EM/2018/18
05/10/2018

Assessment of radiological doses to marine and terrestrial representative persons (critical groups) at site limits as proposed for the Sellafield Major Permit Review

[redacted]

Aerial Methodology

The aerial dose assessment was conducted using the methodology detailed in SLSP2.11.109 and the dose per unit discharge factors (Long-term Aerial Dose Release Ratios, LADRRs) detailed in SLF2.11.109.01. Discharges at site limits cannot be directly used to calculate doses at site limits as these discharges are distributed across numerous contributing stacks each with different dose consequences due to (i) difference in their effective stack heights (ESHs) or; (ii) differences in the physical properties of the discharged radioactivity. Consequently, the discharges of radionuclides at the plant limits (termed Q_P) for named stacks, were used to calculate doses at plant limits using the effective stack heights and radionuclide physical properties specific to each stack to derive plant specific dose factors (F_P). These doses at plant limits were then summed in order to determine the cumulative dose impact across all the stacks on the site (termed D_C). This calculation methodology is shown in Equation 1.

$$D_C = \sum Q_P F_P \qquad \text{Equation 1}$$

The RSA permit includes limits for specific named radionuclides as well as for 'Total Alpha' and 'Total Beta'. In line with SLSP 2.11.109 'Total Alpha' was assessed as Pu-239 and 'Total Beta' was assessed as Cs-137. Discharges of specifically named alpha and beta emitting radionuclides would also contribute to the doses assessed using the plant limit discharges for 'Total Alpha' and 'Total Beta'. However, the corrections were found to have a relatively minor impact on the calculated doses (a maximum of 5 % overprediction in total doses) and were not included in order to preserve the transparency of the assessment methodology.

Aerial Results

The results of the aerial assessment are shown in Tables 1 and 2 and summarised in Table 3.

Marine Methodology

The marine dose assessment was conducted using the methodology detailed in SLSP2.11.109 and the dose per unit discharge factors (Marine Dose Release Ratios, MDRRs) detailed in SLF2.11.109.01. These factors are listed in Appendix A.

In order to avoid double counting of 'Total Beta' discharges the discharges of specific beta emitting radionuclides were subtracted from the 'Total Beta'. As the sum of the discharges of specifically named alpha emitting radionuclides were greater than the 'Total Alpha' discharge then the site discharge limit for 'Total Alpha' would take precedence and hence only the 'Total Alpha' discharges were assessed.

Marine Results

The results of the marine assessment are shown in Table 4.

Table 1: Aerial doses for cumulative plant limits.

Species	Dose (micro-Sv)		
	Adult	Child	Infant
Tritium	1.2	1.2	2.3
Carbon-14	1.8	2.0	3.5
Krypton-85	3.4	2.3	2.3
Strontium-90	0.03	0.05	0.07
Ruthenium-106	0.08	0.06	0.06
Antimony-125	0.20	0.09	0.09
Iodine-129	13	19	22
Iodine-131	0.29	0.64	2.8
Caesium-137	0.42	0.18	0.18
Plutonium-Alpha	0.35	0.19	0.11
Plutonium-241	0.01	0.007	0.003
Americium-241 & Curium-242	0.18	0.10	0.06
Alpha-emitting radionuclides associated with particulate matter	3.3	1.7	0.84
Beta-emitting radionuclides associated with particulate matter	16	6.8	6.7
Total	40	35	41

Table 2: Aerial doses for cumulative Phase 1 notification levels.

Species	Dose (micro-Sv)		
	Adult	**Child**	**Infant**
Tritium	0.20	0.20	0.36
Carbon-14	0.29	0.33	0.58
Krypton-85	1.5	1.1	1.1
Strontium-90	0.0002	0.0003	0.0005
Ruthenium-106	0.005	0.003	0.003
Antimony-125	0.16	0.07	0.07
Iodine-129	4.8	7.0	8.2
Iodine-131	0.01	0.03	0.12
Caesium-137	0.02	0.01	0.01
Plutonium-Alpha	0.10	0.05	0.03
Plutonium-241	0.00005	0.00003	0.00001
Americium-241 & Curium-242	0.05	0.03	0.02
Alpha-emitting radionuclides associated with particulate matter	0.70	0.36	0.17
Beta-emitting radionuclides associated with particulate matter	4.7	2.0	2.0
Total	13	11	13

Table 3: Aerial doses (in micro-Sv) summary.

