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Planning Department.

15th June, 2023.

By Email to: nuclear@economie.fgov.be
FPS Economy,
SMEs, Self-employed and Energy,
Public Consultation Doel 4 and Tihange 3,
Boulevard du Roi Albert II 16,
1000 Brussels.

Re: Transboundary Environmental Public Consultation -Belgium Doel 4 and Tihange 3.

Dear Sir/Madam,

I refer to the above-mentioned Transboundary Environmental Public Consultation in relation to the proposed 10 year extension to the operational life of the Doel 4 and Tihange 3 nuclear power plants. Please note that Meath County Council has no comment to make in relation to same.

Yours Sincerely,

Alan Russell

Alan Russell,
Senior Executive Planner.

Transboundary Environmental Public Consultation – Doel 4 & Tihange 3 Nuclear Power Plants

The Environmental Protection Agency (EPA) is an independent public body in Ireland established under the Environmental Protection Agency Act 1992. The EPA has responsibilities for a wide range of licensing, enforcement, monitoring and assessment activities associated with environmental protection and protection of people from the harmful effects of ionising radiation, both natural and human-made

The EPA welcomes this opportunity to participate in the Transboundary Environmental Impact Assessment public consultation being undertaken in relation to the proposed 10-year extension of the operational life of the Doel 4 and Tihange 3 nuclear reactors in Belgium and their related nuclear safety works.

A short summary of the Environmental Impact Assessment Report reviewed by EPA is provided in section 1 of this document. EPA's assessment of the potential impact on Ireland from the Long-Term Operation (LTO) of Doel 4 and Tihange 3 is provided in section 2.

1. Introduction

The Doel and Tihange Nuclear Power Plants in Belgium are operated by ENGIE Electrabel SA. Doel Nuclear Power Plant (Doel NPP) contains four nuclear reactors, Tihange NPP contains three reactors. Both Doel 4 and Tihange 3 began operations in 1985 and were due to cease operation in 2025.

In January 2023, the Belgian government and operator ENGIE Electrabel SA came to an agreement to keep the country's two youngest nuclear reactors (Doel 4 and Tihange 3), open for a further 10 years beyond their planned 2025 shut down date. The latest date for shutdown of both units if extended by 10 years is December 2037.

This lifetime extension is subject to an Environmental Impact assessment (EIA) and a public consultation under the Espoo and Aarhus Conventions and the EIA Directives.

1.1. Methodology for the Environmental Impact Assessment (EIA)

The EIA to examine the impacts of the LTO of Doel 4 and Tihange 3 and related nuclear safety works is termed the 'project'. The related nuclear safety works considered in the EIA include both design improvements and ageing management. Design improvements include managing potential heat waves and associated temperatures, strengthening the habitability of emergency planning centres in case of severe accidents, and additional (mobile) cooling systems for irradiated nuclear fuel, which can be switched on in accident situations. With regard to ageing management, the safety authority (the Federal Agency for Nuclear Control) estimates that the large mechanical components (reactor vessel, reactor cover, steam generators) do not need to be replaced; for other components (smaller mechanical components such as pumps or valves, electrical equipment, instrumentation, civil structures), there will only be a complete picture of the possible replacement works once Electrabel SA has completed its studies. The EIA has four parts.

1. The first part describes the general framework and methodology used in the project.
2. The second part outlines the EIA for Doel 4 which addresses both radiological and non-radiological impacts of the LTO of the reactors
3. The third part outlines the EIA for Tihange 3 which addresses both radiological and non-radiological impacts of the LTO of the reactors.
4. The final part summarises the outcomes of the EIA project.

The EIA examines two scenarios –

- the LTO of Doel 4 and Tihange 3 and related nuclear safety works and
- the baseline state where Doel 4 and Tihange 3 are permanently shut down in 2025.

This EIA analysed the difference between the baseline scenario and the expected situation as part of the LTO using existing data up to 2022, as well as projected data for the period 2023 to 2025.

2. EPA Assessment of the Potential Impact on Ireland from the LTO of Doel 4 and Tihange 3

The Doel Nuclear Power Plant (NPP) is situated approximately 730 km from the east coast of Ireland and the Tihange NPP is approximately 820 km from the east coast of Ireland. This is greater than the recommended maximum IAEA Ingestion and commodities planning distance (ICPD) of 300 km for reactors with a thermal output in excess of 1,000 MW (the nominal thermal power for the Doel 4 and Tihange 3 reactors are 1,038 MW). Within the ICPD, arrangements are required to take response actions for protecting the food chain, water supply and other commodities from contamination and for protecting the public from the ingestion of food, milk and drinking water and from the use of commodities other than food with possible contamination following a significant radioactive release.

Although Ireland falls outside the ICPD for the Doel and Tihange NPP, it is within the 1,000 km distance that the IAEA uses to designate States as falling into Zone 1 for emergency response purposes. The IAEA considers States that are within 1,000 km of an Accident State to be more likely to be affected by a nuclear emergency there. In the event of a nuclear emergency, direct liaison is established by IAEA with these Zone 1 States and information on monitoring results and protective actions planned/taken in those Zone 1 States may be requested.

2.1 Potential Impact from Routine Operation

Currently, during routine operations, the dose to the most exposed person arising from routine discharges from the Doel 4 and Tihange 3 reactors are indistinguishable from natural variability in background radiation. In addition, there are no transboundary effects on humans or the environment during the normal current operation of the Doel 4 and Tihange 3 reactors. If Doel 4 and Tihange 3 are extended for another 10 years beyond 2025, liquid and gaseous discharges under normal operation will be of the same level as those currently resulting from the operation of Doel 4 and Tihange 3.

