Dispersion of aqueous effluent from Hunterston power stations Annex – Additional Scenarios

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Executive Summary

Now that electricity generation at Hunterston B has ended, the reactors no longer need a constant, high flow of coolant. It will be expensive to operate and maintain the cooling water pumps, and they will eventually need to be turned off and removed as the station is decommissioned. Therefore, EDF are considering alternative discharge arrangements that demonstrate Best Practicable Means (BPM) for the discharge of aqueous effluents into the Firth of Clyde without the main cooling water flow.

This report is an annex to the main report *Dispersion of aqueous effluent from Hunterston power stations,* which discusses the impact of removal of main cooling water flow and changing the discharge location. Building on the executive summary of the main report, this annex responds to queries from the Scottish Environment Protection Agency (SEPA) following a consultation about the proposed alternative discharge arrangements.

A clarification was requested referring to "purging the lines" in the original report.

Reference to "purging the lines" in the original report is to ensure that the full contents of the tanks is discharged to sea. The model did not represent any dilution that may occur from purging the lines after discharge.

An additional scenario was requested for Hunterston A permit limit discharges to the bank compartment.

Given that no geometry details of the Hunterston A discharge line are available, discharge frequency, delay time and duration of the discharge were based on the equivalent Hunterston A + B scenario (Scenario 3 in the main report). A volumetric discharge rate for Hunterston A of 17 $m^3 h^{-1}$ was provided for the purpose of this assessment.

Table 1 summarises the activity concentrations in unfiltered seawater, filtered seawater and dry top sediment in East of Little Cumbrae Bank only. Activity concentrations in other compartments are two orders of magnitude lower. When Table 1 is compared with Tables 20 and 21 in the main report, the number of discharges, reduction in flow rate, geometry details of the Hunterston A discharge line, discharge frequency, delay time and duration of the discharge have negligible impact on the 'discharge cycle moving averages' and therefore no dose consequences.

Table 1 – Discharge cycle averaged activity concentrations in East of Little Cumbrae Bank compartment for Hunterston A permit limit discharges to the bank compartment over five years

Medium	H-3	Cs-134*	Cs-137	Pu-239**	Pu-241	Am-241
Unfiltered seawater ($Bq\ l^{-1}$)	9.23E-03	1.83E-02	4.89E-02	5.70E-04	5.69E-04	3.99E-08
Filtered seawater ($Bq\ l^{-1}$)	9.23E-03	1.76E-02	4.70E-02	2.85E-04	2.84E-04	1.90E-09
Dry top sediment ($Bq\ kg^{-1}$)	1.95E-02	8.24E+00	4.16E+01	6.44E+00	5.75E+00	2.31E-02

* Cs-134 is a surrogate for other beta/gamma emitters.

** Pu-239 is a surrogate for (other) alpha emitters.

An additional scenario was requested for Hunterston A and Hunterston B permit limit discharges to the bank compartment, centred around low tide. The results for this scenario were used to inform a dose assessment for an open water swimmer.

The scenario reflects the unlikely scenario where the annual aqueous discharge limits for Hunterston A and Hunterston B are simultaneously released in one discharge. Maximum activity concentrations calculated in GoldSim Scenario 7 were scaled to a swimmer dilution volume of 12,500 m^3, based on SEPA definitions (the volume occupied by the swimmer would cover an area of 50 m by 50 m and be about 5 m deep).

Table 2 presents the dose assessment results for an open water swimmer. About 50% of the dose is due to inadvertent ingestion of tritium, 45% is due to inadvertent ingestion of S-35, Cs-137, and unspecified radionuclides, and 5% is due to external irradiation. The dose is below the public dose limit of 1 mSv quoted in the Ionising Radiation Regulations 2017 and the effective site and source dose constraints for future discharges of 0.5 mSv/y and 0.3 mSv/y, respectively, as applied under the Environmental Authorisations (Scotland) Regulations 2018 (EASR). Hunterston A and Hunterston B contribute 17% and 83% respectively to the total dose.