	Cumulative Plant Annual Limit	**Phase 1 Notification Levels**
Adult Max Dose (micro-Sv)	40	13
Child Max Dose (micro-Sv)	34	11
Infant Max Dose (micro-Sv)	41	13

Table 4: Marine doses (in micro-Sv) summary (to adults).

	Current limit (GBq)		Phase 1 (GBq)		Phase 2 (GBq)			
					Upper Tier		Lower Tier	
	Discharge (GBq)	Dose (micro-Sv)	Discharge (GBq)	Dose (micro-Sv)	Discharge (GBq)	Dose (micro-Sv)	Discharge (GBq)	Dose (micro-Sv)
Tritium	1.8E+07	0.3	1.1E+07	0.2	7.2E+06	0.1	1.4E+06	0.0
Carbon-14	2.1E+04	18.5	1.8E+04	15.8	1.1E+04	9.3	8.4E+03	7.4
Cobalt-60	3.6E+03	15.6	3.6E+03	15.6	3.6E+03	15.6	3.6E+03	15.6
Strontium-90	4.5E+04	12.8	3.6E+04	10.3	3.2E+04	9.0	2.3E+04	6.4
Zirconium-95 + Niobium-95	2.8E+03	2.5						
Technetium-99	1.0E+04	4.3	9.0E+03	3.9	8.0E+03	3.4	6.0E+03	2.6
Ruthenium-106	5.1E+04	79.8	3.6E+04	55.9	1.5E+04	23.9	1.0E+04	16.0
Iodine-129	2.0E+03	1.8	1.6E+03	1.5	8.0E+02	0.7	4.0E+02	0.4
Caesium-134	1.6E+03	1.0				0.0		0.0
Caesium-137	3.4E+04	16.2	2.7E+04	13.0	2.4E+04	11.3	1.7E+04	8.1
Cerium-144	4.0E+03	2.3						
Neptunium-237	7.3E+02	-[a]						
Plutonium-Alpha	7.0E+02	-[a]	7.0E+02	-[a]	6.3E+02	-[a]	4.2E+02	-[a]
Plutonium-241	2.5E+04	-[a]	2.0E+04	-[a]	1.8E+04	-[a]	7.5E+03	-[a]
Americium-241	3.0E+02	-[a]	2.7E+02	-[a]	2.4E+02	-[a]	1.5E+02	-[a]
Curium-243+244	5.0E+01	-[a]						
Alpha-emitting radionuclides	9.0E+02	39.7	8.1E+02	35.7	7.2E+02	31.8	4.5E+02	19.8
Beta-emitting radionuclides	1.8E+05	18.1[b]	1.4E+05	19.8[b]	1.3E+05	24.7[b]	8.1E+04	13.2[b]
Total dose (micro-Sv)		212.8		171.4		129.8		89.4

Notes: a - not included as total alpha provide limiting site discharge; b - discharges of specific beta emitting radionuclides (Co-60, Sr-90, Zr-95,Nb-95, Ru-106, Cs-134, Cs-137, Ce-144) are subtracted for the dose assessment to avoid double counting.

Appendix A: Data used in the assessments

Table A1: Effective stack heights used in the aerial assessment

Stack	Effective stack height (m)	Notes on physical properties of the discharge
FGMSP & Decanning Facility stack	25	
Original, 1st and 2nd Extensions MSSS stack	30	
Fuel Handling Plant stack (FHP)	55	
Waste Vitrification Plant stack (WVP)	45	Applies "Magnox" characteristics for I-129.
Site Ion Exchange Plant stack (SIXEP)	50	
Thermal Oxide Reprocessing Plant and Sellafield MOX Plant stack (THORP)	125	
Solvent Treatment Plant and HALES vessel ventilation stack (STP)	105	
Analytical Services & Product Finishing and Storage Plant stack (AS and PF&S)	75	
Waste Encapsulation Plant stack (WEP)	60	
3rd Extension MSSS stack	45	
National Nuclear Laboratory stack (NNL)	50	
Decontamination Centre stack	30	
Separation Area Ventilation stack (SAV)	130	Applies "Magnox" characteristics for I-129.
Open Fuel Storage Ponds & Other approved outlets	40	Uses the "Ponds" parameters for "Alpha" and "Beta" accounting for the 5 micron AMAD particle size.