The continued operation of Doel 4 and Tihange 3 for a further ten years will lead to additional radioactive waste and spent fuel. There will be a small increase in radioactive waste (approximately 2%) and these will be processed and stored in Belgium. Spent fuel assemblies will processed and stored at new Spent Fuel Storage facilities currently under construction at the Doel and Tihange NPP. No cross-border impacts are anticipated from the processing and storage of waste and spent nuclear fuel.

2.2 Potential Impact from Accidents

Three reference accident scenarios were considered as part of the EIA for Doel 4 and Tihange 3:

1. A Loss of Coolant Accident (LOCA),
2. a Fuel Handling Accident (FHA) and
3. a Complete Station Blackout (CSBO) with core melt.

Both the LOCA and FHA are considered design basis accidents, whereas the CSBO with core melt would be considered a beyond design basis accident.

Despite the fact that Doel 4 and Tihange 3 reactors are of the same type and power, differences have been noted in the effects for the same accident scenarios. This is because of the differences in design and safety systems at the two sites. The dose to a member of the public for the design basis accidents (LOCA and FHA) for both Doel 4 and Tihange 3 were found to be lower than the applicable limits described in the General Data under Article 37 of the Euratom Treaty as part of their original licence applications.

Although the probability of these accidents is very small, an assessment of the transboundary impacts of the three accident scenarios (LOCA, FHA and CSBO) were conducted. These assessments have shown that the accidents meet the licensed limits for the neighbouring countries of the Netherlands, France, Germany, Luxembourg and the United Kingdom.

For both Doel 4 and Tihange 3, the accident scenario that would result in the highest Total Effective Dose for neighbouring countries would be the CSBO. The dose in the UK as a result of a CSBO accident at Doel 4 is reduced by a factor of 22 when compared to the dose at the Dutch border and the dose to the UK as a result of a CSBO accident at Tihange 3 is reduced by a factor of 12 compared to the dose at the French border. The impact on Ireland would be considerably lower than that estimated for the UK and France given that the impact of any accident decreases with distance. Therefore, it was concluded that a CSBO accident at Doel 4 or Tihange 3 there would be a non-significant radiological impact on Ireland.

3. Conclusion

There is no measurable radiological impact expected from the routine releases from Doel 4 and Tihange 3. After implementation of all nuclear safety works it is expected that there is a lower probability of an accident resulting in radioactive discharges during the operational phase than in the baseline situation.

A severe accident at either of these sites in conjunction with unfavourable weather conditions could give rise to limited radioactive contamination in Ireland. Even if no or very little radioactive contamination is deposited in Ireland, a 2016 study by the Economic and Social Research Institute has shown that a large-scale nuclear accident occurring anywhere in north-western Europe would have a negative impact on Ireland's economy.

Kevin Kelleher
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20 June 2023

The Potential Economic Impact of a Nuclear Accident - An Irish Case Study

Prepared by the Economic and Social Research Institute

for the Department of the Environment, Community and Local Government

John Curtis, Edgar Morgenroth, Bryan Coyne

21 April 2016

This paper has been peer reviewed. The authors are solely responsible for the content and the views expressed. The Institute does not itself take institutional policy positions.

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Executive Summary

International experience of major nuclear accidents, including the Chernobyl and Fukushima Dai-ichi accidents, has shown that such accidents can have significant economic consequences in addition to impacts on health, environment and society. This report focuses on the potential economic costs that would be associated with a nuclear accident close to Ireland in north-western Europe. Developing estimates of the scale of economic losses that would arise in the event of a nuclear accident serves a number of useful purposes. Firstly, such information can inform decisions related to whether it is in Ireland's interests to be a signatory to a number of international treaties and conventions concerning nuclear emergencies, remediation and liabilities. Secondly, the analysis should help inform national positions on policy and legislative developments in Europe and internationally with respect to the nuclear risks and management. Finally, an assessment of the economic vulnerabilities will help inform emergency management and mitigation policies. It must be stressed that the risk of a nuclear accident is very small, and particularly so with respect to other energy sources (NEA-OECD, 2010).

Estimating the economic impacts of a nuclear accident is fraught with difficulty. The approach adopted in this report is to develop a systematic methodology to estimate costs and losses directly attributable to an accident, as well as any losses associated with reputational damage that might arise if Ireland was widely perceived to be within the geographical zone affected by an accident, e.g. in export markets. The methodology employed is not exhaustive but focuses on the sectors and activities where the impacts are likely to be of significant magnitude and where suitable data is available to help quantify the potential losses. In particular the analysis considers direct and reputational impacts on tourism, agriculture and food, allowing not just for the immediate effects but also the longer-run reputational effects. In addition to estimating direct impacts and reputational losses in the agriculture, food and tourism sectors the analysis also estimates second round or indirect impacts to the wider economy. The analysis is likely to have omitted many potential losses and therefore, the estimates provided represent a lower bound estimate of total losses.

The scale of the physical or economic impact of a nuclear accident depends on the nature and severity of an accident, as well as, the prevailing weather conditions. Rather than consider the large range of potentially feasible outcomes that might arise in the event of a nuclear accident, we consider just four scenarios to develop indicative estimates of the scale of economic losses that might arise. These scenarios are designed to provide a spectrum of outcomes across different seasons and they comprise a scenario where there is no actual radiological impact on Ireland; one where there is some low-level contamination of the environment and food in Ireland; one where the degree of contamination of the environment and food in Ireland warrants food controls and agriculture protective actions for a number of months; and finally one encompassing significant contamination of the environment and food in Ireland such that people are advised to remain indoors as much as possible for up to 48 hours. It is important to note that the study does not assess the probability of any of the scenarios actually occurring. Rather, it aims to assess the potential cost to Ireland under alternative hypothetical scenarios.

Under **scenario one**, where there is no actual contamination in Ireland, the losses are assumed to be limited to reputational losses, particularly in relation to tourism and export markets, and the total discounted loss is estimated at **€4 billion**.

