1.1E-03	1.1E-03	4.3E-04	4.4E-04	5.3E-05
Te-125m	8.8E-06	8.6E-05	1.2E-05	6.8E-06	9.3E-05	1.7E-05	7.0E-06	1.1E-04	4.8E-05	9.3E-05	3.1E-06	6.7E-06	8.9E-06
Cs-134	1.1E-02	2.7E-04	1.1E-02	1.2E-02	3.3E-04	1.2E-02	4.2E-05	3.4E-06	2.4E-02	7.0E-04	1.2E-02	1.2E-02	3.0E-05
Cs-137	2.4E-03	1.3E-04	2.3E-03	2.6E-03	1.1E-04	2.5E-03	2.3E-05	1.4E-06	5.2E-03	2.3E-04	2.6E-03	2.5E-03	2.3E-05
Pu-238 +	8.4E-06	2.5E-06	7.0E-07	2.4E-05	8.1E-06	6.6E-06	8.4E-06	7.5E-04	9.2E-06	8.1E-06	3.0E-06	2.4E-05	3.8E-05
Pu-239 +	1.3E-05	3.7E-06	1.0E-06	3.6E-05	1.2E-05	9.8E-06	1.3E-05	1.1E-03	1.4E-05	1.2E-05	4.4E-06	3.6E-05	5.6E-05
Pu-241 +	3.1E-07	8.9E-08	2.8E-08	8.9E-07	2.9E-07	2.4E-07	3.0E-07	2.8E-05	3.4E-07	2.9E-07	1.1E-07	8.8E-07	1.4E-06
Am-241 +	9.5E-07	2.7E-07	9.5E-07	1.1E-06	9.0E-07	6.7E-05	2.8E-07	1.4E-04	6.8E-05	9.0E-07	9.3E-07	1.1E-06	2.7E-06
Cm-242 +	6.1E-07	1.8E-07	2.2E-07	5.2E-06	5.8E-07	1.4E-05	6.0E-07	1.2E-04	1.4E-05	5.8E-07	4.1E-08	5.2E-06	2.7E-06
Total[b]	**8.8E-02**	**1.6E-03**	**8.6E-02**	**9.4E-02**	**2.8E-03**	**9.4E-02**	**3.2E-04**	**2.4E-03**	**1.9E-01**	**3.3E-03**	**9.4E-02**	**9.3E-02**	**4.7E-04**

a: '+' symbol indicates that the dose from daughter radionuclides is included.
b: Highest dose rate is highlighted in red.

Table 16: Risk Quotients for Discharges at the Proposed Limits

Organism	Risk Quotient	
	Expected value	Conservative value
TERRESTRIAL		
Amphibian	3.6E-04	1.1E-03
Annelid	7.8E-05	2.3E-04
Arthropod - detritivorous	3.2E-04	9.7E-04
Bird	3.1E-04	9.4E-04
Flying insects	2.8E-04	8.4E-04
Grasses & Herbs	5.3E-04	1.6E-03
Lichen & Bryophytes	3.7E-04	1.1E-03
Mammal - large	2.6E-04	7.8E-04
Mammal - small-burrowing	1.8E-04	5.4E-04
Mollusc - gastropod	2.7E-04	8.1E-04
Reptile	3.5E-04	1.0E-03
Tree	3.7E-04	1.1E-03
MARINE		
Benthic fish	8.8E-03	2.6E-02
Bird	1.6E-04	4.9E-04
Crustacean	8.6E-03	2.6E-02
Macroalgae	9.4E-03	2.8E-02
Mammal	2.8E-04	8.5E-04
Mollusc - bivalve	9.4E-03	2.8E-02
Pelagic fish	3.2E-05	9.7E-05
Phytoplankton	2.4E-04	7.3E-04
Polychaete worm	1.9E-02	5.7E-02
Reptile	3.3E-04	9.9E-04
Sea anemones & True coral	9.4E-03	2.8E-02
Vascular plant	9.3E-03	2.8E-02
Zooplankton	4.7E-05	1.4E-04

7 Distribution List

Name	AMS ID