Table A2: Dose per unit discharge factors for adults used in the aerial assessment

Radionuclide	Effective stack height (m)										
	25	**30**	**40**	**45**	**50**	**55**	**60**	**75**	**105**	**125**	**130**
Tritium	2.26E-08	1.88E-08	1.37E-08	1.19E-08	1.04E-08	9.03E-09	7.87E-09	5.13E-09	2.11E-09	1.18E-09	1.03E-09
Carbon-14	1.83E-06	1.52E-06	1.11E-06	9.70E-07	8.49E-07	7.44E-07	6.52E-07	4.32E-07	1.82E-07	1.03E-07	9.00E-08
Krypton-85	1.64E-10	1.35E-10	9.70E-11	8.31E-11	7.12E-11	6.09E-11	5.19E-11	3.16E-11	1.15E-11	6.16E-12	5.34E-12
Strontium-90	5.25E-05	4.54E-05	3.58E-05	3.24E-05	2.95E-05	2.70E-05	2.48E-05	1.95E-05	1.35E-05	1.15E-05	1.11E-05
Ruthenium-106	8.16E-06	6.85E-06	5.11E-06	4.47E-06	3.93E-06	3.46E-06	3.05E-06	2.12E-06	1.17E-06	8.98E-07	8.55E-07
Antimony-125	1.34E-05	1.16E-05	9.08E-06	8.17E-06	7.39E-06	6.71E-06	6.12E-06	4.76E-06	3.33E-06	2.89E-06	2.82E-06
Iodine-129	1.93E-03	1.63E-03	1.22E-03	1.07E-03	9.44E-04	8.36E-04	7.40E-04	5.11E-04	2.48E-04	1.64E-04	1.49E-04
Iodine-129 (Magnox)	8.16E-04	6.88E-04	5.13E-04	4.51E-04	3.99E-04	3.53E-04	3.12E-04	2.15E-04	1.04E-04	6.89E-05	6.29E-05
Iodine-131	5.09E-05	4.28E-05	3.19E-05	2.81E-05	2.48E-05	2.19E-05	1.94E-05	1.33E-05	6.43E-06	4.24E-06	3.87E-06
Caesium-137	9.18E-05	7.95E-05	6.29E-05	5.69E-05	5.18E-05	4.73E-05	4.34E-05	3.43E-05	2.44E-05	2.13E-05	2.07E-05
Plutonium-alpha	9.16E-03	7.55E-03	5.42E-03	4.65E-03	3.98E-03	3.41E-03	2.91E-03	1.77E-03	6.51E-04	3.54E-04	3.08E-04
Plutonium-241	1.66E-04	1.37E-04	9.82E-05	8.42E-05	7.22E-05	6.18E-05	5.27E-05	3.23E-05	1.20E-05	6.59E-06	5.75E-06
Americium-241 & Curium-242	7.71E-03	6.35E-03	4.56E-03	3.91E-03	3.35E-03	2.87E-03	2.45E-03	1.49E-03	5.50E-04	3.00E-04	2.61E-04
Alpha-emitting radionuclides associated with particulate matter	9.16E-03	7.55E-03	5.42E-03	4.65E-03	3.98E-03	3.41E-03	2.91E-03	1.77E-03	6.51E-04	3.54E-04	3.08E-04
Alpha-emitting radionuclides associated with particulate matter (Ponds)	-	-	4.46E-03	-	-	-	-	-	-	-	-
Beta-emitting radionuclides associated with particulate matter	9.18E-05	7.95E-05	6.29E-05	5.69E-05	5.18E-05	4.73E-05	4.34E-05	3.43E-05	2.44E-05	2.13E-05	2.07E-05
Beta-emitting radionuclides associated with particulate matter (Ponds)	-	-	1.12E-03	-	-	-	-	-	-	-	-

