Assessment of the Impact on the Irish Public and Marine Environment Arising from Liquid Discharges from Potential New Build Power Plants in the United Kingdom

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Keywords: New Build, Marine Modelling, Dose Assessment, Irish Sea

Abstract

The impact of any potential increase in radioactive effluent discharges into the Irish marine environment arising from new build Nuclear Power Plants (NPPs) in the UK is of considerable concern to the Irish public. In order to address these concerns, an assessment of the possible impact of nuclear new build discharges on the Irish population and marine environment was made by the Radiological Protection Institute of Ireland (RPII).

The radioactivity concentrations in the Irish Sea and the committed effective dose to the Irish population arising from routine liquid discharges from the proposed new build NPP sites were estimated using the PC-CREAM-08 software, which is based on the European Commission's Consequences of Releases to the Environment: Assessment Methodology (CREAM).

The PC-CREAM-08 software is unable to model discharges over periods of less than one year but a non-routine discharge is usually assumed to occur over a much shorter time scale. For this reason, radioactivity concentrations in the Irish Sea arising from a non-routine discharge were calculated using a three dimensional Princeton Ocean Model which can simulate the releases of a conservative radionuclide tracer from each of the proposed NPP sites. This model has been validated and shown to be capable of simulating the transport of a conservative radionuclide tracer in the Irish Sea. Radioactivity levels in seawater on the east coast of Ireland were computed by the model and analysis of the radioactivity present and transit times were conducted for selected NPP sites. The effective doses arising from the non-routine discharges were determined using appropriate dose calculations based on the CREAM.

1. Introduction

The UK's National Policy Statement for Nuclear Power Generation by the UK's Department of Energy and Climate Change lists eight sites that have been identified, through a strategic site assessment, as being suitable for new nuclear development before the end of 2025 [1]. These eight sites are Hinkley Point, Oldbury, Sellafield, Sizewell, Wylfa, Bradwell, Hartlepool and Heysham.

In response to this the RPII undertook a project to investige the likely radiological impact on the Irish environment and the Irish population from potential new build in the UK

The work described here considers the impact that routine and non-routine liquid discharges into the Irish Sea will have on the Irish marine environment and the Irish population. Therefore, only the five sites located on the west coast of the UK are assessed, namely, Hinkley Point, Oldbury, Wylfa, Heysham and Sellafield (Figure 1).

2. Methodology

2.1 Generic reactor concept – Source terms

The potential liquid discharges into the marine environment from a proposed new nuclear build site is dependent upon the type and number of reactors at each site. Since this information has not yet been finalised the assessments carried out in this work are based on a generic reactor design which is itself based on the two reactor designs that are currently deemed acceptable for building in the UK by the Office for Nuclear Regulation [2]. These are the UK EPR by Areva and Électricité de France (EDF) [3] and the Westinghouse AP-1000 [4].

The radionuclides used for routine liquid discharges are based on a comprehensive review of the EPR and AP-1000 Generic Design Assessment (GDA) documentation [3,4]. When both Areva/EDF and Westinghouse have provided discharge values for a given radionuclide, the higher of the two values has been selected to provide a conservative estimate for the generic reactor design. Routine discharges were assumed to be released continuously and uniformly throughout the year. A total of 59 radionuclides that could be discharged into the marine environment during routine operations of the generic reactor were identified. Table 1 outlines the ten most significant radionuclides discharged in terms of activity discharged ($GBq.yr^{-1}$).

For non-routine discharges two source terms were considered. The first source term is based on the assumption that an entire year's routine liquid discharges are released over a short time period, i.e. one week. The second source term assumes that the total volume of the reactor coolant is discharged into the marine environment over the same short time period. Table 1outlines the ten most significant radionuclides discharged in terms of activity discharged for both non-routine scenarios (GBq).

Annual Routine Liquid Discharges and Non-routine Discharges - Scenario 1		Non-routine Discharge - Scenario 2	
Radionuclide	**Discharge (GBq)**	**Radionuclide**	**Discharge (GBq)**
H-3	75,000	I-133	63,000
C-14	95	I-135	42,000
Co-60	3	I-131	33,000
Co-58	2.07	I-132	24,600
Ni-63	1.14	H-3	11,100
Fe-55	1.06	Cs-136	11,100
Cs-137	0.945	Cs-134	10,200
Sb-125	0.815	I-134	9,000
Ag-110m	0.57	Co-58	3,000
Cs-134	0.56	Cr-51	2,850

Table 1. Ten most significant discharges in terms of activity for annual routine liquid discharges and non-routine discharges (GBq).