Scenario two assumes some low-level contamination in Ireland which requires the imposition of some food controls and agriculture protective actions for a number of days in order to reassure the public that there are no health concerns. In addition to reputational losses some direct losses are also incurred which relate to laboratory and monitoring costs. This scenario also assumes direct losses associated with restrictions on food imports from Ireland. The economic loss to Ireland in such a scenario is estimated to total **€18 billion**. The significantly larger loss compared to scenario one is explained by the wider set of losses as well as the longer time period over which losses are incurred.

Scenario three assumes moderate environmental contamination, requiring food controls and agriculture protection actions to be put in place for a number of months. In this scenario it is assumed that no protective actions for people are necessary. This scenario is assumed to occur in February (as opposed to May in all other scenarios), where winter feedstocks for animals have been largely used up requiring the purchase of feedstocks. Under this scenario more significant radiological testing and monitoring costs are incurred. The impact on exports is significant due to restrictions on food imports from Ireland. Consumers in Ireland are likely to switch away from Irish food products. The impact on tourism is also significant and the reputational damage extends over a longer time horizon. The impact of such a scenario is estimated to be **€80 billion**.

Scenario four constitutes the most severe scenario considered where high levels of radioactive contamination are assumed. Levels of contamination are such that they warrant food controls and agriculture protective actions for a number of years. The impacts under this scenario extend to 60 years, though the most substantial economic impacts arise in the first 30 years. Within this scenario it is assumed that Irish agricultural production is lost after the nuclear accident. It is assumed that

EU markets will be the first to recommence imports from Ireland but it may take up to 15 years before international markets outside the EU recommence trade. Irish consumers will also face higher food costs, as it is assumed that most food will be imported in the first few years. Under this scenario the estimated discounted economic lose is **€161 billion**.

A nuclear accident is likely to have a wide range of economic losses and social impacts, many of which are not considered within this report. The approach taken in assessing the scale of losses was to focus on areas where there is strong empirical evidence underpinning any estimates provided. The analysis specifically focuses on the areas where the direct impacts are likely to be greatest: agriculture and food, tourism, and exports. We consider the impact to the wider Irish economy by assessing the links between these three sectors and the rest of the economy. Consequently, the estimates in this report represent lower bound estimates of the potential economic impacts in the scenarios examined. The impacts that are not considered may potentially be quite large. For example, the public perception of radiological risk could lead to more people engaging with the health services but no estimate is provided of these additional health costs. The report also does not estimate the costs associated with the disposal of contaminated or condemned materials, as well as losses associated with wealth or migration flows that might arise in the event of a nuclear accident.

DISCLAIMER

The scenarios used in this report are intended to be illustrative. In the event of an accident, official advice from relevant authorities will be tailored to the particular circumstances that arise. The control measures used in modelling are not necessarily indicative of those which may be used in the event of a nuclear accident. Please refer to "The National Emergency Plan for Nuclear Accidents" (NEPNA) at www.environ.ie, which is intended specifically to cater for a major emergency at a nuclear installation abroad that could result in radioactive contamination reaching Ireland.

1. Introduction

The Department of Environment, Community and Local Government (DECLG) and the Radiological Protection Institute of Ireland (RPII)[1] have been engaged over a number of years in assessing the potential risks to Ireland from civil nuclear facilities abroad, including those in the United Kingdom. This culminated in recent reports undertaken by Bley et al. (2012) and RPII (2013), which consider the nuclear and radiological aspects of a nuclear accident[2] and potential implications for Ireland. This report focuses on the potential economic costs that might be associated with a nuclear accident. Developing estimates of the scale of economic losses that might arise in the event of a nuclear accident serves a number of useful purposes. Such information will inform decisions related to whether it is in Ireland's interests to be a signatory to a number of international treaties and conventions concerning nuclear emergencies, remediation and liabilities.[3] The analysis will help inform national positions on policy and legislative developments in Europe and internationally with respect to the nuclear risks and their management.

The process of estimating the economic impacts of a nuclear accident is a difficult one. The approach we have taken, which is described later in detail, is to develop a systematic methodology to estimate costs and losses directly attributable to an accident, as well as any losses associated with reputational damage, e.g. in export markets. The methodology employed focuses on the sectors and activities where the impacts are of significant magnitude and where suitable data is available to help quantify the potential losses. Invariably we have omitted many potential losses and consequently the estimates provided represent lower bound estimates. The scale of the radiological or economic impact of a nuclear accident depends on its nature and severity in addition to the prevailing weather conditions. Rather than consider the large distribution of potentially feasible outcomes that might arise in the event of a nuclear accident, we consider just four scenarios, to develop indicative estimates of the scale of economic losses that might arise.

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[1] RPII has since transitioned into the Office of Radiological Protection (ORP) within the Environmental Protection Agency (EPA)

[2] The International Atomic Energy Agency defines a nuclear accident as "any accident involving facilities or activities from which a release of radioactive material occurs or is likely to occur and which has resulted or may result in an international transboundary release that could be of radiological safety significance for another State" (IAEA, 2007)