Table 2 – Dose assessment for an open water swimmer in the East of Little Cumbrae compartment

Discharge assumptions	Internal Dose (µSv)	External Dose (µSv)	Total Dose (µSv)
The annual discharge limits for Hunterston A and Hunterston B simultaneously released in one discharge centred around low tide and dispersed as modelled in GoldSim. Maximum activity concentration scaled to the swimmer dilution volume of 12,500 m^3.	187	11	198

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1 Introduction

There are two power stations at Hunterston, Hunterston A and Hunterston B. Hunterston A is a former Magnox power station that is being decommissioned and is operated by Magnox Ltd [1]. Hunterston B is an advanced gas-cooled reactor (AGR) power station that stopped generating electricity in 2022 and will now be defueled and then decommissioned. It is operated by EDF Energy Nuclear Generation Ltd (EDF) [2].

Both power stations discharge aqueous effluent into the Firth of Clyde through the Hunterston B cooling water outlet, although the discharges from the two stations are governed by separate environmental permits [3,4]. Both permits allow discharges only when the cooling water flow is at least 7 $m^3 s^{-1}$; this is to ensure adequate dilution and dispersion of the radionuclides in the discharges.

Now that electricity generation at Hunterston B has ended, the reactors no longer need a constant, high flow of coolant. It will be expensive to operate and maintain the existing cooling water pumps, and they will eventually need to be decommissioned and removed as the station is decommissioned. Therefore, EDF are considering alternative discharge arrangements that will not need the cooling water flow [5]. Any new discharge arrangements could also be different to the current arrangements in other ways; for example, the discharge outlet may be at a different location, or the discharges may be done at different times.

Five scenarios were discussed in the main report [6]. Following consultation of the Scottish Environment Protection Agency (SEPA), two additional scenarios have been identified for assessment:

- Discharges during the flood tide with Hunterston A permit limit discharges and no Hunterston B discharges (as Scenario 3, but without Hunterston B and with a low flow rate).
- Discharges at low tide with Hunterston A and B permit limit discharges and associated open water swimmer dose calculations.

Also, a clarification of the meaning of “purging the lines” was requested.

The model used has been fully outlined in the main report. This annex focuses on the additional scenarios.

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2 Clarifications

A clarification was requested on the meaning of, “purging the lines” in the original report [6].

Reference to “purging the lines” in the original report is to ensure that the full contents of the tanks is discharged to sea. The model did not include any dilution that may occur from purging the lines after discharge.

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3 Scenarios

The following scenarios were modelled in the main report [6]:

1. Baseline scenario: current system with discharges to the bank[1] during ebb tides with a continuous flow of cooling water (unit discharges).

2. Alternative discharge to the bank: discharges to the bank during ebb tides with a low flow of clean water while discharging (and no flow of clean water when not discharging) (unit discharges).

3. Scenario 2 with site limits for A station and B station: as Scenario 2, (discharges from both power stations at the annual limits set in their permits [3,4]).

4. Scenario 2 with discharges during the flood tide: as Scenario 2, but with discharges during the flood tide, rather than the ebb tide (unit discharges).

5. Discharge to the channel: discharges further from shore (to deeper water)[1] during ebb tides with a low flow rate of water through the pipe while discharging (and no flow of water through the pipe when not discharging) (unit discharges).

To respond to SEPA's queries, two additional scenarios are modelled:

6. Discharges during the flood tide with Hunterston A permit limit discharges and no Hunterston B discharges (as Scenario 3, but without Hunterston B and with a low flow rate).

7. Discharges at low tide with Hunterston A and B permit limits released simultaneously in one discharge and associated open water swimmer dose calculations. Exposure scenarios were conceptualised to represent assumptions provided by SEPA (e.g. volume and exposure duration).

As explained in the main report [6], start and end times depend on when the discharges are switched on and off. They also include a delay for the flow through the discharge line. Table 3 summarises the start and end times for the additional scenarios. For Scenario 6, these have been applied as for Scenario 3 in the main report. For Scenario 7, a discharge of the same duration is centred around low tide.

In both scenarios, the following assumptions are made consistent with all scenarios described in the main report:

- Activity is discharged at a constant rate within the GoldSim discharge window, and no activity is discharged otherwise.

- Water flow through the pipe is at a constant rate while flowing and no water flows from the pipe otherwise.[2]

- The outfall is always submerged.

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[1] The banks are shallow water compartments overlying a single layer of sediment. They exchange only with their adjacent channel compartments. They represent sheltered areas of the shoreline.