Table A3: Dose per unit discharge factors for children used for the aerial assessment

Radionuclide	Effective stack height (m)										
	25	30	40	45	50	55	60	75	105	125	130
Tritium	2.25E-08	1.87E-08	1.36E-08	1.18E-08	1.03E-08	9.01E-09	7.86E-09	5.15E-09	2.13E-09	1.20E-09	1.05E-09
Carbon-14	2.06E-06	1.71E-06	1.25E-06	1.09E-06	9.57E-07	8.39E-07	7.35E-07	4.87E-07	2.05E-07	1.16E-07	1.01E-07
Krypton-85	1.15E-10	9.48E-11	6.80E-11	5.82E-11	4.99E-11	4.27E-11	3.64E-11	2.21E-11	8.04E-12	4.32E-12	3.74E-12
Strontium-90	8.00E-05	6.94E-05	5.51E-05	5.00E-05	4.57E-05	4.20E-05	3.86E-05	3.08E-05	2.16E-05	1.85E-05	1.80E-05
Ruthenium-106	5.76E-06	4.81E-06	3.55E-06	3.09E-06	2.70E-06	2.36E-06	2.06E-06	1.39E-06	7.04E-07	5.14E-07	4.83E-07
Antimony-125	5.90E-06	5.07E-06	3.95E-06	3.55E-06	3.20E-06	2.90E-06	2.64E-06	2.03E-06	1.39E-06	1.19E-06	1.16E-06
Iodine-129	2.89E-03	2.44E-03	1.82E-03	1.60E-03	1.41E-03	1.25E-03	1.11E-03	7.65E-04	3.71E-04	2.45E-04	2.24E-04
Iodine-129 (Magnox)	9.66E-04	8.14E-04	6.07E-04	5.34E-04	4.72E-04	4.18E-04	3.70E-04	2.55E-04	1.24E-04	8.16E-05	7.46E-05
Iodine-131	1.12E-04	9.45E-05	7.05E-05	6.20E-05	5.48E-05	4.85E-05	4.29E-05	2.95E-05	1.43E-05	9.42E-06	8.61E-06
Caesium-137	3.99E-05	3.46E-05	2.75E-05	2.49E-05	2.27E-05	2.07E-05	1.90E-05	1.51E-05	1.08E-05	9.36E-06	9.11E-06
Plutonium-alpha	5.01E-03	4.13E-03	2.96E-03	2.54E-03	2.18E-03	1.86E-03	1.59E-03	9.69E-04	3.55E-04	1.93E-04	1.68E-04
Plutonium-241	8.70E-05	7.17E-05	5.15E-05	4.41E-05	3.79E-05	3.24E-05	2.76E-05	1.69E-05	6.23E-06	3.41E-06	2.97E-06
Americium-241 & Curium-242	4.18E-03	3.45E-03	2.47E-03	2.12E-03	1.82E-03	1.56E-03	1.33E-03	8.09E-04	2.97E-04	1.62E-04	1.41E-04
Alpha-emitting radionuclides associated with particulate matter	5.01E-03	4.13E-03	2.96E-03	2.54E-03	2.18E-03	1.86E-03	1.59E-03	9.69E-04	3.55E-04	1.93E-04	1.68E-04
Alpha-emitting radionuclides associated with particulate matter (Ponds)	-	-	2.23E-03	-	-	-	-	-	-	-	-
Beta-emitting radionuclides associated with particulate matter	3.99E-05	3.46E-05	2.75E-05	2.49E-05	2.27E-05	2.07E-05	1.90E-05	1.51E-05	1.08E-05	9.36E-06	9.11E-06
Beta-emitting radionuclides associated with particulate matter (Ponds)	-	-	4.87E-04	-	-	-	-	-	-	-	-

Table A4: Dose per unit discharge factors for infants used for the aerial assessment