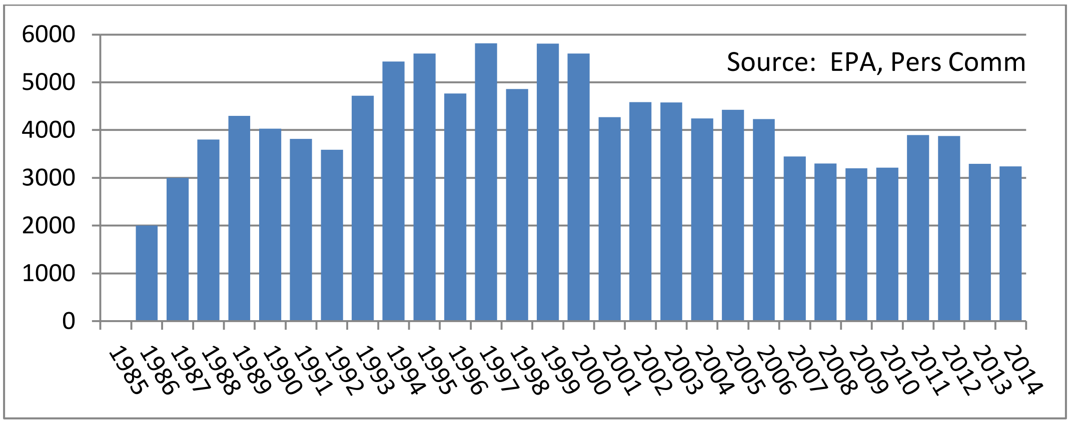
[3] Convention on Third Party Liability in the Field of Nuclear Energy of 29 July 1960 (the "Paris Convention"); Convention of 31 January 1963 Supplementary to the Paris Convention of 29 July 1960 (the "Brussels Supplementary Convention"); Convention on Civil Liability for Nuclear Damage of 21 May 1963 (the "Vienna Convention"); Joint Protocol Relating to the Application of the Vienna Convention and Paris Convention; Protocol to Amend the Vienna Convention (the "1997 Amending Protocol"); Convention on Supplementary Compensation for Nuclear Damage (the "Compensation Convention")

This report was commissioned by the Department of the Environment, Community and Local Government (DECLG) and the work was overseen by a steering committee comprising DECLG, the Department of Agriculture, Food and the Marine (DAFM) and the Environmental Protection Agency (EPA). The objective of the analysis was to estimate the impact on the Irish economy of a nuclear accident at a facility abroad in north-western Europe, for four different scenarios. The scenarios were developed by the project steering committee and their design was based on varying levels of radiological contamination within Ireland occurring during times of the year when its impact is likely to be greatest. The scenarios are not intended to represent an accident at any particular location; rather they are intended to illustrate the potential scale of economic impacts associated with an accident that has radiological impacts of varying severity on Ireland.

The risk of a nuclear accident is very small, and particularly so with respect to other energy sources (NEA-OECD, 2010). However, in the event of an accident the economic impacts are substantial. For example, Pascucci-Cahen and Patrick (2012) estimate an economic impact ranging from €120-430 billion to the French economy due to a hypothetical accident at one of its nuclear power plants. So while the risk of a nuclear accident may be small, one purpose of this study is to provide an indicative value of the cost it would impose on Ireland's economy and society.

Such economic costs and losses have previously occurred following nuclear accidents, both in the country where the accident occurred and in other countries affected by fallout from the accident. For example, a variety of estimates from the 1990s placed the costs of the Chernobyl accident to Ukraine, Belarus and the Russian Federation at hundreds of billions of US dollars (UN Chernobyl Forum, 2005). And, following the Chernobyl (1986) and Fukushima (2011) nuclear accidents, Irish exports were impacted with the requirement to put in place significantly increased food/environmental monitoring programmes and increased demand for certification of Irish products for export, as illustrated in Figure 1 (Nuclear Energy Board, 1987; RPII, 2012).

Figure 1: Number of Certificates Issued



The report is structured as follows. Section 2 describes the methodology we have used to assess losses. Section 3 describes the four accident scenarios that are examined. Data sources are briefly described in section 4, whereas section 5 provides an assessment of the potential losses of each scenario accident in turn. The report concludes with a brief summary in section 6.

2. Methods

The Nuclear Energy Agency (NEA), an agency within the Organisation for Economic Co-operation and Development (OECD), published the most comprehensive review to date of methodological approaches for assessing the economic consequences of nuclear accidents (NEA-OECD, 2000). The nuclear sector in a number of countries have developed models[4] to estimate the off-site financial consequences of nuclear accidents including items such as lost wages, relocation expenses of the evacuated population, decontamination costs, loss of crops and milk, and interdicted land costs. In addition, the models estimate major public health effects (e.g. fatalities, injuries, and latent cancer fatalities) plus estimates of their associated financial costs are assigned to these health effects. These models, while not available for this study, are also not directly relevant for Ireland, as the models are particular to the countries and regions where specific nuclear power generation plants are located. As the current study is limited to an analysis of four scenario accidents, developing an analogous model for Ireland would be disproportionately expensive. A common feature of many of these international models is the use of an 'input-output' methodology to assess the impacts across the economy, which is an approach we follow in our analysis.

Without an existing model available to examine the economic consequences to Ireland of a nuclear accident we developed a simple methodological framework. The method uses a bottom-up approach to identify the impacts within the main sectors affected and then uses input-output methods to estimate the effect on the wider economy. In addition to providing a description of the scale of the nuclear accident as it affects Ireland, the four scenarios developed assumptions on the accident response guidance that State Authorities might issue. Using this guidance it was possible to develop a detailed picture of the potential effects within the primary affected sectors, agriculture, food and tourism.

[4] The CRAC and MACCS models in the United States; the ARANO model in Finland; the MECA model in Spain; and the COCO and CONDOR models in the United Kingdom.

Direct Costs & Losses

The estimation of losses in this report consists of three distinct components arising in the three areas, agriculture and food, tourism and exports:

- Direct Costs
- Direct Losses
- Reputational Losses

In addition, the impact to the rest of the economy is estimated separately using an input-output methodology, which is discussed later.

Direct costs are additional expenditures incurred directly as a result of a nuclear accident. An example of a direct cost is the cost of testing for contamination in the wake of an accident. The nature and duration that direct costs arise in the event of an accident vary across the scenarios.

Direct losses relate to the value lost that is incurred directly as a result of a nuclear accident. An example of this is the value of animals culled as part of a decontamination scheme. Although the cost of running the scheme is a direct cost, the culled animals would have provided value to the economy had they not been destroyed and are therefore classed as direct losses. Estimates of direct losses are based on the value of output as reported in the most recent data available and calculated on an annual basis. For example, estimates of losses associated with restrictions on imports from Ireland are equivalent to the value of exports as most recently reported by the Central Statistics Office. This approach ignores any increased value associated with a counterfactual growth in export markets.