[2] We assume that the water flow rate though the pipe is not affected by changes in head at the discharge point as the tide changes.

- Temperature differences between the effluent and sea will not significantly affect contaminant dispersion on the scales of interest.

Table 3 – Discharge start and end times used in the GoldSim model

Scenario	Description	Start of release into Firth (h after high tide)	End of release into Firth (h after high tide)
6. Scenario 2 with site limits for A station only	Discharge of unit activity to bank during ebb tide; water flow through pipe of 0.0047 $m^3 s^{-1*}$ while discharging and 0 $m^3 s^{-1}$ the rest of the time	1.4	4.6
7. Low tide discharge with site limits for A station and B station	Discharge at permitted limits to bank during ebb tide; one discharge per year, water flow through pipe of 0.0131 $m^3 s^{-1**}$ while discharging and 0 $m^3 s^{-1}$ the rest of the time	4.4	7.6

*0.0047 $m^3 s^{-1}$ is based on the rate at which Hunterston A tanks can be emptied, i.e. 17 $m^3 h^{-1}$.

**0.0131 $m^3 s^{-1}$ is based on the rate at which Hunterston A and Hunterston B tanks can be emptied, i.e. 47 $m^3 h^{-1}$.

The annual discharge limits specified in the current Permits for Hunterston A and Hunterston B are given in Table 4 [3,4]. Other Beta/Gamma emitters are modelled as Cs-134. Alpha emitters are modelled as Pu-239.

Table 4 – Aqueous discharge limits in the current Permits for Hunterston A and Hunterston B

	Aqueous discharge limits (GBq)						
Station	H-3	S-35	Co-60	Other Beta/Gamma emitters	Cs-137	Alpha	Pu-241
Hunterston A	30	N/A	N/A	60	160	2	2
Hunterston B	700000	6000	10	150	N/A	1	N/A

4 Results

In this section, we give the relevant results for each additional scenario.

4.1 Scenario 6: alternative discharge to the bank, with Hunterston A permit limit discharges

Scenario 6 considers discharges to the bank during an ebb tide with a clean water flow of 0.0047 m^3 s^{-1} (with the water flow from Hunterston A only operating while effluent is discharged). This represents alternative discharge arrangements that are equivalent to the existing arrangements, but without the continuous cooling water flow. Discharges are every three tides, and the discharges from the permit of Hunterston A were modelled.

For this scenario, all parameters apart from the source term are identical to those used for Scenario 3 (alternative discharge arrangements to the bank, permit limits) (Subsection 6.3 of the main report).

Average activity concentrations for the final discharge cycle of the 5-year simulation period in unfiltered and filtered seawater are given in Table 5 and Table 6. The activity concentrations of Am-241 are several orders of magnitude lower than the activity concentrations of other radionuclides. The maximum activity concentrations are found in the East of Little Cumbrae Bank compartment (highlighted in blue), where the discharges occur. Apart from Am-241, the activity concentrations in the other compartments are about two orders of magnitude lower.

Table 5 – Discharge cycle averaged activity concentrations in unfiltered seawater for Hunterston A permit limit discharges to the bank compartment over five years

Discharge cycle averaged unfiltered seawater activity concentrations per radionuclide (Bq l^{-1})						
Compartment	H-3	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
East of Little Cumbrae	1.60E-04	3.09E-04	8.40E-04	8.80E-06	8.75E-06	1.33E-09
Hunterston to Millport	1.05E-04	1.98E-04	5.45E-04	5.31E-06	5.27E-06	1.11E-09
North of Largs	5.90E-05	1.07E-04	3.02E-04	2.44E-06	2.41E-06	9.26E-10
Northeast of Great Cumbrae	7.20E-05	1.33E-04	3.71E-04	3.24E-06	3.20E-06	9.93E-10
Outer Firth	4.77E-05	8.56E-05	2.44E-04	1.90E-06	1.87E-06	7.92E-10
Southeast of Great Cumbrae	8.74E-05	1.63E-04	4.53E-04	4.20E-06	4.16E-06	1.06E-09
West of Cumbrae	5.93E-05	1.08E-04	3.05E-04	2.53E-06	2.50E-06	8.92E-10
Northeast of Great Cumbrae Bank	7.16E-05	1.31E-04	3.67E-04	2.99E-06	2.95E-06	1.04E-09
Southeast of Great Cumbrae Bank 1	8.52E-05	1.58E-04	4.39E-04	3.79E-06	3.75E-06	1.14E-09
Southeast of Great Cumbrae Bank 2	8.52E-05	1.58E-04	4.39E-04	3.79E-06	3.75E-06	1.14E-09
Hunterston to Millport Bank 1	1.07E-04	2.01E-04	5.53E-04	5.08E-06	5.03E-06	1.28E-09
Hunterston to Millport Bank 2	1.07E-04	2.01E-04	5.53E-04	5.08E-06	5.03E-06	1.28E-09

