



Environmental Protection Agency

Potential radiological impact
on Ireland of postulated severe
accidents at Sellafield



Office of Radiological Protection

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

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- Advising Government on matters relating to radiological safety and emergency response.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

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- Promoting radon testing in homes and workplaces and encouraging remediation where necessary.

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- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiological Protection
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

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Summary

This study assessed the potential radiological impact on Ireland of a range of severe hypothetical accident scenarios at the Sellafield nuclear fuel reprocessing plant. The hypothetical accident scenarios studied were those identified in a risk assessment of Sellafield commissioned by the Irish Government as having the greatest potential to have an impact on Ireland. The previous Sellafield risk assessment identified the potential accident scenarios and their immediate radiological impacts for Ireland. This report extends the assessment to consider the potential impacts of the most severe accidents into the longer term. The report presents the estimated potential increase in radiation doses to people and contamination of the environment for a year following the accident.

For each of the accidents considered, the predicted radiation doses were found to be below the levels which would give rise to sheltering, relocation or evacuation of people being required. However, without appropriate food controls, significant radiation doses could be incurred in the year following the accident through the consumption of contaminated foods. Ireland's National Emergency Plan for Nuclear Accidents (NEPNA) envisages the introduction of food controls and on-farm measures, as appropriate, to reduce radiation doses from this pathway and ensure all food for sale is safe to eat. This highlights the importance of the introduction of effective food controls as highlighted in NEPNA.

While protective actions have been shown to be very effective in controlling radioactivity levels in foods for sale, and hence radiation doses to people, they do have significant socio-economic implications and costs.

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1 Introduction

Sellafield is a 600-hectare (1,480 acres) nuclear site in the north west of England, approximately 180 km (112 miles) from the north east coast of Ireland. It is one of two nuclear fuel reprocessing sites in Europe and is the largest nuclear site in Europe. The site has over 1,000 nuclear facilities that process and store used nuclear fuel and other radioactive materials. In addition, the UK's main facility for the disposal of solid low-level radioactive waste (LLW) is located at Drigg, approximately 5 km from the Sellafield site. This facility has operated as the UK's national LLW disposal facility since 1959.

The operation of the nuclear fuel reprocessing plants at Sellafield results in the authorised discharge of low-level radioactive materials in the form of liquids and gases into the environment. The radionuclides discharged are transported and dispersed by normal environmental processes such as air mixing and sea currents. Some of the radioactivity discharged reaches Ireland and concentrations are routinely monitored by the Environmental Protection Agency. While the levels of artificial radioactivity in the Irish environment are detectable, they are low and do not pose a significant risk to the health of the Irish population (EPA, 2015). Further details on the activities at the Sellafield nuclear site are given in Chapter 2.

The Irish Government and people living in Ireland have long been concerned about how an incident at Sellafield might impact Ireland and the Irish Sea given its location, its operating history, and the amount and type of radioactive materials on the site. In 2000, following a visit by staff to Sellafield, the Radiological Protection Institute of Ireland (RPII) prepared a report on the safety of the Highly Active Storage Tanks (HASTs) that are used for storage of high activity radioactive liquid waste (Turvey & Hone, 2000). The report, based on scrutiny of detailed safety documentation, noted the risks associated with the storage of high-level radioactive waste in liquid form and that the consequences of a very severe accident had not been adequately assessed.

The RPII visited the Sellafield site again in 2004 to see at first hand a number of the key facilities of particular interest and concern to Ireland and to explore the changing nature of operations at the site. The visit noted the complexity and interdependency of operations at the site and identified several significant hazards on the site. In addition, the RPII were informed that issues identified during the visit in 2000 (incomplete safety case and independent cooling of the HASTs) were subsequently addressed (RPII, 2005).

In 2008, the Irish Government commissioned a team of independent experts to determine the potential risks to Ireland associated with the Sellafield Site and the Low-

Level Waste Repository, located near the site at Drigg. A Probabilistic Risk Assessment (PRA)¹ of the Sellafield site was completed to answer three questions:

1. What types of incidents could cause damage that would release radioactive materials (as solid, liquid, or gas)?
2. What is the likelihood of those incidents?
3. What are the consequences to Ireland?

The results of the PRA showed that, following an incident at Sellafield or the Low-Level Waste Repository, some radioactive materials could reach Ireland but at levels far below the dose levels that could cause observable health effects in Ireland. The PRA did, however, find that some very rare severe incidents have the potential to create significant socioeconomic impacts in Ireland². This current study assesses the radiological consequences of the very rare severe incident scenarios identified by the expert team in more detail and extends their assessment to consider the potential impacts into the longer term.

Radionuclides released into the air will be transported, dispersed and diluted by the wind and air currents. During transport, radionuclides can be deposited onto the ground/vegetation/buildings by a number of mechanisms including impact with underlying surfaces, settling due to gravity and scouring from the atmosphere by rain, hail or snow ('washout'). The dispersion and deposition of radioactivity in the air is largely determined by the prevailing weather conditions at the point of discharge and along the path of the radioactive plume. Radioactivity in the air can irradiate the population externally ('cloudshine') and internally via inhalation. Once deposited, the radioactivity can irradiate the population externally ('groundshine') and internally, mainly via ingestion of foods containing the radioactivity and, to a lesser extent, via inhalation of re-suspended radioactivity that had previously been deposited onto the ground or building surfaces.

For this assessment, the transfer of radioactivity to Ireland from the Sellafield or Drigg sites was predicted through the use of environmental transfer models and the

¹ Probabilistic Risk Assessment (PRA), is a comprehensive, structured approach to identifying *failure scenarios*, constituting a conceptual and mathematical tool for deriving numerical estimates of *risk* (IAEA, 2007)

² The Irish Government has since commissioned the Economic and Social Research Institute (ESRI) to carry out a study to assess the Potential Economic Impact on Ireland of a Nuclear Incident.

resulting environmental concentrations and radiation doses to people were calculated for a range of different exposure pathways:

- External exposure from radionuclides in the passing cloud (cloudshine)
- Internal exposure due to inhalation
- External exposure from radionuclides on the ground (groundshine)
- Transfer of radionuclides through the foodchain and subsequent internal exposure due to ingestion of contaminated foodstuffs

Ireland has a National Emergency Plan for Nuclear Accidents (NEPNA) to provide a coordinated emergency response to a situation where there is widespread radioactive contamination in Ireland (DECLG, 2005). The central purpose of the NEPNA is to minimise the impact on Ireland and its people in the event of a major nuclear accident abroad. The NEPNA includes guidance on protective actions such as sheltering and food controls to reduce the radiation dose received by the population. In this current study, in order to assess the maximum radiation doses arising from the scenarios studies, it has been assumed that none of the planned protective actions are taken

2 Background on the Sellafield Nuclear Fuel Reprocessing Plant

The main activities at the Sellafield nuclear site include the storage and reprocessing of spent (or used) nuclear fuel, the storage of plutonium and uranium, and the control of high-level radioactive waste. There are no nuclear power plants in operation to generate electricity at the Sellafield site.

2.1 Sellafield Site operations

When nuclear fuel is removed from a reactor it contains potentially re-useable uranium (96%) and plutonium (1%) and a number of highly radioactive materials collectively called fission products (3%). The used or 'spent' nuclear fuel is highly radioactive, generates a large amount of heat and needs to be managed very carefully to protect people and the environment. Reprocessing, a series of chemical procedures that separates plutonium and uranium from other nuclear waste, is used by some countries as a way to manage their spent nuclear fuel. The recovered uranium and plutonium is stored and could be re-used as nuclear fuel.

There are two reprocessing plants on the Sellafield site. One of these, the Magnox reprocessing plant, handles spent fuel from the UK's Magnox reactors. Magnox technology was developed in, and was principally confined to, the UK. The Thermal Oxide Reprocessing Plant (THORP) reprocesses uranium oxide nuclear fuel that is used in several different types of nuclear reactors in the UK, Europe and Japan.

Reprocessing generates large amounts of radioactive material for which there is no end use. This waste material is classified according to its radioactive content as high, intermediate or low-level waste. The high-level (liquid) radioactive waste (HLW) is concentrated (to reduce the volume of material that has to be managed) by evaporation to produce Highly Active Liquor (HAL). This liquor is then incorporated into glass blocks in a process known as 'vitrification' in the Waste Vitrification Plant (WVP) at Sellafield. The vitrification process serves to immobilise the HAL. The HAL is self-heating and is stored in actively cooled Highly Active Storage Tanks (HASTs). HAL stocks at Sellafield represent a significant fraction of the total radioactivity stored on the site (ONR, 2014)

Intermediate-level radioactive waste (ILW) is stored on-site at Sellafield while low-level radioactive waste (LLW) produced at Sellafield is disposed of at the nearby UK national Low Level Waste Repository (LLWR) facility at Drigg. Reprocessing also gives rise to authorised low-level liquid radioactive discharges into the Irish Sea and gaseous radioactive discharges to the air.