Both direct costs and losses arise as a result of a nuclear accident. Ultimately these costs and losses arise because perceived or actual threats to human health result in changed demand for Irish products. This includes any restrictions in EU or global markets of imports from Ireland. Losses will also arise because of perceived threats to human health even if products are officially certified as fit for consumption. This type of loss might arise because of a loss in trust in Irish produce and is termed a reputational loss. It is noteworthy that the largest category of losses in the study of the costs of a French nuclear accident (Pascucci-Cahen and Patrick, 2012) was reputational loss, accounting for approximately 40% of total losses.

Reputational Losses

Reputational losses include the value of uncontaminated and perfectly safe produce which is not consumed; lost tourism revenue because tourists choose to travel to alternative destinations which are perceived to be safer; and more generally a loss in exports. In the aftermath of a nuclear accident it is reasonable to expect that consumers will consider Irish produce to be contaminated, regardless of whether it is certified as safe to consume. In the context of food export markets it is likely that exports will fall (in some instances dramatically) compared to pre-accident levels. Reputational losses can be exacerbated by import restrictions (e.g. EU or international restrictions on imports from Ireland) and it may take an extended period after import restrictions are rescinded before pre-accident trade levels are resumed.

Consider an example of a country's restrictions on food imports from Ireland, which will result in direct costs, losses and reputational losses. The **direct loss** is the value of exports that would have been exported in the absence of the restriction. **Direct costs** will also arise from the import restriction as the throughput of produce will have to be managed (e.g. via storage or destruction) or new EU markets developed. Irish market share will collapse while distribution and marketing channels will potentially be severed over the duration of the assumed import restriction. When the restriction on imports from Ireland is rescinded it is likely that it may take time to re-establish a foothold in previous markets. For instance, there may be a lingering reticence to consume products from a country perceived to have been contaminated or simply there may be fierce competition within the market. So a **reputational loss** exists beyond the period of the restriction on imports.

The tourism sector will also suffer reputational losses. If a nuclear accident occurs, it is anticipated that potential tourists will change their holiday destination away from Ireland for personal safety reasons. Losses to the tourism sector are considered to be primarily reputational in nature and substantial. It is unlikely that there will be specific tourism related **direct costs** (e.g. contamination clean-up) and as tourism is unlikely to be prohibited, no significant **direct losses** are envisaged.

The scale of reputational losses will depend on the circumstances of a nuclear accident and therefore ex-ante estimates of reputational losses are very subjective. We investigated whether the circumstances surrounding a number of major incidents (incl. nuclear accidents, food scares, and travel advisories) would provide insight on estimating reputational losses in the event of a nuclear accident in north-western Europe. Unfortunately, we were unable to find a suitable historical precedent to help inform estimates of reputational losses. Nuclear accidents, such as those at Three Mile Island, Chernobyl or Fukushima Daiichi, provide a historical basis for gauging the extent and scale of reputational damage but these accidents within their own countries are disproportionally large compared to potential damages that might arise in Ireland from a nuclear accident nearby in north-western Europe. More useful would be the impact on neighbouring countries. Data on the economic consequences of the Chernobyl accident in Norway, described in

NEA-OECD (2000), are not reported in sufficient detail to prove useful in an Irish context. In addition, the scale of the radiological impact within Norway does not easily match any of the scenarios developed for this study. Recent international events might also be expected to provide some insight. For example, the impact of the Eyjafjallajökull ash cloud on tourism numbers, but that event grounded most air travel rather than affected the decision of people whether to travel. In Ireland the Foot and Mouth Disease (FMD) outbreak in 2001 led to tourism sector losses of €210m (Indecon, 2002) but there are few parallels between the FMD outbreak and the potential reputational losses that might arise in the event of a nuclear accident, particularly as the human health risks under the FMD outbreak were negligible. Possibly more relevant are the SARS and avian flu cases in Asia but because these viruses are spread by person-to-person contact, the impact on tourism and trade may be substantially different than in a nuclear accident. Without finding a suitable historical precedent to fully inform estimates of reputational damage we instead used a stylised mathematical approach to model growth in reputational loss through time with the model's parameters informed by several food and travel crises.