Radionuclide	Effective stack height (m)										
	25	30	40	45	50	55	60	75	105	125	130
Tritium	3.99E-08	3.32E-08	2.42E-08	2.11E-08	1.84E-08	1.61E-08	1.41E-08	9.31E-09	3.89E-09	2.20E-09	1.92E-09
Carbon-14	3.67E-06	3.05E-06	2.23E-06	1.94E-06	1.70E-06	1.49E-06	1.31E-06	8.66E-07	3.65E-07	2.07E-07	1.81E-07
Krypton-85	1.15E-10	9.48E-11	6.80E-11	5.82E-11	4.99E-11	4.27E-11	3.64E-11	2.21E-11	8.04E-12	4.32E-12	3.74E-12
Strontium-90	1.08E-04	9.34E-05	7.44E-05	6.77E-05	6.20E-05	5.70E-05	5.26E-05	4.21E-05	2.98E-05	2.56E-05	2.49E-05
Ruthenium-106	5.49E-06	4.59E-06	3.40E-06	2.96E-06	2.59E-06	2.27E-06	1.99E-06	1.35E-06	6.99E-07	5.17E-07	4.88E-07
Antimony-125	5.98E-06	5.14E-06	4.01E-06	3.60E-06	3.25E-06	2.94E-06	2.67E-06	2.06E-06	1.41E-06	1.21E-06	1.18E-06
Iodine-129	3.52E-03	2.96E-03	2.21E-03	1.94E-03	1.72E-03	1.52E-03	1.35E-03	9.30E-04	4.51E-04	2.98E-04	2.72E-04
Iodine-129 (Magnox)	5.39E-04	4.54E-04	3.39E-04	2.98E-04	2.63E-04	2.33E-04	2.06E-04	1.42E-04	6.90E-05	4.56E-05	4.16E-05
Iodine-131	4.86E-04	4.09E-04	3.06E-04	2.69E-04	2.37E-04	2.10E-04	1.86E-04	1.28E-04	6.22E-05	4.11E-05	3.75E-05
Caesium-137	3.93E-05	3.40E-05	2.70E-05	2.45E-05	2.23E-05	2.04E-05	1.87E-05	1.49E-05	1.06E-05	9.23E-06	8.99E-06
Plutonium-alpha	2.76E-03	2.27E-03	1.63E-03	1.40E-03	1.20E-03	1.03E-03	8.75E-04	5.34E-04	1.96E-04	1.07E-04	9.28E-05
Plutonium-241	3.51E-05	2.90E-05	2.08E-05	1.78E-05	1.53E-05	1.31E-05	1.12E-05	6.86E-06	2.56E-06	1.43E-06	1.25E-06
Americium-241 & Curium-242	2.48E-03	2.04E-03	1.47E-03	1.26E-03	1.08E-03	9.22E-04	7.86E-04	4.80E-04	1.77E-04	9.66E-05	8.40E-05
Alpha-emitting radionuclides associated with particulate matter	2.76E-03	2.27E-03	1.63E-03	1.40E-03	1.20E-03	1.03E-03	8.75E-04	5.34E-04	1.96E-04	1.07E-04	9.28E-05
Alpha-emitting radionuclides associated with particulate matter (Ponds)	-	-	1.02E-03	-	-	-	-	-	-	-	-
Beta-emitting radionuclides associated with particulate matter	3.93E-05	3.40E-05	2.70E-05	2.45E-05	2.23E-05	2.04E-05	1.87E-05	1.49E-05	1.06E-05	9.23E-06	8.99E-06
Beta-emitting radionuclides associated with particulate matter (Ponds)	-	-	4.81E-04	-	-	-	-	-	-	-	-

Table A5: Dose per unit discharge factors used for the marine assessment.

Nuclide	**Adult (micro-Sv/ GBq)**
Tritium H-3	1.4E-08
Carbon-14	8.8E-04
Cobalt-60	4.3E-03
Strontium-90	2.9E-04
Zirconium-95 & Niobium-95 in total	8.9E-04
Technetium-99	4.3E-04
Ruthenium-106	1.6E-03
Iodine-129	9.1E-04
Caesium-134	6.0E-04
Caesium-137	4.8E-04
Cerium-144	5.8E-04
Neptunium-237	5.5E-03
Plutonium-Alpha	4.4E-02
Plutonium-241	9.1E-04
Americium-241	4.3E-02
Curium-243+244	1.5E-02
Alpha-emitting radionuclides	4.4E-02
Beta-emitting radionuclides	4.8E-04