2.2 Highly Active Storage Tanks

There are 21 Highly Active Storage Tanks (HASTs) on the Sellafield site. The first eight HASTs were commissioned in 1955 and brought into active use between 1955 and 1970 as the volume of waste produced increased. Each of these has a working volume of 70 cubic metres. The remaining 13 HASTs were built during the 1970s and 1980s and each has a working volume of 145 cubic metres. For safety reasons, a policy of keeping one tank empty for every three in use has been maintained in the event that one of the other HASTs needs to be emptied at short notice (RP11, 2005).

The HASTs are housed in thick reinforced concrete cells. The heat generating capacity of the waste (up to several kilowatts per cubic metre) necessitates continuous cooling of the tanks to prevent evaporation and, ultimately in the case of those tanks with the larger radioactive inventories, boiling and release to atmosphere of their contents. For safety reasons the HASTs are also segregated into 'cells' to provide isolation from the other tanks. The first eight tanks were installed two per cell while the remaining 13 tanks were installed one per cell (RP11, 2005).

Spent nuclear fuel is placed into water pools at the reactor site when it is removed from the reactor core to provide cooling and shielding as it is highly radioactive and generates considerable heat. After a cooling period of a few years the short lived, and most highly radioactive, waste products will have decayed and the rate of heat production from the spent fuel will have declined appreciably. This not only reduces the hazard during the transport and reprocessing of the spent fuel but also means that the HASTs into which the liquid HLW is placed, after the extraction of the plutonium and uranium, contain only long lived radionuclides such as caesium-134, caesium-137 and strontium-90 (NEA, 1994) (Turvey & Hone, 2000).

As part of an examination of safety documentation related to the storage of liquid HLW at Sellafield, Turvey & Hone (2000) estimated the isotopic inventory of a freshly filled HAST (see Table 1). They assumed the HAST to contain 100 cubic metres of HAL. Together caesium-134 (Cs-134), caesium-137 (Cs-137) and strontium-90 (Sr-90) account for the largest quantity of radiologically harmful substances in the HASTs. This information was used in this current study to estimate the source terms outlined in §3.2.

Table 1. Typical isotopic inventory of a freshly filled (100 m³) HAST (Turvey & Hone, 2000)

Radionuclide	Bq
Zr-95	1.40×10^{15}
Nb-95	5.80×10^{14}
Ru-106	1.33×10^{16}
Sb-125	1.64×10^{15}
Cs-134	1.04×10^{16}
Cs-137	5.26×10^{17}
Ce-144	9.65×10^{15}
Eu-154	4.41×10^{15}
Eu-155	3.39×10^{15}
Sr-90	3.60×10^{17}
Am-241	2.72×10^{15}
Cm-242	4.57×10^{13}
Cm-243+244	1.92×10^{14}

3 The Sellafield Probabilistic Risk Assessment (PRA)

3.1 Study methodology and findings

In 2008, the Irish Government commissioned a team of independent experts to complete an assessment of the potential risks to Ireland associated with the Sellafield Site and the Low-Level Waste Repository at Drigg, located near the site. The team reviewed operations at Sellafield and Drigg to answer three questions:

1. What types of incidents could cause damage that would release radioactive materials (as solid, liquid, or gas)?
2. What is the likelihood of those incidents?
3. What are the consequences to Ireland?

Methodology

The PRA team used a range of PRA¹ techniques to estimate the likelihood of radioactive material being released from Sellafield or Drigg that may have an impact on Ireland or Irish interests. The analyses performed are listed in Figure 1. They considered scenarios involving possible accidents inside a range of facilities as well as accidents with the various systems that support those facilities. In addition, the team analysed external events. Some examples of the initiating events considered include human errors, mechanical equipment failures, loss of support systems such as electrical power, environmental events such as severe storms, and external events such as aircraft crashes, meteorite impacts and deliberate attacks.

The PRA team then looked at the possible sequences of actions that could happen after the initiating event – for example, what might happen if a human error is not detected immediately, or if measures to prevent the release of radioactive material are unsuccessful. They used site-specific information and performance data for similar facilities to estimate the outcome. The team then calculated how often such incidents might occur and estimated the range of possible releases of radioactive material that could impact Ireland.

While many of the incidents that could occur at Sellafield involve liquid contaminants, the release of airborne contamination into the atmosphere has the greatest potential to impact on the environment of Ireland (DECLG, 2012) (RPII, 2013). Consequently, liquid releases are not considered in this report.

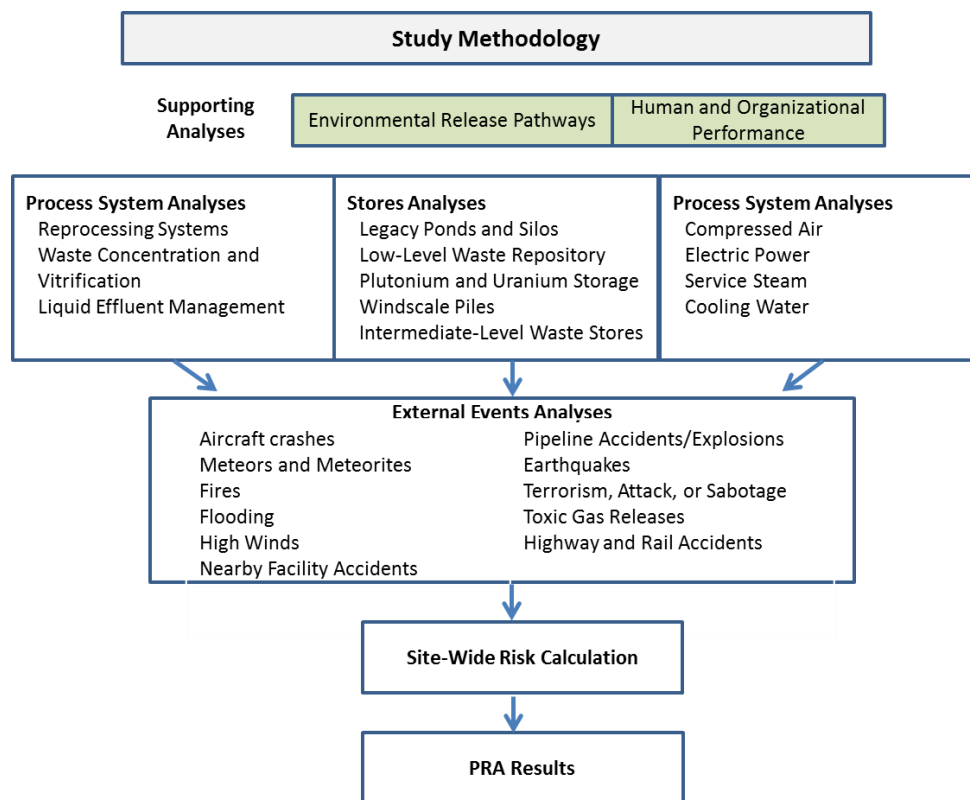


Figure 1. Overview of the PRA Study Methodology (DECLG, 2012)

Findings

The PRA assessment considered the immediate period after the radioactive release and during the passage of the radioactive plume. Based on the findings of the PRA, an incident at Sellafield or Drigg would result in no observable health effects in Ireland. The PRA did predict some very rare severe incidents at Sellafield or Drigg with varying capability to release radioactive materials high enough into the air so that the materials could be transported significant distances beyond the site boundary and reach Ireland. Such incidents would have the potential to create significant socioeconomic impacts in Ireland (DECLG, 2012).

The PRA team reported that these very rare severe incidents are extremely unlikely (less than a 0.02% chance over the next 100 years). A list of the very rare severe incidents together with the estimated frequency and corresponding probability of occurrence in the next 100 years is given in Table 2 (DECLG, 2012).

Table 2: Very rare severe incidents that disperse highly concentrated radioactive materials or release large quantities of intermediate activity materials (DECLG, 2012).

Incident	Best Estimate Frequency, event per year	Probability that the incident will occur at some time in the next 100 years	
		Best Estimate	Range of Uncertainty
Meteorite impact into a facility that contains highly radioactive materials	7×10^{-7}	0.007%	0.00009% to 0.03%
Severe earthquake damage to a facility that contains used nuclear fuel	6×10^{-7}	0.006%	0.002% to 0.01%
Test missile crash into a facility that contains highly radioactive materials	2×10^{-7}	0.002%	0.0002% to 0.006%
Aircraft crash into a facility that contains highly radioactive materials	2×10^{-7}	0.002%	0.00003% to 0.007%
Severe site-wide earthquake damage	5×10^{-8}	0.0005%	0.00002% to 0.002%
Any of the above very rare severe incidents	2×10^{-6}	0.02%	0.003% to 0.05%

3.2 Release Source terms

Of the very rare severe incidents identified by the PRA team, a number involve facilities containing highly radioactive material. There are many facilities on the Sellafield site where radioactive materials are stored in different forms. The Highly Active Storage Tanks (HASTs) contain the most highly concentrated radioactive materials in liquid form at Sellafield, posing the greatest risk to Ireland and the PRA considered the release of ‘*a portion of the contents of a..*’ HAST (DECLG, 2012).

For the purposes of this assessment, the PRA team provided details on the amount of radioactive material released from the HASTs and four release scenarios (described in in Table 3).