Model of Reputational Loss Recovery

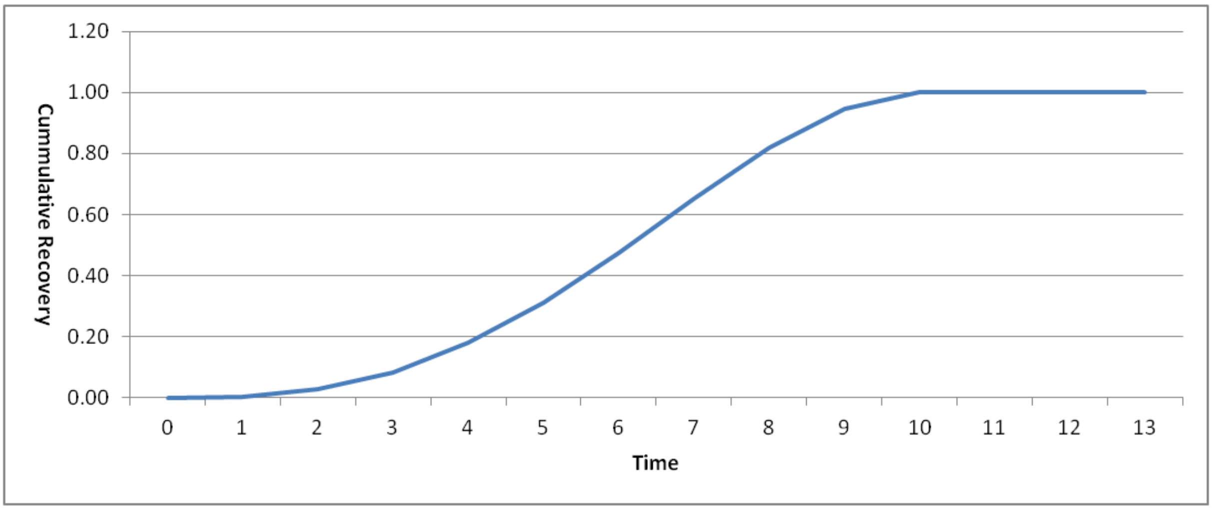
Gompertz curves have long been used as a growth curve for both biological and economic phenomena (Gompertz, 1825; Prescott, 1922; Winsor, 1932). They continue to be used to model situations where there is an initial slow growth, a middle period of very strong growth, which is followed by slower growth to an asymptotic maximum. For example, Gompertz curves have recently been used to model mobile phone adaptation (Yamakawa et al., 2013), energy consumption (Gutiérrez et al., 2005), and the growth of media coverage of disasters (Wei et al., 2009). The conventional 'S'-shaped curve of the Gompertz function is a reasonable approach to model reputational losses. Maximum losses occur almost instantaneously with a subsequent slow recovery of losses immediately after the nuclear accident. As time elapses, consumers gather more information (e.g. initial fears were either unfounded or safety measures implemented) and a period of strong recovery ensues. However, for various reasons (e.g. lingering suspicions among some consumers) the rate of recovery plateaus before a full recovery is achieved.

Gompertz curves[5] have several known shortcomings (Kececioglu et al, 1994; Sánchez-Chóliz et al, 2002; Yin et al. (2003), Jarne et al., 2007), one of which is relevant to the estimation of reputational losses here. A Gompertz curve's upper asymptote occurs as time tends to infinity, which in the context of modelling reputational loses means that losses are never fully recovered, e.g. tourism

[5] Logistic, Richards, and Weibull growth equations are alternatives frequently used in the literature.

would never recover to pre-accident levels. For the four scenarios examined it would be unreasonably pessimistic to assume that reputational loses are not recovered within a finite time period so we use a minor adaptation by Yin et al. (2003) that allows determinate growth and full recovery within a specified finite timeframe. Yin et al.'s growth function starts at zero and recovers to its full value by the end of a specified duration. Using this function enables us to systematically model and estimate the value of reputational losses until full recovery is achieved within a finite period. A graphical illustration of a Gompertz function incorporating Yin et al.'s adaptation is presented in Figure 2. The extreme left of the curve is the time immediately after the accident, the time of maximum loss. The vertical axis measures cumulative recovery. Initially there is a slow recovery, in Figure 2 it is less than 20% after 4 years. The pace of recovery increases and reaches a full recovery, in the case of Figure 2 after 10 years.

Figure 2: Gompertz function



Equation (1) follows Yin et al. (2003), and describes the proportional recovery of reputational loss for product or industry i in time period t, such that $0 \leq \lambda_{it} \leq 1$.[6]

$$\lambda_{it} = \left(1 + \frac{t_{ie} - t_i}{t_{ie} - t_{im}}\right)\left(\frac{t_i}{t_{ie}}\right)^{\frac{t_{ie}}{t_{ie} - t_{im}}} \quad (1)$$

So the proportional reputational loss at any time compared to the initial pre-accident period is (1-λ_{it}). To estimate the scale of reputational loss at each period t we must initially specify two parameters: t_{ie}, which is the time period when reputational loss is fully recovered, and t_{im}, which is

[6] We evaluated λ_{it} at the mid-point of each year, i.e. t_i=0.5, 1.5, 2.5 years etc. to calculate the average reputational loss across each period.

the time when the rate of maximum recovery is achieved (i.e. the inflection point near the centre part of the 'S'-shaped curve). In the context of a nuclear accident, choice of both of these parameters is subjective. Parameter t_{ie}, which is the time period when reputational loss is fully recovered, will vary across scenarios and by sector/product and is discussed below. However, we assume t_{im} is a fixed proportion of t_{ie} across all sectors/products and scenarios. While there is no empirical evidence on what the appropriate value for this parameter should be, studies of the diffusion of new products suggest that the value could be greater than ½ (Gutiérrez et al., 2005; Dergiades and Dasilas, 2010; Kaldasch, 2011; Yamakawa et al., 2013). For our purposes we assume that $t_{im} = {}^{2}/_{3}\, t_{ie}$. This assumption means that recovery will not be uniform and instead that the initial recovery will be very slow followed by a strong pulse later.

The value of parameter t_{ie}, which is the time period when reputational loss is fully recovered, varies across scenarios and by sector/product. But there was little accessible data guiding what the value of the parameter might be. For example, studies by Mendoza et al. (2012) and Guo and Xiong (2011) examining the tourism impact of earthquakes in China found that tourism numbers fully recovered in one instance within 4 months but had not recovered within 10 months of another earthquake. Huang and Min (2002) also found that inbound tourist arrivals had not recovered to pre-earthquake levels 11 months after an earthquake in Taiwan. Examining tourist reaction to the SARS crisis in Asia may have greater relevance, as both SARS and a nuclear accident have potential associated health risks to the general population. Mao et al. (2010) found that Japanese tourist numbers visiting Taiwan only recovered to pre-accident levels 14 months after Taiwan was officially removed from the list of SARS-affected areas. In the case of US tourists to Taiwan the recovery was much quicker. The data, where available, suggests where there is a severe and well publicised safety risk that the duration of reputational losses may be quite long. However, there is insufficient data to draw definitive inferences.