Discharge cycle averaged unfiltered seawater activity concentrations per radionuclide (Bq l^{-1})						
Compartment	H-3	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
East of Little Cumbrae Bank	9.23E-03	1.83E-02	4.89E-02	5.70E-04	5.69E-04	3.99E-08

Table 6 – Discharge cycle averaged activity concentrations in filtered seawater for Hunterston A permit limit discharges to the bank compartment over five years

Discharge cycle averaged filtered seawater activity concentrations per radionuclide (Bq l^{-1})						
Compartment	H-3	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
East of Little Cumbrae	1.60E-04	2.97E-04	8.08E-04	4.40E-06	4.37E-06	6.33E-11
Hunterston to Millport	1.05E-04	1.90E-04	5.24E-04	2.66E-06	2.64E-06	5.28E-11
North of Largs	5.90E-05	1.03E-04	2.91E-04	1.22E-06	1.20E-06	4.41E-11
Northeast of Great Cumbrae	7.20E-05	1.28E-04	3.57E-04	1.62E-06	1.60E-06	4.73E-11
Outer Firth	4.77E-05	8.23E-05	2.34E-04	9.50E-07	9.33E-07	3.77E-11
Southeast of Great Cumbrae	8.74E-05	1.57E-04	4.36E-04	2.10E-06	2.08E-06	5.03E-11
West of Cumbrae	5.93E-05	1.04E-04	2.93E-04	1.27E-06	1.25E-06	4.25E-11
Northeast of Great Cumbrae Bank	7.16E-05	1.26E-04	3.53E-04	1.50E-06	1.48E-06	4.94E-11
Southeast of Great Cumbrae Bank 1	8.52E-05	1.52E-04	4.22E-04	1.90E-06	1.87E-06	5.41E-11
Southeast of Great Cumbrae Bank 2	8.52E-05	1.52E-04	4.22E-04	1.90E-06	1.87E-06	5.41E-11
Hunterston to Millport Bank 1	1.07E-04	1.93E-04	5.32E-04	2.54E-06	2.52E-06	6.10E-11
Hunterston to Millport Bank 2	1.07E-04	1.93E-04	5.32E-04	2.54E-06	2.52E-06	6.10E-11
East of Little Cumbrae Bank	9.23E-03	1.76E-02	4.70E-02	2.85E-04	2.84E-04	1.90E-09

Average activity concentrations in the final discharge cycle of the simulation in dry top sediment are given in Table 7. While Am-241 is not significant in seawater, Am-241 activity concentrations in dry top sediment are potentially significant. The maximum activity concentrations are found in the East of Little Cumbrae Bank compartment (highlighted in blue), where the discharges occur. The activity concentrations in the other compartments are about two orders of magnitude lower.

Table 7 – Discharge cycle averaged activity concentrations in dry top sediment for Hunterston A permit limit discharges to the bank compartment over five years

Discharge cycle averaged dry top sediment activity concentrations per radionuclide (Bq kg^{-1})						
Compartment	H-3	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
East of Little Cumbrae	2.38E-04	1.38E-01	7.02E-01	9.76E-02	8.70E-02	3.55E-04
Hunterston to Millport	1.55E-04	8.84E-02	4.53E-01	5.85E-02	5.21E-02	2.15E-04
North of Largs	8.73E-05	4.74E-02	2.47E-01	2.60E-02	2.31E-02	9.92E-05