There are no details publicly available on the current HAST inventories and/or the distribution of HAL between the 21 tanks on the Sellafield site. In this study, the typical isotopic inventory of a freshly filled HAST estimated by Turvey and Hone (2000) are used (Table 1). Given the on-going reduction in HAL volumes contained in the HASTs since 2001 (ONR, 2011), it is likely that the HAL quantities assumed in this study are an overestimate.

A full evaluation of the impacts following an accidental release would consider the half-life, environmental mobility, and radiotoxicity per unit activity for every radionuclide contained in the HAST. In the HAST radionuclide inventory listed in Table 1 caesium-134, caesium-137 and strontium-90 are of most concern from a health perspective. However, for the purposes of this assessment, caesium-137 and caesium-134 were used as surrogates for the full range of potential radiological impacts from incidents at Sellafield. This was considered a reasonable approach as caesium-137 and caesium-134 are the main contributors to the radiation dose to people and strontium-90 has low volatility and so significant amounts of this radionuclide are unlikely to reach Ireland.

Table 3. Accident scenarios used in this study

Release Scenario	Description of the Event
Scenario A	An unspecified severe event resulting in a continuous aerial release over two hours with a 50 kW heat input to the plume
Scenario B	An unspecified severe event resulting in a continuous aerial release over two hours with a 500 kW heat input to the plume
Scenario C	Meteorite impact resulting in a continuous release over 5 minutes
Scenario D	Impact of a large aircraft resulting in a continuous release over 30 minutes

4 Methodology for the assessment of radiological impact

The radiation dose assessment completed in this study comprised two separate stages. Firstly, atmospheric dispersion modelling was performed for releases from the Sellafield site using the weather scenarios identified as ‘worst case’ in terms of potential impact on Ireland i.e. the weather conditions were such that a radioactive plume from Sellafield would travel across Ireland and deposit significant amounts of radioactive material. Secondly, the outputs of the dispersion modelling were then used in an ingestion dose model to simulate the transfer of radioactivity in the food chain.

The EPA utilises the Accident Report and Guiding Operational System Nuclear Decision Support System (ARGOS) as its primary tool for assessing the consequences of a nuclear or radiological emergency. ARGOS includes the following components:

- Databases containing radiological monitoring data; dose coefficients; nuclear reactor characteristics; and meteorological data.
- RIMPUFF (Risø-Mesoscale-PUFF), an atmospheric dispersion model driven by meteorological forecast data provided by Met Éireann, which enables the transport and dispersal of radioactive contamination to be predicted; and
- ECOSYS, a model for simulation of contamination of the food chain and assessment of radiation doses following a nuclear or radiological emergency;
- Geographical maps for displaying measured data and model results.

Further details on the models used in this assessment (RIMPUFF and ECOSYS) can be found in Appendix 1.

4.1 Identification of the ‘worst case’ weather scenario

The ‘worst case’ weather scenarios for releases from the area around Sellafield which were previously identified as part of an assessment of the potential radiological implications for Ireland of the proposed nuclear power plants in the UK (RPII, 2013) were used in this study. In general, winds reaching Ireland come from the west so any radioactive plume originating in England would be directed away from Ireland. In addition, the deposition of airborne radioactive material is greatest where the plume coincides with rain (‘Wet deposition’). Thus, in order to assess the worst possible impact of an airborne radioactive release from Sellafield, weather scenarios with easterly winds and rain over the Ireland were identified based on an assessment of 21 years of weather data (RPII, 2013).

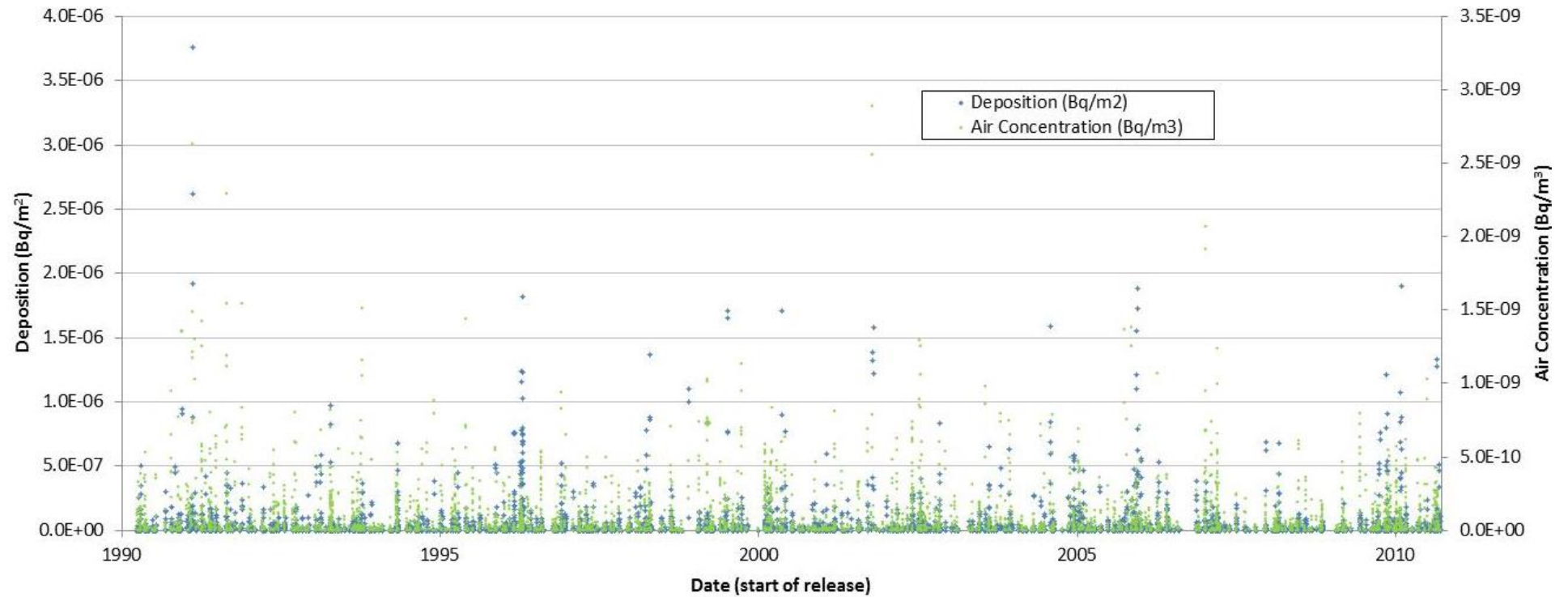
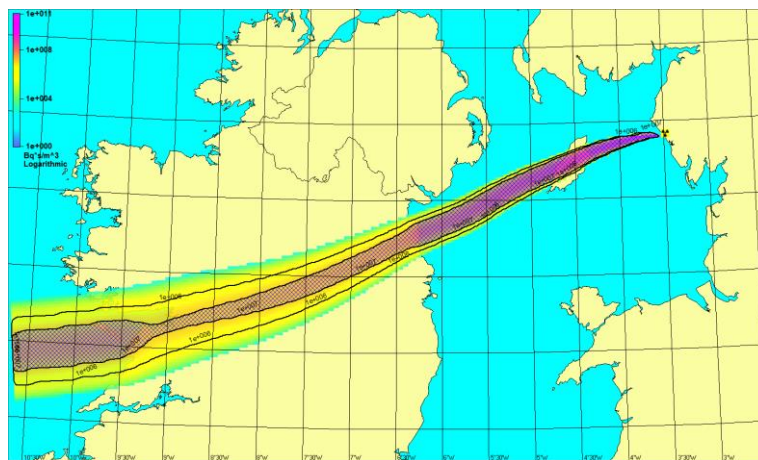


Figure 2. Radioactivity in air concentrations (Bq/m³) and deposition (Bq/m²) resulting from unit radioactivity releases from the Sellafield site over the period 1990 to 2010 (RPII, 2013)

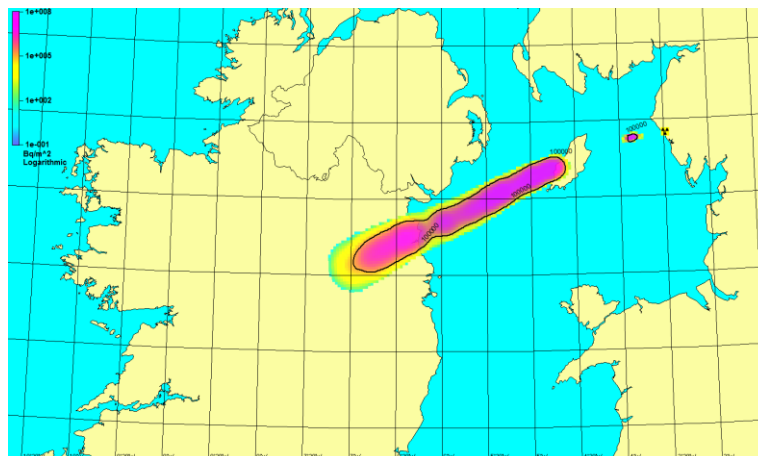
5 Results of the assessment

5.1 Radiation doses assessment

The four incident release scenarios outlined in §3.2 were modelled using the two real weather patterns (§4.1) that maximise the deposition of radioactivity on the east coast of Ireland. As an example, the time-integrated activity concentrations in air and wet deposition patterns for caesium-137, 20 hours³ after the start of a meteorite impact (Scenario C) using weather data from 29th November 2010 are presented in Figure 3. In this simulation, the radioactive plume reaches the Irish east coast eight hours after the start of the release and it takes the plume nine hours to traverse the country.