2.2 Routine discharges

The potential dose to the Irish population from routine liquid discharges from the five identified sites located on the west coast of the UK were determined using the DORIS and MARINE ASSESSOR modules of the PC-CREAM-08 software. DORIS is a compartmental model for predicting dispersion of radionuclides in north European coastal waters and the Mediterranean Sea and the MARINE ASSESSOR module calculates effective doses due to continuous and constant discharges of radionuclides into the marine environment. This software is based on the European Commission's Consequences of Releases to the Environment: Assessment Methodology (CREAM) for evaluating the radiological consequences of discharges of radioactive effluents during normal operations [5] and was developed by the Health Protection Agency in the UK [6].

The mean radioactivity concentrations over 50 years in the seawater, biota and sediments were determined for the Irish Sea West and Irish Sea South compartments (Figure 1). This was carried out using the DORIS module in conjunction with the 59 radionuclides identified as being routinely discharged during the operation of a generic reactor. The releases were modelled at each of the five potential new build sites located on the west coast of the UK. For each of the DORIS model runs the pre-defined sites for these locations were used. The element dependent parameters i.e. concentration factors (CF) for fish, crustaceans and molluscs and coastal sediment concentration factors (k_d) are the default PC-CREAM-08 values for the Irish Sea. For all other input parameters the PC-CREAM-08 default values for northern European waters have been used.