Discharge cycle averaged dry top sediment activity concentrations per radionuclide (Bq kg^{-1})						
Compartment	H-3	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
Northeast of Great Cumbrae	1.07E-04	5.89E-02	3.05E-01	3.49E-02	3.11E-02	1.31E-04
Outer Firth	7.05E-05	3.78E-02	1.98E-01	2.01E-02	1.78E-02	7.72E-05
Southeast of Great Cumbrae	1.29E-04	7.27E-02	3.74E-01	4.58E-02	4.08E-02	1.70E-04
West of Cumbrae	8.78E-05	4.79E-02	2.49E-01	2.71E-02	2.41E-02	1.03E-04
Northeast of Great Cumbrae Bank	1.51E-04	5.84E-02	3.03E-01	3.22E-02	2.86E-02	1.21E-04
Southeast of Great Cumbrae Bank 1	1.80E-04	7.05E-02	3.64E-01	4.11E-02	3.66E-02	1.54E-04
Southeast of Great Cumbrae Bank 2	1.80E-04	7.05E-02	3.64E-01	4.11E-02	3.66E-02	1.54E-04
Hunterston to Millport Bank 1	2.26E-04	8.98E-02	4.61E-01	5.56E-02	4.95E-02	2.06E-04
Hunterston to Millport Bank 2	2.26E-04	8.98E-02	4.61E-01	5.56E-02	4.95E-02	2.06E-04
East of Little Cumbrae Bank	1.95E-02	8.24E+00	4.16E+01	6.44E+00	5.75E+00	2.31E-02

4.2 Scenario 7: alternative discharge arrangements to the bank, with Hunterston A and B permit limit discharges centred around low tide

Scenario 7 considers discharges to the bank during an ebb tide with a clean water flow of 0.0131 m^3 s^{-1} (with the water flow from Hunterston A and B only operating while effluent is discharged). This represents alternative discharge arrangements without the continuous cooling water flow. Only one discharge occurs are in a year, and permit limits of Hunterston A and B were modelled. The discharge window is centred around low tide (see Table 3 on page 14). The duration of the discharge is as in Scenario 3.

This scenario is used as a source for a dose assessment for an open water swimmer. The modelling results were upscaled to account for double permit limit discharges and for a reduced dilution volume.

$$Swimmer\ Scaling\ Factor = \frac{Model\ Dilution\ Volume}{Swimmer\ Dilution\ Volume}$$

Only the activity concentrations in unfiltered water are considered, external irradiation from bed sediment is ignored as the swimmer is shielded by the water column.

4.2.1 Activity concentrations in unfiltered seawater

Maximum activity concentrations in unfiltered seawater are given in Table 8. The activity concentrations of Am-241 are several orders of magnitude lower than the activity concentrations of other radionuclides. The maximum activity concentrations are found in the East of Little Cumbrae Bank compartment (highlighted in blue), where the discharges occur.

Apart from Am-241, the activity concentrations in the other compartments are about two orders of magnitude lower.

Table 8 – Maximum activity concentrations in unfiltered seawater for double Hunterston A and B permit limit discharges to the bank compartment centred around low tide over five years

	Maximum unfiltered seawater activity concentrations per radionuclide (Bq l^{-1})							
Compartment	H-3	S-35	Co-60	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
East of Little Cumbrae	5.50E+02	4.69E+00	7.51E-03	1.64E-01	1.25E-01	2.29E-03	1.52E-03	7.76E-09
Hunterston to Millport	2.59E+02	2.21E+00	3.52E-03	7.75E-02	5.91E-02	1.08E-03	7.17E-04	4.54E-09
North of Largs	1.10E+01	9.02E-02	1.29E-04	3.25E-03	2.49E-03	4.14E-05	2.76E-05	1.62E-09
Northeast of Great Cumbrae	5.48E+01	4.63E-01	7.05E-04	1.63E-02	1.25E-02	2.19E-04	1.46E-04	1.98E-09
Outer Firth	4.95E+00	4.01E-02	5.76E-05	1.46E-03	1.12E-03	1.85E-05	1.23E-05	1.36E-09
Southeast of Great Cumbrae	1.25E+02	1.06E+00	1.64E-03	3.73E-02	2.85E-02	5.07E-04	3.38E-04	2.99E-09
West of Cumbrae	2.49E+01	2.11E-01	3.29E-04	7.44E-03	5.68E-03	1.01E-04	6.76E-05	1.48E-09
Northeast of Great Cumbrae Bank	3.16E+01	2.64E-01	3.64E-04	9.33E-03	7.14E-03	1.17E-04	7.78E-05	1.82E-09
Southeast of Great Cumbrae Bank 1	6.12E+01	5.13E-01	7.23E-04	1.81E-02	1.38E-02	2.30E-04	1.53E-04	2.67E-09
Southeast of Great Cumbrae Bank 2	6.12E+01	5.13E-01	7.23E-04	1.81E-02	1.38E-02	2.30E-04	1.53E-04	2.67E-09
Hunterston to Millport Bank 1	1.17E+02	9.86E-01	1.43E-03	3.47E-02	2.65E-02	4.51E-04	3.01E-04	3.96E-09
Hunterston to Millport Bank 2	1.17E+02	9.85E-01	1.43E-03	3.47E-02	2.64E-02	4.51E-04	3.01E-04	3.96E-09
East of Little Cumbrae Bank	6.85E+04	5.87E+02	9.70E-01	2.06E+01	1.57E+01	2.92E-01	1.95E-01	4.28E-07