(a) Caesium-137 in air (isolines 1×10^6 Bq.s/m³ and 1×10^7 Bq.s/m³ (hatched))



(b) Caesium-137 Surface deposition (wet) (isoline 1×10^5 Bq/m²)

Figure 3. Dispersion model results following a meteorite impact at the HAST facility (modelled using weather data from 29th November 2010)

³ After 20 hours the plume has passed across Ireland.

The total radiation dose to an adult living on the east coast of Ireland during passage of the plume was calculated by summing the contributions from the inhalation, cloudshine and groundshine pathways for caesium-134 and caesium-137. This was done for each of the four release scenarios and using the two weather patterns. The predicted doses immediately due to the passage of the plume are reported in Table 4 (a) for the May release date and Table 4 (b) for the November release date.

Table 4. Cumulative radiation doses (μSv) by pathway and accident scenario during plume passage for the May release date (a) and November release date (b)

Radiation dose (μSv)					
(a)		Inhalation	Cloudshine	Groundshine	Total
	Scenario A (May)	440	1.8	3.5	450
	Scenario B (May)	510	1.9	3.4	520
	Scenario C (May)	2,400	7.1	5.7	2,400
	Scenario D (May)	750	1.6	1.3	750
(b)		Inhalation	Cloudshine	Groundshine	Total
	Scenario A (Nov)	620	1.3	55	680
	Scenario B (Nov)	630	1.3	69	700
	Scenario C (Nov)	860	2.1	170	1,000
	Scenario D (Nov)	640	0.5	65	710

The cumulative radiation doses after one week for the May and November release dates are presented in Table 5 (a) and Table 5 (b), respectively.

Finally, the cumulative radiation doses after one year for the May and November release dates are presented in Table 6(a) and Table 6 (b). In all cases the radiation doses due to groundshine were higher following the November release because of the higher levels of precipitation which gave rise to higher ground deposition.

Table 5. Cumulative radiation doses (μSv) by pathway and source term one week after the May release date (a) and November release date (b)

Radiation dose (μSv)					
(a)	Inhalation	Cloudshine	Groundshine	Total	
	Scenario A (May)	440	1.8	74	520
	Scenario B (May)	510	1.9	73	590
	Scenario C (May)	2,400	7.1	170	2,600
	Scenario D (May)	750	1.6	43	800
(b)	Inhalation	Cloudshine	Groundshine	Total	
	Scenario A (Nov)	620	1.3	930	1,600
	Scenario B (Nov)	630	1.3	1,100	1,700
	Scenario C (Nov)	860	2.1	2,800	3,700
	Scenario D (Nov)	640	0.5	1,100	1,700

Table 6. Cumulative radiation doses (μSv) by pathway and source term one year after the May release date (a) and November release date (b)

Radiation dose (μSv)					
(a)	Inhalation	Cloudshine	Groundshine	Total	
	Scenario A (May)	440	1.8	2,500	2,900
	Scenario B (May)	510	1.9	2,500	3,000
	Scenario C (May)	2,400	7.1	5,600	8,000
	Scenario D (May)	750	1.6	1,500	2,300
(b)	Inhalation	Cloudshine	Groundshine	Total	
	Scenario A (Nov)	620	1.3	32,000	33,000
	Scenario B (Nov)	630	1.3	39,000	40,000
	Scenario C (Nov)	860	2.1	96,000	97,000
	Scenario D (Nov)	640	0.5	36,000	37,000

In all cases, the radiation doses were calculated assuming that no protective actions were taken i.e. people were outdoors while the plume was passing overhead and radioactivity deposited on the ground remained in place and was not washed away either

naturally via rain or by deliberate cleaning to reduce groundshine doses. The inhalation and cloudshine exposure pathways are only relevant during the passage of the plume, while the groundshine exposure pathway continues to contribute to radiation doses until the radioactivity either decays away or is removed (through natural processes or clean-up actions).

It is important to note that there are large uncertainties in the use of model simulations. The RIMPUFF atmospheric dispersion model applies (numerical) approximations in order to simulate atmospheric dispersion processes. This inevitably leads to uncertainties in the model predictions. Further uncertainties may arise from the meteorological data, the RIMPUFF meteorological data processor, the terrain data, etc. In addition, there are uncertainties in the source terms and accident scenario assumptions. The source term for the HASTs has been chosen based on the publicly available information. However the HAL contents are most likely overestimated given the reduction in HAL stocks since 2001.

RIMPUFF was developed to simulate the release of radioactivity from nuclear power plants. RIMPUFF models aerosols and it would be reasonable to assume that a portion of the releases due to a serious accident at a nuclear power plant would be in aerosol form. This current study has focused on a release from the Sellafield HAST tanks which contains a suspension of radionuclides in nitric acid (which is an aqueous solution). It is possible that a release from the HAST tanks would consist of mainly water vapour which would quickly condense and deposit close to the release site. If this is the case, the predicted doses for Ireland may be a significant overestimate but they do provide a 'bounding estimate' for the purposes of impact assessment and emergency planning.

All of the above radiation doses for the different release scenarios and dates were then compared to the internationally accepted intervention levels above which protective actions to reduce radiation doses are recommended (Table 7).

For each of the four scenarios for the May and November release dates, the predicted radiation doses immediately after the passage of the plume and one week after the passage of the plume were below the intervention levels for protective actions set out in Table 7. The predicted radiation dose from inhalation, cloudshine and groundshine was conservatively estimated to be between 2,000 and 8,000 μSv one year after a release in May and between 33,000 and 97,000 μSv one year after a release in November. These predicted doses are below the intervention level recommended for temporary relocation of 100,000 μSv for the first year, but only marginally below in the

case of Scenario C – a meteorite impact in November. The major part of this dose is attributable to groundshine which would likely be lower than predicted due to the removal of surface contamination from the ground (by rain or deliberate washing of paths/roads) or ploughing of land.

Table 7. Emergency intervention levels for various protective actions IAEA (2011) and RPII (2013)

Protective action	Intervention level (in terms of projected radiation dose)	Notes
Sheltering (staying indoors)	10,000 μ Sv over two days	Most effective during passage of the plume. Can reduce radiation doses from all radionuclides and groundshine, cloudshine and inhalation pathways by up to 80%
Evacuation	International guidance: 100,000 μ Sv in one week	
Temporary relocation	30,000 μ Sv in 1 st month 100,000 μ Sv in 1 st year	Largely to avoid radiation dose from groundshine pathway
Food controls	5,000 μ Sv per annum from food ingestion	In the EU, intervention levels for food controls are defined based on maximum permitted levels (of radioactivity in food) rather than on predicted radiation doses, however the use of this intervention level is a useful screening tool to identify where further assessment of predicted radioactivity levels in food is required

5.2 Ingestion doses

The predicted radiation doses from ingesting contaminated foods were calculated using the ECOSYS model. These radiation doses were treated separately as, in an emergency situation, the implementation of food controls and agricultural measures can substantially reduce the transfer of radioactivity to the foodchain. In this study, dose assessments were made on the assumption that no protective actions were implemented. Thus, the radiation doses predicted (Table 8 and Table 9) represent an overly pessimistic estimate of what might be expected for the release scenario/weather combinations studied.

Table 8. Summary of ingestion doses (μSv) to adults one year after a May release date

	Combined radiation dose from inhalation, cloudshine and groundshine (μSv)	Ingestion dose (μSv)
Scenario A (May)	2,900	150,000
Scenario B (May)	3,000	120,000
Scenario C (May)	8,000	370,000
Scenario D (May)	2,300	170,000

Table 9. Summary of ingestion doses (μSv) to adults one year after a November release date

	Combined radiation dose from inhalation, cloudshine and groundshine (μSv)	Ingestion dose (μSv)
Scenario A (Nov)	33,000	79,000
Scenario B (Nov)	40,000	93,000
Scenario C (Nov)	97,000	220,000
Scenario D (Nov)	37,000	88,000

The highest radiation dose are predicted from Scenario C (meteorite impact) at 378,000 μSv after one year for the May release date. If no protective actions were taken, a dose of this magnitude might be expected to result in an observable increase in cancers in the decades following the accident. For comparison, the annual average radiation dose from all sources of radiation received by the Irish population is estimated to be 4,037 μSv (RPII, 2014). It is clear that for all of the release scenarios considered in this study, one year after the incident the vast majority of the total radiation dose would be expected to arise from ingestion of contaminated food as shown in Figure 4. With the appropriate food and agricultural controls, the radiation dose due to ingestion could be largely avoided.