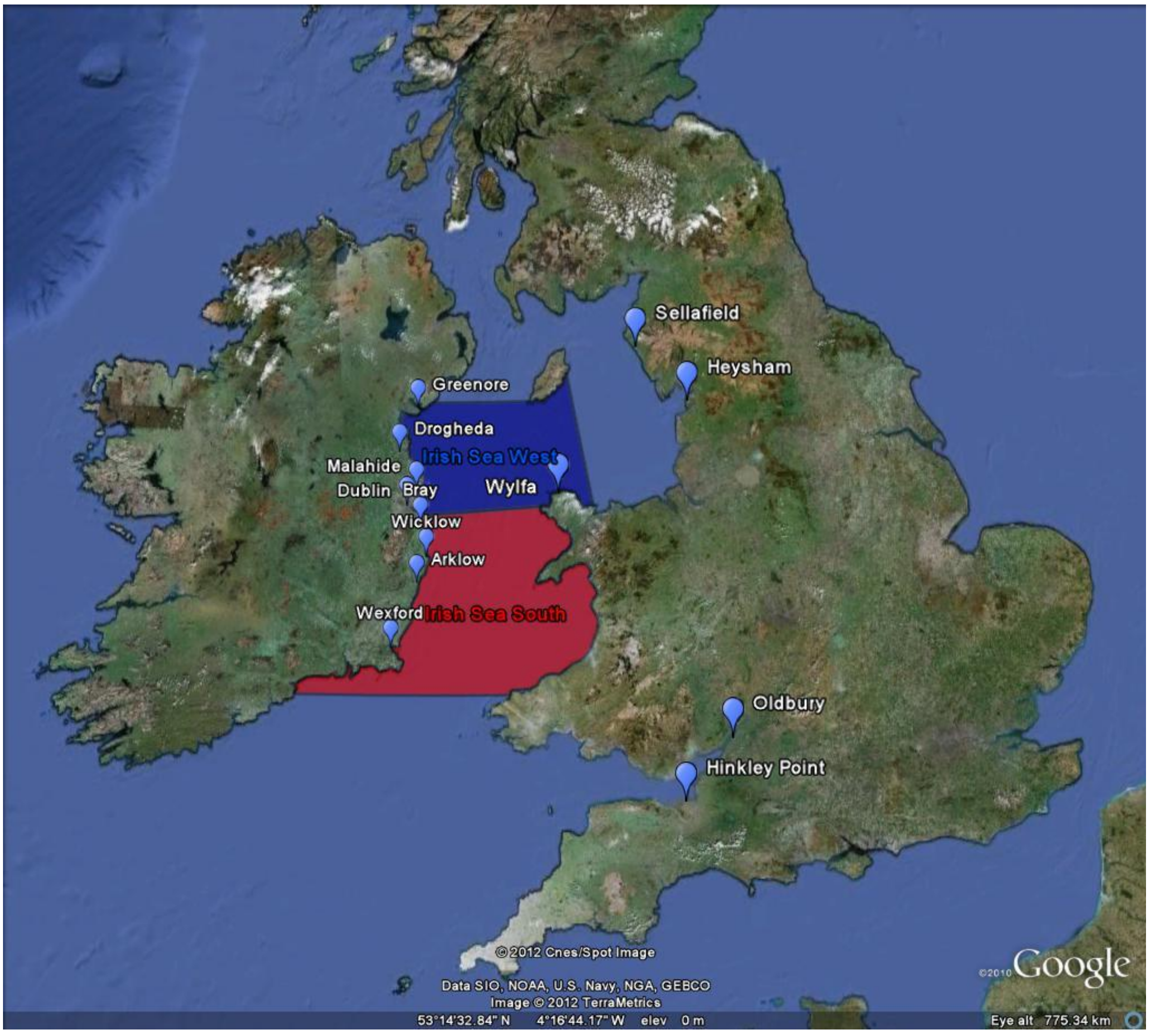

Figure 1. Irish Sea West and Irish Sea South compartments, potential new build sites on the west coast of the UK and receptor points along the east coast of Ireland (for non-routine discharges). [7]

The concentrations calculated using DORIS were used as input to the MARINE ASSESSOR module of PC-CREAM-08 to determine the dose to the Irish population arising from the routine liquid discharges after 50 years. The individual effective adult dose ($Sv.yr^{-1}$) in the 50^{th} year was calculated. The dose pathways taken into consideration were internal irradiation from ingestion of seafood and external irradiation arising from activity on beach sediments and fishing equipment handled by fishermen and coastal workers. The doses for three adult groups were determined for each of the proposed sites. These groups are two high rate seafood consumer groups (Group A and Group B) identified during a habits survey conducted on behalf of the RPII [8] and one typical seafood consumer based on an Irish National Adult Nutrition Survey [9]. Group A are commercial fishermen based along the north-east Irish coast who consume large amounts of fish and crustaceans. Group B are commercial oyster and mussel farmers based along the north-east coast who consume large amounts of molluscs. The habits data for these three groups are outlined in Table 2.

Exposure Pathway		Group A	Group B	Typical Consumer
Seafood Consumption ($kg.yr^{-1}$)	Fish	26	20	8.4
	Crustaceans	10	-	0.5
	Molluscs	-	5	0.1
Time on Beach ($h.yr^{-1}$)		-	410	410
Handling Fishing Gear ($h.yr^{-1}$)		2500	730	-

Table 2. Habits data for the three seafood consumer groups.

2.3 Non-routine discharges

The radioactivity in the Irish marine environment arising from non-routine discharges was determined in a two stage process. Firstly, the radioactivity concentrations in seawater were modelled. Then, using the results from this modelling the radioactivity concentrations in biota and sediment were determined using the appropriate CF and k_d values.