Table 9 shows the maximum activity concentrations in unfiltered seawater scaled to the swimmer dilution volume. The Model Dilution Volume for East of Cumbrae compartment is 9.45 10^6 m^3 and the Swimmer Dilution Volume is 12,500 m^3 (based on the SEPA definition of 50 m wide × 50 m long × 5 m deep). We applied a Swimmer Scaling Factor of 756 to the modelling results. Maximum values refer directly to the values presented in Table 8.

Table 9 – Activity concentrations in unfiltered seawater for double Hunterston A and B permit limit discharges to the bank compartment centred around low tide over five years, scaled to the swimmer dilution volume

	Unfiltered seawater activity concentrations per radionuclide in East of Little Cumbrae compartment scaled to the swimmer dilution volume (Bq l^{-1})							
Compartment	H-3	S-35	Co-60	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
Maximum values	5.18E+07	4.44E+05	7.34E+02	1.55E+04	1.18E+04	2.21E+02	1.47E+02	3.24E-04

Figure 1 shows the variation of the activity concentration of H-3 in unfiltered seawater in the dilution volume occupied by the swimmer compartment over the first 10 days. The peak value is reached shortly after the discharge.

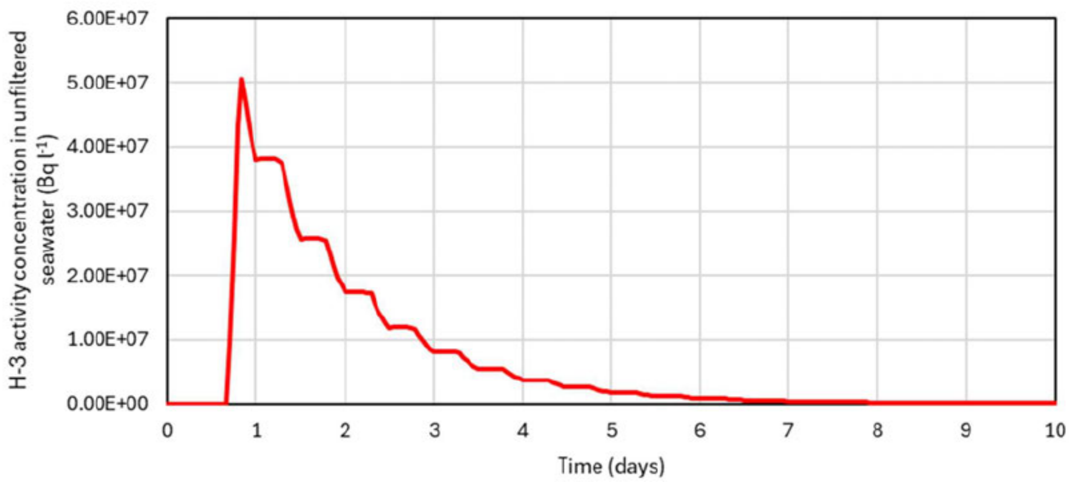

Figure 1 – Activity concentration of H-3 in unfiltered seawater in the swimmer dilution volume for alternative discharge arrangements to the bank (Scenario 7)

4.2.2 Dose assessment for an open water swimmer

The scenario reflects the unlikely scenario where the annual aqueous discharge limits for Hunterston A and Hunterston B are released simultaneously during one discharge. Maximum activity concentrations calculated in GoldSim Scenario 7 were scaled to a swimmer dilution volume of 12,500 m^3, based on SEPA definitions (the volume occupied by the swimmer would cover an area of 50 m by 50 m and be about 5 m deep).