Instead we formulated a simple rule based on scenario characteristics to establish values for t_{ie} in each case. We assumed that the minimum duration of reputational losses is 6 months (i.e. a nuclear accident with no radiological impact within Ireland) and the maximum is assumed to be 15 years.[7] Where there are direct losses of specific duration outlined in the scenarios (e.g. import restrictions) we assumed the duration of reputational losses would be equal to twice the duration of direct

[7] The duration of reputational losses is not necessarily the total duration of impact from a nuclear accident. In the worst case scenario the duration of impact is 60 years, 15 of which comprised reputational damages.

losses, with a minimum of 1 year. We assumed duration of reputational loss associated with domestic consumption of Irish produce is the same as for EU consumers.[8]

We assume that the level of reputational loss in the initial period, R_{i1}, is some fraction, α_i, of the total value of pre-accident activity, V_i.

$$R_{i1} = \alpha_i \mathrm{V}_i \qquad 0 \leq \alpha_i \leq 1, \mathrm{t}{=}1 \tag{2}$$

For reputational losses less than one year (i.e. 6 months duration) R_{i1} is adjusted proportionally. To calculate sector i's reputational losses in subsequent periods we multiply the proportion of reputational loss in time period t (1-λ_{it}) by the value of reputational loss in the initial period after the accident, R_{i1}.

$$R_{it} = (1 - \lambda_{it})\, R_{i1} \qquad \mathrm{t} > 1 \tag{3}$$

Or

$$R_{it} = (1 - \lambda_{it})\alpha_i \mathrm{V}_i \qquad \mathrm{t} > 1 \tag{4}$$

In the case of import restrictions on Irish product $\alpha_i = 1$ and the calculation of reputational losses subsequent to lifting of import restrictions (e.g. as Irish exports levels gradually recover) is given by

$$R_{it} = (1 - \lambda_{it})\mathrm{V}_i \qquad \mathrm{t} \geq 1 \tag{5}$$

where $\mathrm{t} = 1$ is the first period after the restriction on imports from Ireland is rescinded. The losses incurred during export/consumption restrictions are calculated as direct losses and equivalent to V_i per annum, whereas reputational losses do not arise until after the restriction is lifted when the producer will have to re-establish market share. Implicit within export market reputation losses are losses associated with losing market share to competitors and losing distribution networks. Even when restrictions on imports from Ireland are rescinded it takes time for exporters to build a presence in international markets.

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[8] There were a few exceptions to these rules. In scenario 1 (which entailed no radiological material falling on Ireland and described in Section 3) Irish households did not change their consumption patterns. All reputational losses in scenario 2 (which entailed no significant radiological material falling on Ireland and described in Section 3) are assumed to be of one year's duration, whereas the assumed duration of reputational loss in the tourism sector in scenarios 3 and 4 (which involved moderate and large amounts of radiation respectively and also described in Section 3) were 6 and 15 years.

In the next section we discuss assumptions about the values selected for α_i where there are no import restrictions but Irish produce loses market share.

Reputational Loss in the initial period – assumptions about α_i

The real value of the parameter α_i is unknown (i.e. the proportion of pre-accident activity levels lost in first period post accident) but likely will vary by product, sector and severity of nuclear accident. For the purpose of this analysis we used evidence from published literature to inform assumptions on its value. We have also made the simplifying assumption of just two values for α_i, one for food related products and sectors, and one for tourism activity. There is insufficient empirical evidence to estimate values for α_i for all products and sectors.

Three crises affecting Irish food products have potential relevance to inform our assumption for the value of α_i: the pork dioxins accident of December 2008, the earlier BSE crisis affecting beef, and the mislabelling of horsemeat and beef in 2013. In each of these instances product remained on the market, although there were products recalls and product declared unfit for human consumption. Both pork and beef continued to be supplied to markets so potentially the impact on consumption of beef or pork in the Irish market could be calculated, or alternatively the effect on the consumption of Irish meat products. A number of reports outline the circumstances of the crises and public perceptions (DAF, 2005; IARG, 2009; Kennedy et al., 2010; DAFM, 2013) but none provide data on the consequent effect on consumption of meat products.[9] However, reports from similar crises elsewhere do provide useful insight. The reduction in consumption associated with the food crises in Table 1 range from 7-72%. The BSE scare and the associated risk of human Creutzfeldt–Jakob disease (vCJD) are associated with the highest reductions in consumption from 50-72%. And even though the BSE scare related to beef, there were spill over effects to other meats (Philippidis and Hubbard, 2005). For the other food scares the effect on demand is lower, as are the potential health impacts. Both Poppe and Kjaernes (2003) and Mazzocchi et al. (2008) suggest that the impact of food safety information depends on the source and its reliability, rather than consumers' socio-demographic characteristics, implying that we can use these estimates as an indication of the potential impact on demand for Irish product. In the context of a nuclear accident we posit that consumers' perceptions of potential health impacts, irrespective of their accuracy, will be closer to the perceived risks associated with BSE contaminated beef than the other food scares listed. We also assume that the reduction in the demand will be roughly the mid-point of the three estimates in Table 1, i.e. 60%. So for food products we use a value of α_i = 0.6.

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[9] Estimates of the cost of the product recall covering the direct costs and losses are provided but there is no data on reputational losses associated with consumers switching to other meat products.