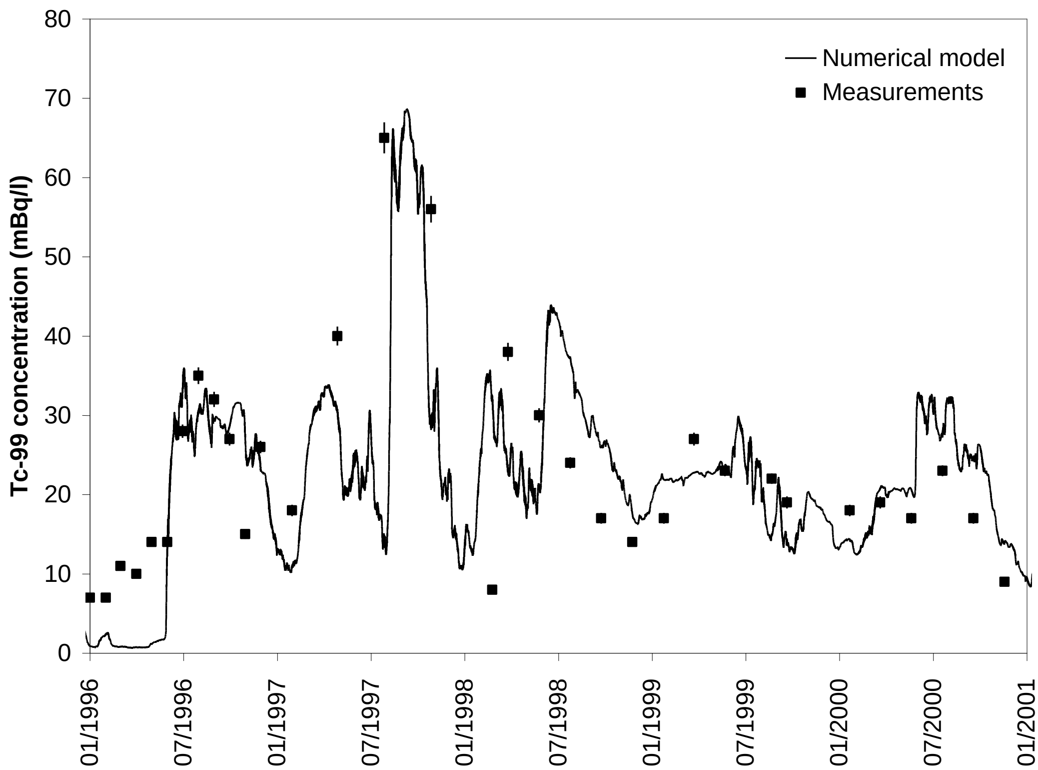

Figure 2. Comparison of modelled and measured Tc-99 activity concentrations in seawater at Balbriggan (east coast of Ireland).

The hydrodynamic model for the Irish Sea used in this project was developed on behalf of the RPII by the Marine Modelling Group at the National University of Ireland, Galway. This model is a three-dimensional Princeton Ocean Model used to simulate hydrodynamic conditions and the transport of a conservative radioactive tracer from the proposed new-build locations. The model simulates effects of tides, winds and density gradients on water level and three-dimensional currents, incorporating both baroclinic and barotropic driven flows. The development of the hydrodynamic module was followed by the application of a material transport model, so that predictions of three-dimensional radionuclide tracer fields could be made. [10, 11, 12]. The evaluation of the transport model accuracy was based on Tc-99 discharged from the Sellafield plant. Modelled distributions were compared to actual Tc-99 measurements in seawater made by the RPII. The spatial distributions of Tc-99 were assessed from seawater samples taken offshore while temporal variations were determined from the coastal sites. Figure 2 compares modelled Tc-99 concentrations on the east coast of Ireland (Balbriggan site) and historic measurements from the RPII's marine monitoring programme. The modelled and measured activity distributions are in good agreement with each other.

2.3.1 Modelling non-routine discharges from the proposed new build sites

The accidental discharge of radionuclides from the proposed new build sites are represented by a single long-lived conservative radionuclide tracer. The release was assumed to take place at a constant rate of 1 $GBq.s^{-1}$ over a period of one week, resulting in a total discharge of 604.8 TBq.

In order to take into account the effects of seasonality on the discharge, simulations were run over the four seasons for each of the five proposed new build sites, leading to a total of 20 simulations. The releases were assumed to take place at a constant rate over a period of one week beginning 1st January (Winter), 1st April (Spring), 1st July (Summer) and 1st October (Autumn).

These simulations were run over a four year period for each of the scenarios in order to take into consideration the time taken for the discharges to be transported throughout the Irish Sea. Previous work has estimated the transport time of the conservative radionuclide from the UK to the east coast of Ireland to be between 80 and 360 days [10].

The meteorological data used in this modelling were obtained from the regional reanalysis ERA-40 dataset of the European Centre for Medium-Range Weather Forecasts (ECMWF) for the Irish Sea (1995 – 1998) and not from predicted or forecasted weather patterns. The model predictions were investigated by analysing a time series of radioactivity concentrations in seawater at eight receptor points covering the large population centres along the east coast of Ireland (Figure 1). The simulation used for the non-routine dose assessment was the scenario that resulted in the highest activity concentrations in seawater at a single receptor point.