We have calculated the internal dose due to inadvertent ingestion of seawater and the external dose due to immersion in unfiltered seawater.

The dose due to inadvertent ingestion of seawater was calculated as:

$$Ingestion\ dose = Activity\ concentration \times Ingestion\ rate \times Time\ spent\ in\ water \times Dose\ coefficient\ for\ ingestion$$

Where

- Ingestion rate is taken from the US Environment Protection Agency (EPA) Exposure Factors Handbook Chapter 3.7 [7]. The maximum value for adults was selected (105 ml h^{-1}). Detailed results of the water ingestion study are presented in Table 10.

- Time spent in water for the purposes of this assessment was agreed between EDF and SEPA (1 h). A single swim was assumed. In the first scenario, the calculated dose could be multiplied by the number of swims[3] to calculate the total dose. In the second scenario, there would only be one swim in peak activity concentration.

- The dose coefficients (see Table 11) were taken from International Commission on Radiological Protection (ICRP) publication 119 [8].

Table 10 – Water ingested while swimming (reproduced from US EPA Exposure Factors Handbook)

Age (years)	Number of study participants	Mean	Percentiles 25th	50th	75th	90th	95th
6 to <11	66	38	15	25	53	77	96
11 to <16	121	44	11	29	48	103	152
16 to <21	84	33	9	19	41	74	105
6 to <21	271	39	11	25	47	87	137
21+	276	28	5	13	29	50	92

Source: Table 3-93 of reference [7]

The external dose due to immersion in unfiltered seawater was calculated as:

$$Immersion\ dose = Activity\ concentration \times Time\ spent\ in\ water \times Dose\ coefficient\ for\ immersion\ in\ water$$

Where

- Time spent in water was agreed between EDF and SEPA (1 h) as above.

- The dose coefficients (see Table 11) were taken from US EPA Federal Guidance Report 15 [9].

Table 11 captures the relevant dose coefficients for ingestion and immersion in water [8,9].

[3] When discharged activities of this level are noticed, action would be taken immediately to reduce the discharged activities. The number of swims would therefore depend on the monitoring / reporting period.

Table 11 – Dose coefficients for ingestion and immersion in water

	Dose coefficients							
Parameter	H-3	S-35	Co-60	Cs-134	Cs-137	Pu-239	Pu-241	Am-241
Dose coefficients for ingestion (Sv Bq^{-1}) (ICRP 119)	1.80E-11	7.70E-10	3.40E-09	1.90E-08	1.30E-08	2.50E-07	4.80E-09	2.00E-07
Dose coefficients for immersion in water (Sv s^{-1} per Bq m^{-3}) (FGR 15)	6.15E-27	3.32E-21	2.53E-16	1.46E-16	5.55E-17	7.26E-21	1.13E-22	1.20E-18

Table 12 presents the dose assessment results for an open water swimmer. About 50% of the dose is due to inadvertent ingestion of tritium, 45% is due to inadvertent ingestion of S-35, Cs-137 and unspecified radionuclides, and 5% is due external irradiation. The doses presented here are for a total swim duration of one hour. The discharge regime assumes one single peak discharge, and that the one-hour swim takes place during the period of peak activity concentration. The dose is below the annual public dose limit of 1 mSv quoted in the Ionising Radiation Regulations 2017 (IRR 2017) [10] and below the effective site and source dose constraints for future discharges of 0.5 mSv/y and 0.3 mSv/y, respectively, under Environmental Authorisations (Scotland) Regulations 2018 (EASR) (see Table 1 in [11]). Hunterston A and Hunterston B contribute 17% and 83% respectively to the total dose.