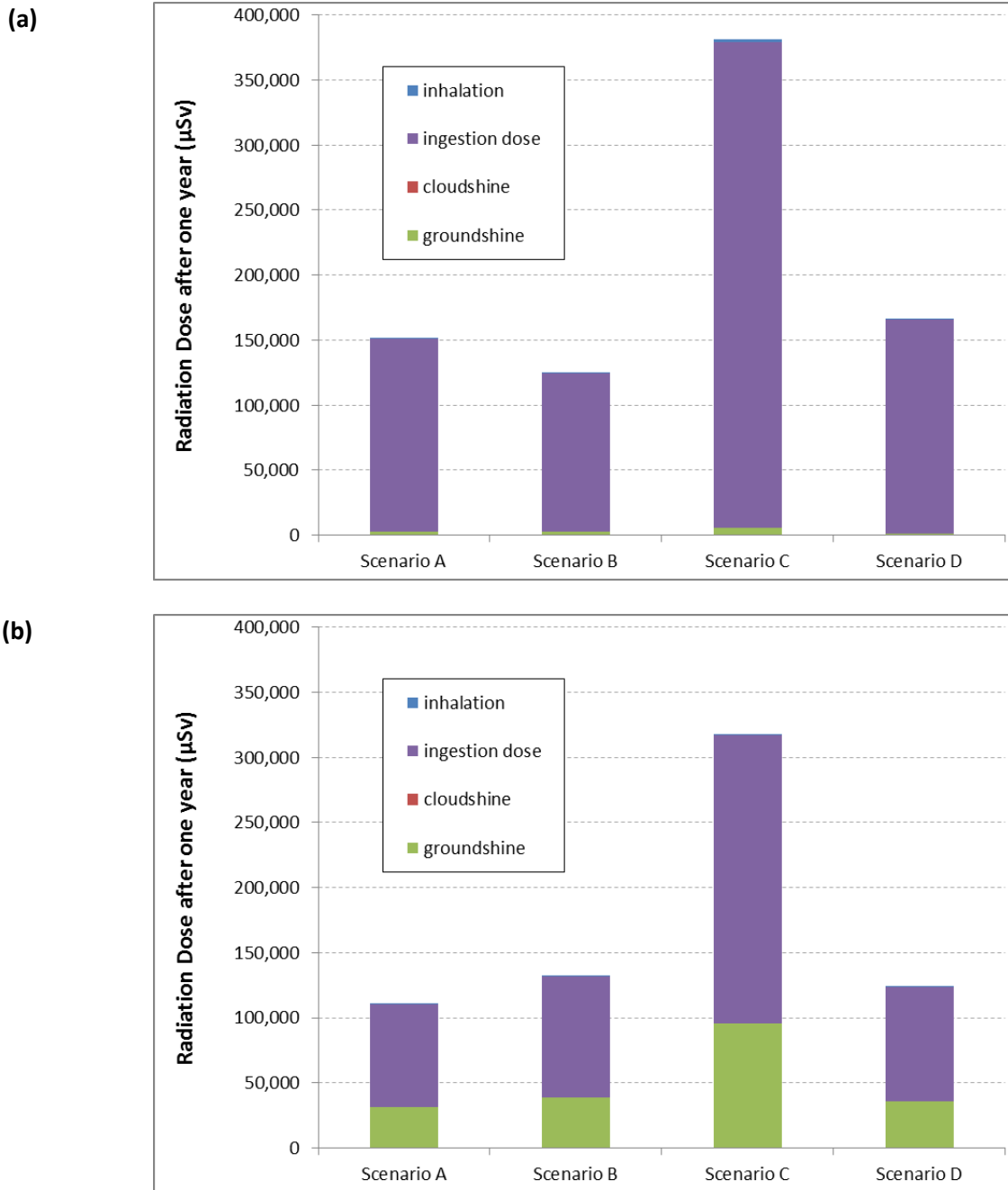


Figure 4. Predicted radiation dose after one year by pathway and source: (a) May release date and (b) November release date

A screening analysis to determine which release scenarios may result in the Maximum Permitted Levels (MPLs) being exceeded in certain foods was carried out by considering the radiation dose from ingestion (in one year); if this exceeds a few thousand micro-sievert (typically 1,000 to 5,000 μSv) then some food controls or agricultural protective actions are likely to be required. As can be seen from Table 8 and Table 9, food controls or agricultural protective actions may be required for all of the release scenarios and dates considered.

The time of the year at which an incident occurs will have an impact on the ingestion doses received by the affected population. It is evident in Figure 4 that the ingestion dose following an accidental release in May is much greater than the ingestion dose received following a November release⁴. This reflects the food growth season i.e. more growth in May than in November. In the examples shown in Figure 4, the contribution to the total radiation dose from ground deposition is much more significant following the release in November due to the higher amount of rain.

As previously noted, most of the ingestion dose can be avoided by the restriction of sale of contaminated food and other agricultural measures taken to reduce transfer of radioactivity into food products. It is important to note that while such protective actions can be highly effective in reducing radiation doses, their implementation is not always straightforward and there will normally be an associated economic cost and issues concerning the disposal of contaminated foodstuffs. In addition, experience of food contamination issues suggests that, even in cases where the EU Maximum Permitted Levels are not exceeded (see §5.4), the economic consequences from loss of market due to the perception that food is contaminated can be considerable.

5.3 Potential impacts on food

Contamination levels in food tend to decrease significantly with time after the first growing season. The variations in activity concentrations of caesium-137 in a range of food types over this one year period are presented in Figure 5. These have been calculated for the Scenario C accident occurring in May – the release date studied that corresponds to the highest growth season. The activity concentrations in food presented are those which would be expected following typical storage times and processing. Although plans are in place for protection of the foodchain as part of the National Emergency Plan for Nuclear Accidents (DECLG, 2005), in order to quantify “worst case” radiation doses it has been assumed that no protective actions were implemented.

5.3.1 Plant-based foods

In Figure 5(a), leafy vegetables (assumed to be growing in the open) are immediately contaminated by foliar uptake of deposited radionuclides. Leafy vegetables are

⁴ The RPII's assessment of the potential radiological implications for Ireland of the proposed nuclear power plants in the UK also predicted higher ingestion doses during summer months (RPII, 2013).

particularly prone to intercepting particles scavenged from the plume by rainfall (wet deposition). Leafy vegetables, such as salad leaves, are assumed to be consumed throughout the growing season. The radioactivity concentrations fall off rapidly due to the influence of various factors including weathering, growth dilution and replacement of contaminated crops by new growth. Other plant foods take longer for increases in concentrations to appear as they are not harvested until sometime after deposition and so radioactivity levels have decreased by the time they are available for consumption (e.g. fruits) or the edible parts of the plant grow underground and so the amount of radioactivity that can transfer to the food is limited (e.g. potatoes).

5.3.2 *Meat*

As shown in Figure 5(b), the increases in activity concentrations of caesium-137 in meat (beef and lamb) take longer to build up (approximately five weeks) due to the delay between the animals consuming contaminated pasture and radioactivity transferring to their muscle (meat). The levels fall off in the autumn as contaminated pasture is replaced by new grass growth and as the contamination is removed from the animals through natural processes such as excretion. The radionuclide concentrations in meat increase again following the switch to winter feeding regimes in November as it is assumed that hay and silage has been made from contaminated grass. In reality, it's reasonable to assume that alternative animal feed would be sourced before the switch to winter feeding regimes and so this second peak need not occur. Indeed, if alternative animal feed or special additives that reduce the transfer of caesium into the animal are sourced soon after the accident, the first peak in radioactivity levels in meat could be substantially reduced or avoided. While these protective actions can be very effective, there are significant economic and resource costs associated with their implementation.

5.3.3 *Dairy produce*

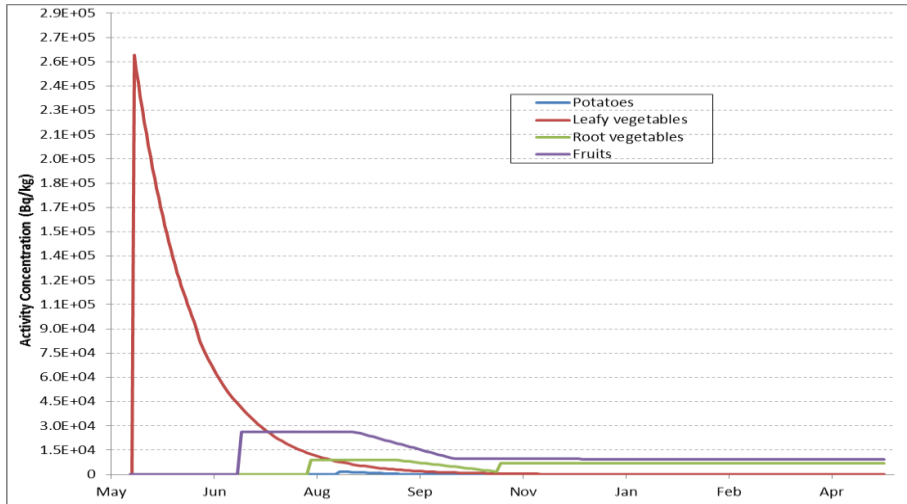
In the case of dairy produce, Figure 5(c), the radioactivity concentrations in milk increase rapidly as the contamination on pasture ingested by grazing dairy cows is quickly transferred to the milk and there is a relatively short time between production of the milk by cows and it being available for purchase. Most caesium in milk products is transferred to the skimmed milk portion at separation and, hence, butter shows relatively low levels of caesium-137. As condensed milk is a concentrated product, higher concentration values are predicted but it is not consumed in very large quantities so the resulting radiation doses are not high. Again, no allowance has been made for the fact that

alternative feed supplies or feed additives could be used to eliminate or reduce the transfer of radioactivity from grass into milk.