Having run the model the scenario resulting in the highest radioactivity concentration in seawater at the receptor points specified in Figure 1 was identified as being an accidental release from the proposed Wylfa site in the first week of April, with a peak activity concentration observed in Greenore, Dundalk. Assuming the release of a conservative radionuclide tracer at 1 $GBq.s^{-1}$ over the first week in April, this leads to a total discharge of 604.8 TBq resulting in a peak activity concentration in seawater of 191 $mBq.l^{-1}$ in Dundalk 161 days later.

This peak activity concentration in seawater of 191 $mBq.l^{-1}$ was observed over a very short time period before decreasing. However, in this work it was assumed that once the activity concentration in seawater peaked, it remained at this level for a period of one year in order to simplify the dose calculations. This assumption in conjunction with the fact that modelling was carried out based on a conservative radionuclide tracer implies any doses determined for the consumer groups would be considered upper bounds of the dose for the discharge scenarios outlined.

Based on these results, the peak dilution factor (*DF*) for seawater at Greenore, Dundalk is:

$$DF = \frac{191 \times 10^{-3}\ Bq/l}{604.8 \times 10^{3}\ GBq} = 3.1581 \times 10^{-7} \left(\frac{Bq/l}{GBq}\right)$$

The peak activity concentration in seawater for each of the radionuclides discharged was determined using:

$$C^{i}_{Seawater} = D_i \times DF \times e^{-\lambda_i t}$$

Where:
$C^{i}_{Seawater}$ is the peak activity concentration in seawater for radionuclide *i*
D_i is the total activity discharged for radionuclide *i* (GBq)

DF is the dilution factor ($Bq.l^{-1}/GBq$)
λ_i is the decay constant for radionuclide *i* ($days^{-1}$)
t is the time taken to reach the peak activity in seawater at Greenore, Dundalk i.e. 161 days

The radioactivity concentrations in fish, shellfish (crustaceans and molluscs) and seaweed were determined by multiplying the activity concentration in seawater by the appropriate concentration factors i.e.

$$C_{Fish} = C_{Seawater} \times CF$$

Where:

C_{Fish} is the activity concentration of the radionuclide in fish ($Bq.kg^{-1}$)
$C_{Seawater}$ is the activity concentration of the radionuclide in seawater ($Bq.kg^{-1}$)
CF is the concentration factor for fish.

The concentration factors are the same as those used in the routine discharge modelling work [6].

Similarly, the radioactivity concentrations in sediments were determined using the same sediment concentration factors for coastal compartments in the DORIS model. The activity concentrations in the sediments were determined by multiplying the radioactivity concentration in seawater by the sediment concentration, or k_d, factor i.e.

$$C_{Sediment} = C_{Seawater} \times k_d$$

Where:

$C_{Sediment}$ is the activity concentration of the radionuclide in sediment ($Bq.kg^{-1}$ wet)
$C_{Seawater}$ is the activity concentration of the radionuclide in seawater ($Bq.kg^{-1}$)
k_d is the sediment concentration factor which are also the same as those used in the routine discharge modelling work.

2.3.2 Non-routine dose assessments

The exposure pathways for non-routine discharges are the same as those for routine discharges, namely internal irradiation from ingestion of seafood and external irradiation arising from radioactivity in beach sediments and fishing equipment handled by fishermen and coastal workers.

The dose calculations are identical to those used in the PC-CREAM 08 software i.e. based on CREAM. This is to ensure consistency between the routine and non-routine dose calculations. These dose calculations were configured in MS Excel [13] to derive the doses to critical Groups A and B and to a typical seafood consumer (Table 2).

3. Results and Discussion

3.1 Routine discharges

A total of 30 model runs were carried out to cover the five proposed NPP sites, the two Irish Sea compartments and the three consumer groups. It was assumed that a single reactor was located at each of the proposed sites. This means that the dose results can be scaled appropriately at a later stage once information becomes available on the number of proposed reactors at each site.
The doses from each of the sites, for a single reactor at each site, and for each of the consumer groups are outlined in Table 4 and displayed in Figure 3.