Table 12 – Dose assessments for an open water swimmer in the East of Little Cumbrae compartment (1 swim)

Discharge assumptions	Internal Dose (μSv)	External Dose (μSv)	Total Dose (μSv)
Annual discharge limits for Hunterston A and Hunterston B released during one discharge centred around low tide and dispersed as modelled in GoldSim. Maximum activity concentration scaled to the swimmer dilution volume of 12,500 m^3.	187	11	198

5 Conclusions

We have used the compartment model of the section of the Firth of Clyde near Hunterston in GoldSim to model the dilution and dispersion of aqueous discharges from Hunterston A and Hunterston B power stations for two additional scenarios. We have also performed dose calculations for an open water simmer by using simple dose models for ingestion and immersion in water. The scenarios modelled in this annex aim to respond to queries from SEPA following a consultation about the proposed alternative discharge arrangements.

Discharged activities are based on the current permit for Hunterston A power station, where other beta/gamma nuclides are modelled as Cs-134 and (other) alpha radionuclides are modelled as Pu-239. Am-241 is included as a significant daughter of Pu-241 in the results. Other daughters of Pu-239 and Pu-241 have been ignored because of their insignificant impact.

A clarification was requested referring to “purging the lines” in the original report.

Reference to “purging the lines” in the original report is to ensure that the full contents of the tanks is discharged to sea, not to model any dilution that may occur from purging the lines after discharge.

An additional scenario was requested for Hunterston A permit limit discharges to the bank compartment.

Given that no geometry details of the Hunterston A discharge line are available, discharge frequency, delay time and duration of the discharge were based on the equivalent Hunterston A + B scenario (Scenario 3 in the main report). A volumetric discharge rate for Hunterston A of 17 $m^3 h^{-1}$ was provided for the purpose of this assessment.

Table 13 summarises the activity concentrations in unfiltered seawater, filtered seawater and dry top sediment in East of Little Cumbrae Bank only. Activity concentrations in other compartments are two orders of magnitude lower. When Table 13 is compared with Tables 20 and 21 in the main report, the number of discharges, reduction in flow rate, geometry details of the Hunterston A discharge line, discharge frequency, delay time and duration of the discharge have negligible impact on the ‘discharge cycle moving averages’ and therefore no dose consequences.

Table 13 – Discharge cycle averaged activity concentrations in East of Little Cumbrae Bank compartment for Hunterston A permit limit discharges to the bank compartment over five years

Medium	H-3	Cs-134*	Cs-137	Pu-239**	Pu-241	Am-241
Unfiltered seawater ($Bq\ l^{-1}$)	9.23E-03	1.83E-02	4.89E-02	5.70E-04	5.69E-04	3.99E-08
Filtered seawater ($Bq\ l^{-1}$)	9.23E-03	1.76E-02	4.70E-02	2.85E-04	2.84E-04	1.90E-09
Dry top sediment ($Bq\ kg^{-1}$)	1.95E-02	8.24E+00	4.16E+01	6.44E+00	5.75E+00	2.31E-02

* Cs-134 is a surrogate for other beta/gamma emitters.

** Pu-239 is a surrogate for (other) alpha emitters.

An additional scenario was requested for Hunterston A and Hunterston B permit limit discharges to the bank compartment, centred around low tide. The results for this scenario were used to inform a dose assessment for an open water swimmer.

Table 14 presents the dose assessment results for an open water swimmer. About 50% of the dose is due to inadvertent ingestion of tritium, 45% is due to inadvertent ingestion of S-35, Cs-137 and unspecified radionuclides, and 5% is due external irradiation. The dose is below the public dose limit of 1 mSv quoted in IRR 2017 [10] and the effective site and source dose constraints for future discharges of 0.5 mSv/y and 0.3 mSv/y, respectively, as applied under (EASR) [11]. Hunterston A and Hunterston B contribute 17% and 83% respectively to the total dose.

Table 14 – Dose assessments for an open water swimmer in the East of Little Cumbrae compartment

Discharge assumptions	Internal Dose (µSv)	External Dose (µSv)	Total Dose (µSv)
The annual discharge limits for Hunterston A and Hunterston B released simultaneously in one discharge centred around low tide and dispersed as modelled in GoldSim. Maximum activity concentration scaled to the swimmer dilution volume of 12,500 m^3.	187	11	198

6 References

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