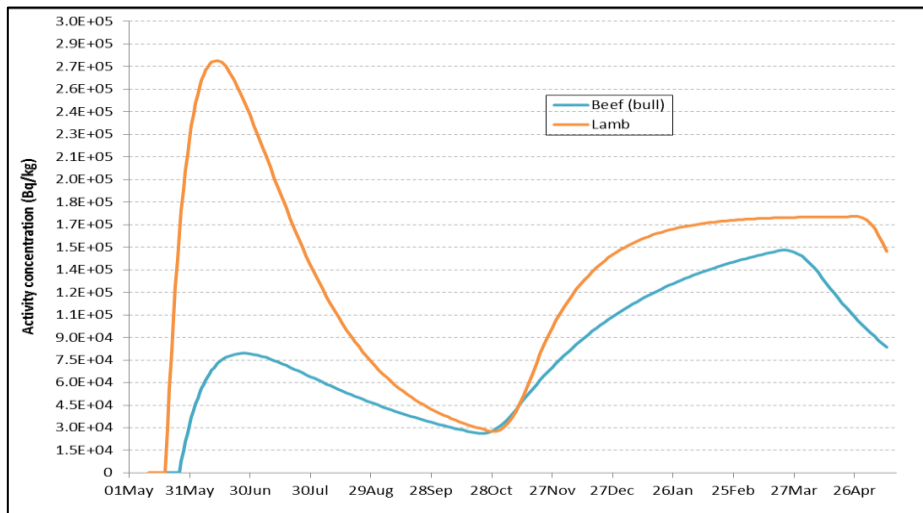
5.3.4 Longer-term contamination levels

Over the longer-term (months to years), radioactivity deposited on soil migrates downwards and reaches the part of soil containing roots. The time of residence of radioactivity in this part of the soil determines its transfer to vegetation. Observations strongly suggest that the downward migration profiles in soil are established very early after contamination under the influence of the conditions prevailing immediately after contamination, such as soil moisture and first rain events (Bréchignac et al., 2000). The further the radioactivity penetrates into the soil, the less the transfer into the food and animal feed grown in that soil and the lower the groundshine radiation dose to people.

(a) Plant foods



(b) Meat



(c) Dairy produce

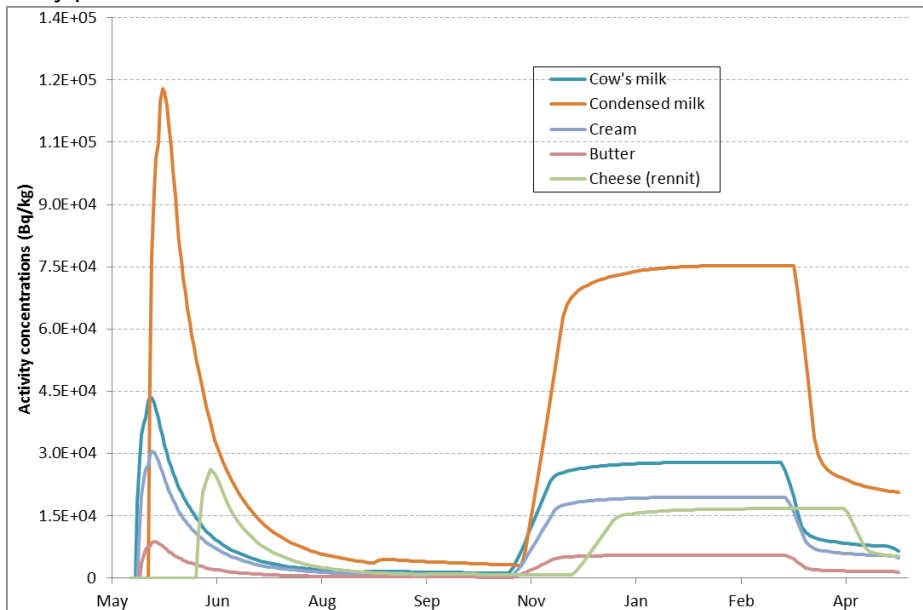


Figure 5. Activity concentrations of caesium-137 in different food groups (for Scenario C occurring in May)

5.4 Comparison of radioactivity concentrations in food with EU Maximum Permitted Levels

Maximum permitted levels (MPLs) for radioactivity in food and animal feed following a nuclear accident or any other radiological emergency destined for sale within the European Union have been established in EU legislation (Table 10 and Table 11). In the event of a nuclear accident, these regulations will be automatically implemented in all EU Member States for a period of three months following the accident during which time, depending on the characteristics of the specific accident, the values of the MPLs may be revised or their application extended.

Following a nuclear or radiological emergency with the potential to affect Ireland, emergency intervention levels would be implemented in order to restrict access to contaminated food thereby minimising the radiological risk, especially to children; and to maintain the safety of, and public confidence in, the commercial food supply. Foods with measured or predicted activity concentrations exceeding the levels would be expected to be replaced with alternative supplies. This assumes the availability of adequate alternative supplies. Controls could also apply to animal feed to ensure that meat and other animal products meet the MPLs for foodstuffs.

Table 10. Maximum permitted levels (MPLs) for foodstuffs (from Council Regulations (EURATOM) No. 2218/89 and No. 770/90)

	MPL in foodstuffs (Bq/kg or Bq/l) ⁽¹⁾			
	Baby foods	Dairy produce	Other foodstuffs except minor foodstuffs	Liquid foodstuffs
Isotopes of strontium, notably Sr-90	75	125	750	125
Isotopes of iodine, notably I-131	150	500	2,000	500
Alpha-emitting isotopes of plutonium and transplutonium elements, notably Pu-239 and Am-241	1	20	80	20
All other radionuclides of half-life greater than 10 days, notably Cs-134 and Cs-137	400	1,000	1,250	1,000

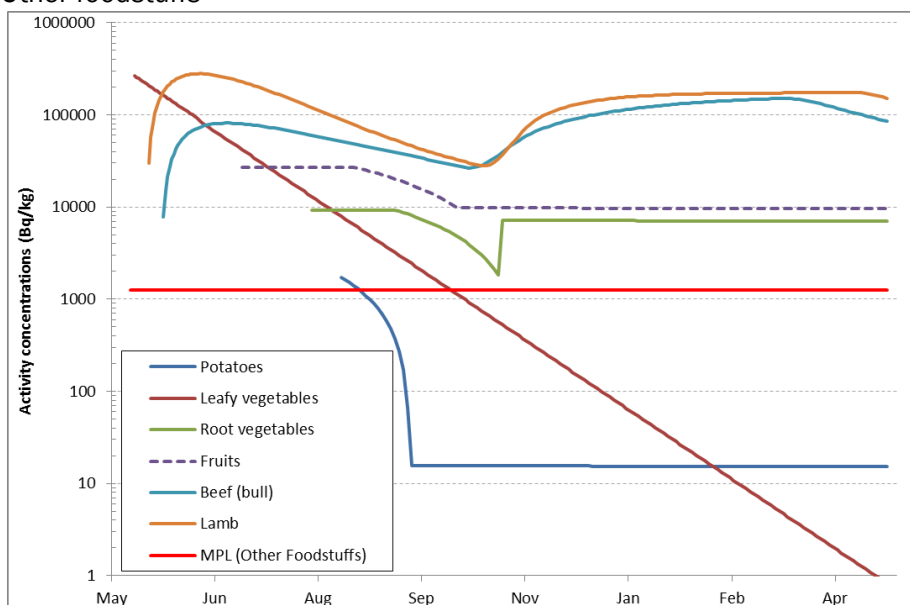
⁽¹⁾ The level applicable to concentrated or dried products is calculated on the basis of the reconstituted product as ready for consumption.

Table 11. Maximum permitted levels (MPLs) for animal feed (from Commission Regulation (EURATOM) No. 770/90)

Animal feed	MPL for caesium-134 + caesium-137 (Bq/kg)
Pigs	1,250
Poultry, lambs, calves	2,500
Other	5,000

The activity concentrations predicted for the accident scenario resulting in the highest radioactivity levels in food have been compared with the EU MPLs. The results of this comparison for dairy produce and other foodstuffs are presented in Figure 6. Analysis of the data clearly shows that, in the absence of any protective actions to reduce or eliminate the contamination of food and animal feed, radioactivity concentrations in many of the food types assessed would exceed the MPLs for a period beyond one year. These results highlight the importance of putting appropriate measures in place to prevent the transfer of radioactivity to foods, where possible, or to reduce it significantly. For example, the second peak in caesium-137 activity concentrations in dairy produce (see Figure 5(c)) could be eliminated by feeding dairy cattle or animals destined for slaughter alternative 'clean' feed. This would be highly effective in eliminating the transfer of radioactivity to animals and, thus, meat and dairy produce but it would have significant costs associated with it as animal feed would need to be sourced from elsewhere.