Discharge Location	Group A Irish Sea West	Group A Irish Sea South	Group B Irish Sea West	Group B Irish Sea South	Typical Consumer Irish Sea West	Typical Consumer Irish Sea South
Sellafield	1.85E-02	6.97E-03	1.33E-02	4.98E-03	5.03E-03	1.87E-03
Heysham	1.85E-02	7.17E-03	1.33E-02	5.12E-03	5.02E-03	1.92E-03
Wylfa	3.81E-02	1.26E-02	2.73E-02	9.02E-03	1.04E-02	3.41E-03
Oldbury	1.90E-04	2.08E-04	1.35E-04	1.48E-04	5.06E-05	5.56E-05
Hinkley Point	1.91E-04	2.10E-04	1.36E-04	1.50E-04	5.08E-05	5.61E-05

Table 4. Individual effective dose ($\mu Sv.yr^{-1}$) after 50 years of routine releases.

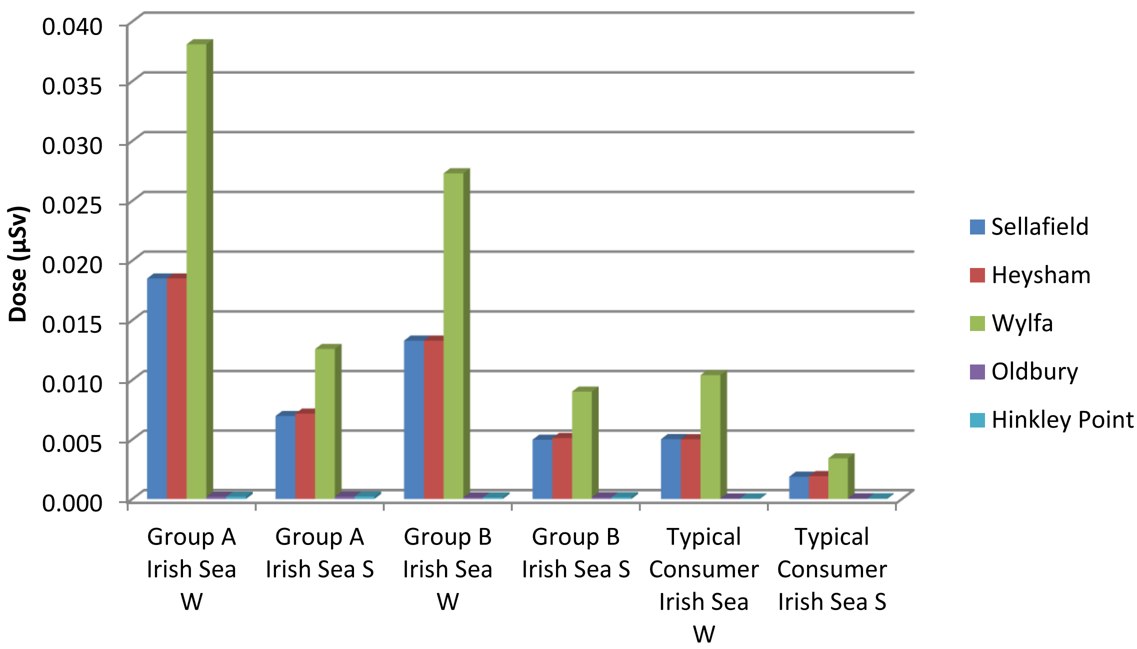

Figure 3. Comparison of effective dose after 50 years from proposed NPP sites.

The doses calculated for each of the consumer groups from all of the proposed NPP sites are radiologically insignificant. The largest doses to the Irish population arise from discharges from the Wylfa site while the smallest doses arise from discharges from the Hinkley Point and Oldbury sites. The doses arising from the Sellafield and Heysham sites, and the Oldbury and Hinkley Point sites are similar to each other.

The dose arising from discharges from Wylfa after 50 years is approximately twice the dose from Sellafield or Heysham and 200 times the dose from Oldbury/Hinkley Point in the western Irish Sea and 60 times the dose from Oldbury/Hinkley Point in the southern Irish Sea.