(a) Other foodstuffs



(b) Dairy produce

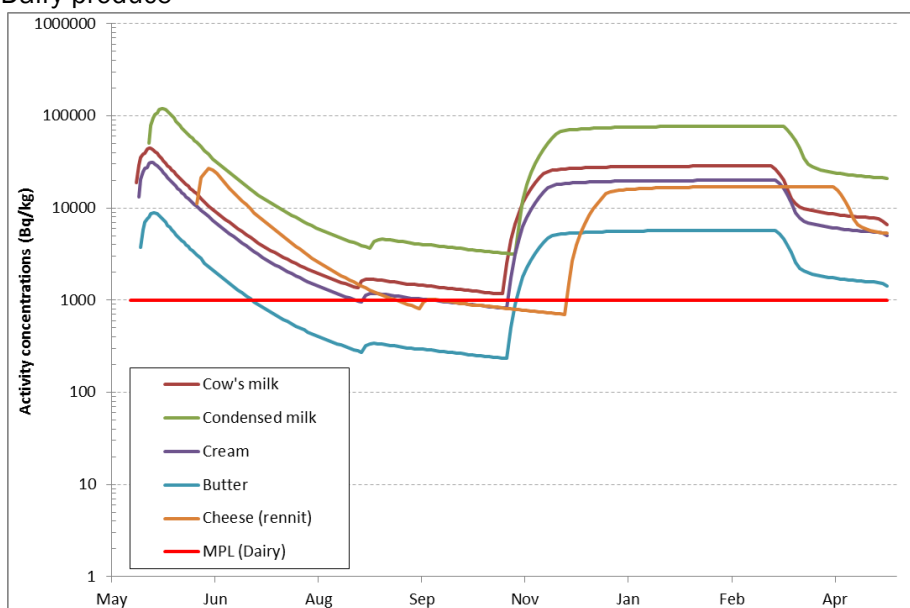


Figure 6. Comparison of radionuclide concentrations in (a) Other foodstuffs and (b) Dairy produce with EU Maximum Permitted Levels (MPL) for the 'All Other Radionuclides' Group (for Scenario C occurring in May)

6 Conclusion and summary

This report outlines the findings of the EPA's assessment of the potential radiation doses to the Irish public following a number of severe hypothetical accidents that were identified as part of a Probabilistic Risk Assessment (PRA) of the Sellafield site. An atmospheric dispersion model was used to simulate the transfer of radioactivity to Ireland following a release from the Sellafield site. This used weather scenarios that were identified as 'worst case' in terms of potential impact on Ireland. These weather conditions comprised easterly winds and rain over the east coast of Ireland during the passage of the plume. During these weather conditions, a radioactive plume arising from Sellafield would travel across Ireland depositing radioactive material along its path. The scenarios with the most significant impacts on Ireland were then analysed using an ingestion dose model to simulate the transfer of radioactivity in the food chain. It should be noted that the occurrence of the specific weather conditions used in the model simulations has a low likelihood. For almost 90% of the time, the prevalent meteorological conditions in Ireland would result in any radioactive plume from Sellafield travelling in an easterly direction (away from Ireland).

For each of the release scenarios considered, the radiation doses to people in Ireland were calculated for three time periods: during the plume passage over Ireland, one week after and finally one year after the radioactive plume had passed. In all cases, the radiation doses received from the inhalation, cloudshine (radioactivity in the air) and groundshine (radiation deposited on the ground) pathways were predicted to be below levels requiring public protective actions such as sheltering, relocation or evacuation. While, the estimated radiation doses are not predicted to exceed the intervention level for sheltering, time spent indoors during plume passage could reduce this radiation dose significantly. If people stayed indoors during the hours the radioactive plume was passing over, these radiation doses could be reduced by up to 80% (depending on the building type).

The radiological impact on Ireland was found to be greatest following a hypothetical meteorite impact on the Sellafield site during the 'worst case' weather period in May. In this scenario, the radiation dose resulting from inhalation, cloudshine and groundshine was found to be just over 8,000 μSv . In addition, the radiation dose from the ingestion of foods containing the radioactivity could be over 370,000 μSv if no protective actions were taken. A dose of this magnitude might be expected to result in an observable increase in cancers in the decades following the accident. For comparison, the annual

average radiation dose from all sources of radiation received by members of the Irish public is estimated to be 4,037 μSv (RPII, 2014).

Ireland has a National Emergency Plan for Nuclear Accidents (NEPNA) to provide a coordinated emergency response to a situation where there is widespread radioactive contamination in Ireland (DECLG, 2005). The goal of NEPNA is to minimise the impact on Ireland and its people in the event of a major nuclear accident abroad. NEPNA includes guidance on protective actions such as sheltering and food controls to reduce the radiation dose received by the population. While these controls have been shown to be very effective in controlling radioactivity levels in foods for sale, and hence radiation doses to people, they do have significant socio-economic implications and costs. This includes the loss of tourism and markets for Irish seafood and farm products because of consumer concerns regarding the levels of artificial radioactivity. Concerns will likely exist even if monitoring data confirms that all food for sale or export complies with the limits set to protect consumer health. These effects could last for months or years following an accident, depending on the severity of the accident and the prevailing weather at that time. The Irish Government commissioned the Economic and Social Research Institute (ESRI) to carry out a study to assess the Potential Economic Impact on Ireland of a Nuclear Incident. A report on this study is due to be published in autumn 2016.

As noted above, if no protective actions are taken in response to the various accident scenarios, the potential radiation doses might be expected to result in an observable increase in cancers in the decades following the accident. This emphasises the importance of the introduction of effective food controls as highlighted in NEPNA.

7 References

- Andersson, K.G. et al., 2011. Revision of deposition and weathering parameters for the ingestion dose module (ECOSYS) of the ARGOS and RODOS decision support systems. *Journal of Environmental Radioactivity*, 102, pp.1024-31.
- Bley, D., Kaplan, S. & Johnson, D., 1992. The strengths and limitations of PSA: where we stand. *Reliability Engineering and System Safety*, 38, pp.3 - 26.
- Bréchnignac, F., Moberg, L. & Suomela, M., 2000. *Long-term environmental behaviour of Radionuclides*. Paris: CEC-IPSN Association.
- DECLG, 2005. *National Emergency Plan for Nuclear Accidents (NEPNA)*. [Online] Available at: <http://www.environ.ie/en/Environment/EnvironmentalRadiation/NationalEmergencyPlan/> [Accessed 12 November 2014].
- DECLG, 2012. *Risks to Ireland from Incidents at the Sellafield Site*. [Online] Dublin: DECLG Available at: <http://www.environ.ie/en/Environment/EnvironmentalRadiation/PublicationsDocuments/FileDownload.31607.en.pdf> [Accessed 2 December 2014].
- EPA, 2015. *Radioactivity Monitoring of the Irish Environment 2012–2013*. Wexford: EPA Office of Radiological Protection.
- HIRLAM, 2013. *HIRLAM (High Resolution Limited Area Model)*. [Online] Available at: <http://hirlam.org/> [Accessed 24 March 2013].
- IAEA, 2007. *IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection*. Vienna: International Atomic Energy Agency IAEA.
- IAEA, 2011. *Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency*. General Safety Guide No. GSG-2. Vienna: IAEA IAEA.
- IUNA, 2011. *National Adult Nutrition Survey*. Summary Report on Food and Nutrient intakes, Physical Measurements, Physical Activity Patterns and Food Choice Motives. IUNA.
- Müller, H. & Pröhl, G., 1993. ECOSYS-87: A Dynamic Model for Assessing Radiological Consequences of Nuclear Accidents. *Health Physics*, 64, pp.232-52.
- NEA, 1994. *The Economics of the Nuclear Fuel Cycle*. Paris: OECD NEA OECD Nuclear Energy Agency.
- ONR, 2011. *The Storage of Liquid High Level Waste at Sellafield: Revised Regulatory Strategy*. Liverpool: ONR.
- ONR, 2011. *The Storage of Liquid High Level Waste at Sellafield: Revised Regulatory Strategy*. [Online] ONR Available at: <http://www.onr.org.uk/halstock-sellafield-public.pdf> [Accessed 10 March 2016].
- ONR, 2014. *ONR quarterly news (October - December 2014)*. Liverpool: ONR Office for Nuclear Regulation.

ONR, 2015. *HAL Stocks: Project Assessment Report – HAL Stocks Specification*. Report ONR-SEL-PAR-14-015. Liverpool: Office for Nuclear Regulation ONR.

RPII, 2005. *Report of the RPII Visit to BNFL Sellafield*. Dublin: RPII.