The most important exposure pathway is the consumption of seafood. It accounts for more than 95% of the overall effective dose to the three consumer groups. The dose from the inhalation of seaspray for critical Group B and a typical seafood consumer was found to be insignificant compared to the other exposure pathways.

The largest doses calculated were found for critical Group A and are 1.4 times greater than the doses to critical Group B and approximately 3.6 times greater than the dose to a typical seafood consumer. This can be primarily attributed to the volume of seafood ingested; as critical Group A ingest 36 $kg.yr^{-1}$ of seafood whereas critical Group B and a typical seafood consumer consume 25 $kg.yr^{-1}$ and 9 $kg.yr^{-1}$, respectively.

The most significant contributor to the overall effective doses is C-14. This radionuclide accounts for more than 90% of the dose for all consumer groups, new build sites and regions of the Irish Sea.

Taking into account the information currently available on the maximum number of proposed reactors [14, 15, 16, 17], the total doses arising from each of the proposed sites are outlined in Table 4. These values were calculated by multiplying the doses determined for a single reactor by the proposed maximum number of reactors at each of the five sites.

Location (Max. Number of Reactors)	Group A Irish Sea West	Group A Irish Sea South	Group B Irish Sea West	Group B Irish Sea South	Typical Consumer Irish Sea West	Typical Consumer Irish Sea South
Sellafield (3)	5.55E-02	2.09E-02	3.99E-02	1.49E-02	1.51E-02	5.61E-03
Heysham (0)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wylfa (4)	1.52E-01	5.04E-02	1.09E-01	3.61E-02	4.16E-02	1.36E-02
Oldbury (3)	5.70E-04	6.24E-04	4.05E-04	4.44E-04	1.52E-04	1.67E-04
Hinkley Point(2)	3.82E-04	4.20E-04	2.72E-04	3.00E-04	1.02E-04	1.12E-04

Table 5. Total Dose (μSv y^{-1}) in year 50 from each proposed site, based on maximum number of proposed reactors.

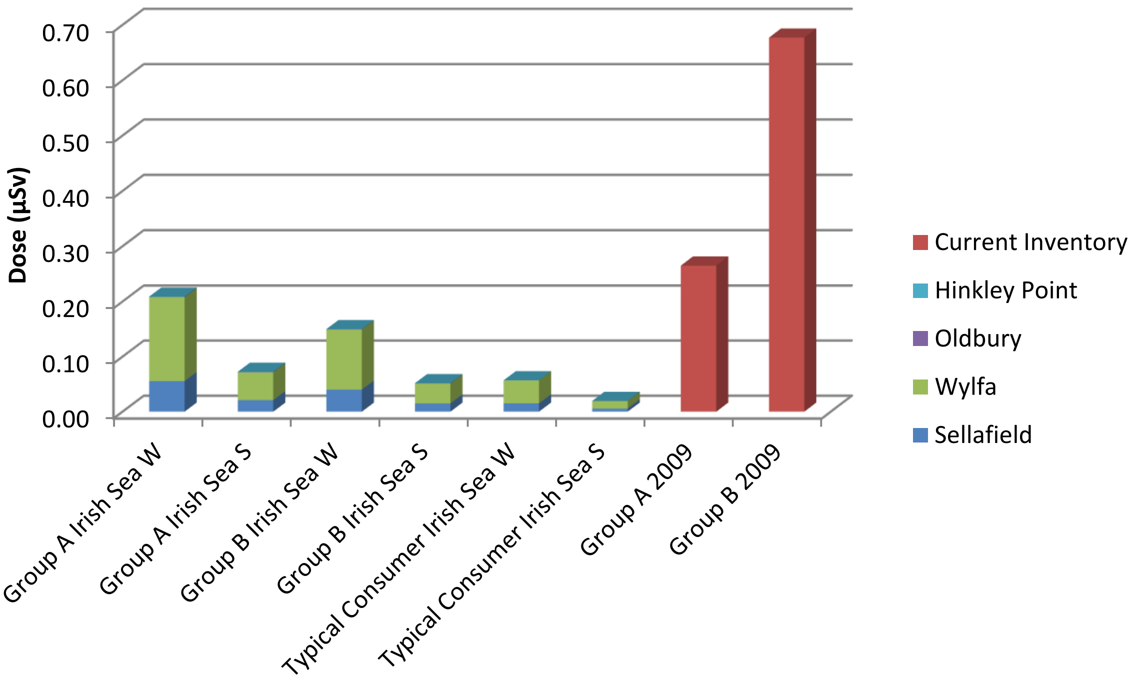

Figure 4. Comparison of the predicted doses arising from the proposed new build sites in the UK to the doses derived from the routine monitoring of the current inventory of radioactivity in the Irish marine environment.