RPII, 2012. *Radioactivity Monitoring of the Irish Environment 2010–2011*. RPII 12/02. Dublin: RPII Radiological Protection Institute of Ireland.

RPII, 2013. *Proposed nuclear power plants in the UK – potential radiological implications for Ireland*. Dublin: RPII.

RPII, 2014. *Radiation Doses Received by the Irish Population*. RPII 14/02. Dublin: RPII Radiological Protection Institute of Ireland.

Thørring, H., Ytre-Eide, M.A. & Liland, A., 2010. *Consequences in Norway after a hypothetical accident at Sellafield - Predicted impacts on the environment*. StrålevernRapport 2010:13. Østerås: Statens strålevern.

Turvey, F.J. & Hone, C., 2000. *Storage of Liquid High-Level Radioactive Waste at Sellafield: An Examination of Safety Documentation*. Dublin: RPII.

US EPA, 2010. *Technology Transfer Network: Support Center for Regulatory Atmospheric Modeling*. [Online] Available at: <http://www.epa.gov/scram001/dispersionindex.htm> [Accessed 12 November 2014].

8 Appendix 1: Models used to predict the dispersion of radioactivity in the air and transfer through the environment

8.1 Description of the RIMPUFF Atmospheric dispersion model

Atmospheric dispersion modelling uses mathematical formulations to characterise the atmospheric processes that transport and disperse a pollutant emitted by a source. RIMPUFF is a modular system which models a continuous release of radioactive materials by a series of consecutively released puffs. At each time step the model advects, diffuses and deposits the individual puffs according to local meteorological parameter values and calculates the gamma-radiation dose components from puffs and deposited radionuclides. The momentary concentrations and radiation doses in grid points are calculated from the increment of the time integrated concentration and from dose rates normalised by the time difference between initial data. A pre-processor converts meteorological data into the format required by the model. Correction of meteorological data for terrain heterogeneity is achieved by a wind flow module. The RIMPUFF model is driven by HIRLAM numerical weather prediction (NWP) data (HIRLAM, 2013), produced by Met Éireann. A subset of the full HIRLAM coverage, covering Ireland and the UK, is extracted and interpolated onto a 15 km square regular latitude longitude grid in a format suitable for the RIMPUFF pre-processor. The HIRLAM surface meteorological parameters used by RIMPUFF include precipitation intensity (mm/hour); atmospheric boundary layer height (m); surface sensible heat flux (W/m^2); and surface momentum flux ($kg/m.s^2$). The multi-level parameters used are geopotential height (m); wind speed (m/s) and direction (decimal degrees); virtual potential temperature (K); and specific humidity (kg/kg) (RPII, 2013).

A range of input parameters were used to characterise a release of radioactive material to the atmosphere in RIMPUFF. For this assessment, it was assumed that 4% of the caesium-134 and caesium-137 contents in a single HAST tank were released for each of the four PRA accident scenarios identified.

Three deposition classes are considered by RIMPUFF: gases (including elementary iodine), organically-bound iodine and aerosol-bound particles. A particle diameter of $1\mu m$ is assumed for the latter class. In effect radionuclides in particulate forms are simulated in exactly the same way with differences in calculated air concentrations, surface concentrations and radiation doses arising only as a result of radionuclide-specific parameters applied in post processing such as release concentrations, dose coefficients,

half-lives. It should be noted that, as a result of the assumption of a particle diameter of 1µm, this model systems tends to overestimate contamination from heavier particles. In this assessment, only one deposition class was applicable. Caesium releases were modelled as aerosol-bound particles. Iodine it is not contained in the HASTs and so was not considered by RIMPUFF

8.2 Description of ECOSYS

The ECOSYS ingestion dose model simulates the transfer of radioactivity in the food chain. This model has an important role in the EPA's emergency preparedness and response capability.

The most important compartments and transfer processes considered in ECOSYS simulate the time-dependent radionuclide contamination of food after accidental deposition onto agricultural land. These include: dry and wet deposition to, and interception by soil and plants; foliar uptake, weathering effects (rain, wind), radioactive decay and growth dilution; root uptake, fixation, desorption and leaching; resuspension of contaminated soil; translocation; transfer from animal feed to animal products; dilution and concentration resulting from processing of food and animal feed; and storage factors. The subsequent radiation exposure of people via the ingestion exposure pathways may also be calculated using the model. Further details on the model can be found in RPII (2013).

ECOSYS is supplied with default input datasets which describe agricultural, climatic and other conditions for Central European regions. These parameters are described in Müller & Pröhl (1993). Some of the default data, mainly element and radionuclide specific data such as environmental transfer factors and physical and biological half-lives, are applicable for all regions of interest. However some parameters are highly sensitive to the characteristics of the region where deposition takes place. The EPA has customised a number of the default parameter datasets to adapt the models for Irish conditions. Firstly the most significant crops, livestock and processed products used as food and animal feed and which are produced in Ireland were defined. Modified parameters then included: growing season, yields and maximum leaf area index for grass; dates for preparation of hay and silage; sowing and harvest dates for field and horticultural crops; variation of foliar coverage for field and horticultural crops; types and volume of feed fed to livestock at various periods during the year; average age of animals at slaughter; human food consumption rates (for calculation of ingestion dose) (IUNA,

2011). The (mean) food consumption rates used in this assessment are given in Table 12.

Table 12. Food consumption rates assumed for assessment of accident scenarios

ECOSYS food group	Adult consumption rates (kg/y)	
	Mean	95 th Per.
Cow's milk	77.4	336.9
Condensed milk	17.9	85.8
Cream	0.4	2.9
Butter	1.1	6.9
Cheese	5.1	17.5
Potatoes	43.8	144.2
Root vegetables	26.3	109.9
Green vegetables	26.3	109.9
Fruit	17.9	71.9
Beef	25.4	117.2
Lamb	4.9	31.9

Other parameters from the default datasets were verified to ensure consistency with the modified datasets mentioned above. These included: deposition velocities for the crop types considered; growth dilution rates for pasture; element specific factors including soil-plant transfer factors; retention coefficients and translocation factors for the crop types considered; element specific factors including feed-animal transfer factors and biological half-lives and metabolism factors for the livestock types considered; processing and storage factors for the foods and animal feeds considered. Recent updates to some parameters: weathering half-life and dry deposition velocities - reported by (Andersson et al., 2011) were also verified for this analysis. Differences in soil-plant transfer due to variations in soil properties were neglected as a first approximation as in the early stages of an emergency, foliar deposition is the key consideration.

In order to run the ECOSYS foodchain and dose model, parameters describing a specific radiological deposition event are required, namely:

- the time-integrated activity concentration (TIAC) in near-ground air
- wet deposition levels;
- precipitation intensity
- date and time of the deposition event

These were derived from the atmospheric dispersion model and numerical weather prediction data).

9 Glossary

- **HAL:** Highly Active Liquor
- **HALES:** Highly Active Liquor Evaporation and Storage
- **HAST:** Highly Active Storage Tanks
- **HLW:** High-level radioactive waste
- **ILW:** Intermediate-level radioactive waste
- **LLW:** Low-level radioactive waste
- **LLWR:** Low-level waste repository
- **Nuclear Facility:** A facility (including associated buildings and equipment) in which nuclear material is produced, processed, used, handled, stored or disposed of (IAEA, 2007)
- **PRA:** Probabilistic Risk Assessment, a comprehensive, structured approach to identifying failure scenarios, constituting a conceptual and mathematical tool for deriving numerical estimates of risk (IAEA, 2007)
- **Raffinate:** The portion of an original liquid that remains after other components have been dissolved by a solvent - the liquid left after a solute has been extracted by solvent extraction
- **RPIL:** Radiological Protection Institute of Ireland
- **WVP:** Waste Vitrification Plant

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL

Tá an Gníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaoil a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaoil a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithhe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.

Eolas: Soláthraimid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithé agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.

Tacaíocht: Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaoil atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaoil inbhuanaithe.

Ár bhFreagrachtaí

Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaoil:

- saoráidí dramhaíola (*m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola*);
- gníomhaíochtaí tionsclaíocha ar scála mór (*m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta*);
- an diantalmhaíocht (*m.sh. muca, éanlaith*);
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe (*OGM*);
- foinsí radaíochta ianúcháin (*m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíochta*);
- áiseanna móra stórála peitрил;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdarás áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhírú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a idíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaoil.

Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uisce idirchríosacha agus cósta na hÉireann, agus screamhuiscí; leibhéal uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaoil

- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil (*m.sh. tuairisciú tréimhsiúil ar staid Chomhshaoil na hÉireann agus Tuarascálacha ar Tháscairí*).

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil

- Taighde comhshaoil a chistiú chun brúnna a shainiú, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta

- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaoil in Éirinn (*m.sh. mórphleananna forbartha*).

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéal radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas

- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaoil ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaoil (*m.sh. Timpeall an Tí, léarscáileanna radóin*).
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht comhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an gníomhaíocht á bainistiú ag Bord Iánamseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:

- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- An Oifig um Cosaint Raideolaíoch
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair inní agus le comhairle a chur ar an mBord.



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