The highest predicted doses are due to discharges from the Wylfa site (up to four reactors have been proposed for this location). The lowest predicted doses are from Hinkley Point (only two reactors have been proposed for this location). These results show that the proposed NPP at Wylfa will have the largest impact from a dose perspective following 50 years of routine releases. Notwithstanding this, the doses to all consumer groups calculated for this site are very small. The doses calculated in this work can be compared to those currently received by consumer Groups A and B arising from the current levels of artificial radioactivity in the Irish Sea. The highest dose derived from this work is the dose to consumer Group A in the Irish Sea West. This dose is still lower than the doses to critical groups A and B based on the results of the RPII's most recent marine monitoring programme [18], as shown in Figure 4.

3.2 Non-Routine discharges

A summary of the doses arising from the two non-routine discharge scenarios described below is presented in Table 6.

	Total Dose (µSv)		
Scenario	**Group A**	**Group B**	**Typical Consumer**
1	1.31×10^{-2}	1.03×10^{-2}	4.09×10^{-3}
2	0.345	0.941	0.745

Table 6. Effective Adult dose (µSv) to consumer groups arising from non-routine discharges into the Irish Sea from the proposed Wylfa site.

3.2.1 Discharge Scenario 1 – one year of routine liquid discharges released at once

The doses calculated for each of the consumer groups arising from discharge scenario 1 are all radiologically insignificant when compared to other sources of radiation to the Irish population [19]. The largest doses calculated for discharge scenario 1 are to critical Groups A and B. These doses are an order of magnitude higher than the dose to a typical consumer. However, it is approximately 300,000 times smaller than the dose to members of the Irish population from all sources of radioactivity i.e 3,950 µSv [19]. The breakdown of the dose for discharge scenario 1 indicates that the pathway of most significance is the ingestion of fish and crustaceans, which accounts for over 99% of the total dose.

3.2.2 Discharge Scenario 2 – total volume of reactor coolant discharged at once

The doses calculated for each of the consumer groups arising from this discharge scenario are higher than those from discharge scenario 1 but still significantly below the estimated dose to the Irish population from all sources of radiation. The doses calculated for discharge scenario 2 are all of the same order of magnitude. The breakdown of the dose to critical Group B for discharge scenario 2 indicates that the most significant pathway is the external gamma dose from sediments (dominated by Mn-54), which accounts for over 80% of the total dose.

4 Summary

The work presented here shows that the doses to the Irish population arising from routine liquid discharges from any potential nuclear new build on the west coast of the UK are significantly below the dose from the current inventory of radionuclides in the Irish Sea and are also significantly smaller than the estimated dose to the Irish population arising from all sources of radiation (of both natural and anthropogenic origin). The radionuclide of most interest for the routine liquid discharges is C-14 while the most significant exposure pathway is the consumption of fish and shellfish.

This work has also shown that the proposed new build site of most significance from a dose point of view for both routine and non-routine discharges is the Wylfa site in Wales which was expected considering its close proximity to the Irish east coast and the movement of seawater within the Irish Sea. However, the dose to the Irish population from non-routine discharges arising from any of the potential new build sites in the UK, as described in this work, are of no radiological significance. The most significant radionuclide from a dose point of view for discharge scenario 1 is again C-14 while the exposure pathway of most interest is the ingestion of seafood. For discharge scenario 2 the most significant pathway is exposure to beach sediments from the gamma emitting Mn-54. It should be noted that the radionuclide dispersion following a non-routine release from new build sites was simulated using a conservative radionuclide tracer and that the dose assessment assumes the levels of radioactivity in seawater remains at its peak activity for at least one year. Therefore these dose assessments should be considered as representative of very conservative dose estimates.

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