Table 1: Literature on demand impact of food scares

Source	Country	Crisis	Food	Peak to trough % change in demand
Philippidis and Hubbard (2005)	UK	BSE	Beef/Mutton/lamb Other meats	-72% in quantity -45% in quantity
Ishida et al. (2010)	Japan	BSE Avian Flu	Beef Chicken	-50% in quantity -25% in quantity
McCluskey et al. (2005)	Japan	BSE	Beef	-70% in value
Latouche et al. (1998)	France	Steroids	Veal	-40% in quantity
Niewczas, M. (2014)	Poland	Food Scares	Food	-30% in quantity
Carter and Smith (2007)	USA	GMO	Corn	-7% in price

Tourists tend to evade risks when choosing travel destinations in order to avoid uncertainty (Chu, 2008, Huang and Min, 2002 and Pizam and Fleischer, 2002). The impact of greater risk (associated with diseases, wars, earthquakes etc.) is believed to have a greater effect on international tourists (Wang, 2009). Without data on the scale of tourists' reaction to nuclear accidents, we have also used published studies on tourists' reaction to other crises to set a value for the scale of reputation losses (α_i) in the tourism sector. We've focused on crises where there is a potential and significant real risk to tourists, including terrorism, SARS and earthquakes and list a number of studies in Table 2. The foot and mouth crisis in the UK is an exception in this regard but Blake et al (2003) provides data showing the large negative regional impact the foot and mouth outbreak had on tourist numbers.[10] Terrorism/war has a significant impact on tourist numbers but the range is quite large from 18-79% reduction in visitors. The lower range may reflect a human trait that bad things happen to others and people maintain their travel plans in the face of higher personal risk. Earthquakes or other natural disasters also bring uncertainty to tourists plus the probability of a recurrent event (e.g. after tremors) is usually high. The studies on tourism following earthquakes in Italy and Taiwan show a decline of tourist numbers ranging from 15-50%. In the case of the SARS crises in Asia the tourism market from the US and Japan to Taiwan almost collapsed. While the risks associated with earthquakes or terrorism may be relatively high, in the case of SARS the risk is

[10] Foot and Mouth disease posed no health risk to humans but the large impact on tourism may reflect measures to control the spread of the disease, such as closing hill walking trails, etc.

pervasive and therefore may explain why the greatest impact on tourism occurs in that situation. In the case of a nuclear accident it is the perception of risk rather than actual risk that matters in the case of reputational losses. The risk associated with a nuclear accident, similar to SARS, may be considered pervasive and so the reaction of tourists is likely to be quite cautious. Hence we posit that the initial impact on tourism numbers will be relatively high and use the figure of 90% for US tourists from Mao et al. (2010). So for the tourism sector we use a value of α_i= 0.9.

Table 2: Literature on the effect of crises on tourism

Source	Tourist Origin	Tourist Destination	Crisis	Impact
Enders and Sandler (1991)	USA	Europe	Terrorism	54% cancelled reservations
D'Amore and Anuza (1986)	USA	Overseas	Terrorism	79% avoid international travel
Stafford et al. (2009)		Ireland	Terrorism	32% would postpone trip
Mc Kercher and Hui (2004)	Hong Kong		Terrorism	39% changed travel plans
Ioannides & Apostolopoulos (1999)	Overseas	Cyprus	War	-18% arrivals
Blake et al (2003)		UK	Foot and Mouth disease	Bookings -80% Cumbria -60% Dumfries and Galloway -50% Northern Ireland -10% across UK
Mao et al. (2010)	Japan Hong Kong USA	Taiwan	SARS	-98% arrivals n/a -90% arrivals
Huang et al. (2008)	Overseas	Taiwan	Earthquake	-15% arrivals
Mazzocchi & Montini (2001)		Italy	Earthquake	-50% arrivals

At this point we have outlined the model assumptions for estimating losses associated with a nuclear accident in the agriculture, food and tourism sectors (including exports) using the mechanism of an adapted Gompertz curve for reputational losses and the value of pre-accident output for other direct losses. Direct costs will also arise, such as those related to additional radiation monitoring. These were estimated based on the volume of monitoring that would occur within the four scenarios. In the next section we outline the methodology used to estimate the impact on the wider economy.

Input-Output Multipliers

The preceding sections have dealt with the direct and reputational effects on key affected sectors. These are also likely to lead to indirect effects. For example, the Irish food sector utilises products and services from a range of sectors, which would not be purchased if demand for Irish food products declined in the event of a nuclear accident where restrictions are placed on imports from Ireland. Thus, a reduction in gross output produced in a sector reduces the demand for intermediate inputs purchased from within the sector and from other sectors.

To assess the scale of these indirect losses one requires information on the economic connections between sectors. These are captured in input-output (I-O) tables, which give a detailed picture of the transactions of all goods and services by industries and final consumers in the economy in a single year. The tables build upon the interdependence of the various sectors of the economy and for this reason can be a useful tool in the area of impact analysis. They are also constructed to be consistent with the system of national accounts. A useful feature of I-O tables is that the effect of a change in final demand for the output of one sector on all sectors can be captured in a simple multiplier which shows the impact of a one unit change in the output of that sector on the total output in the economy.[11,12]

While I-O tables provide a convenient and consistent framework for the analysis of the economic connections between sectors in an economy, they also have a number of drawbacks that need to be kept in mind when interpreting the results. Firstly, as the production of I-O tables with detailed sector-specific coverage is costly, these are only produced periodically. For Ireland the most recent I-O tables are for 2011 and cover 58 sectors.[13] This is important as the application of I-O tables for impact analysis takes the relationship between the sectors as fixed, which in practice does not hold. This is a particularly important problem when conducting analysis over a longer time horizon, where the relationship between sectors is likely to change significantly. For example while almost 59% of the Irish intermediate inputs used in the Food, Beverages and Tobacco sector in 1990 came from the Agriculture, Forestry and Fishing sector that share has declined to less than 50% in 2011. A second drawback is that given the fixed nature of I-O tables they do not allow for any behavioural response. In practice sectors are likely to respond to demand changes, for example through a loss of

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[11] See Miller and Blair (2009) for a detailed treatment of Input-Output analysis and Rose et al. (1997) for an application of I-O tables to assess the impact of an earthquake.

[12] For the purposes of the analysis in this report, the 2011 I-O tables are used and the parameters are identical for each scenario, but as described elsewhere the scenarios differ in the extent of the impact.

[13] See http://www.cso.ie/en/releasesandpublications/ep/p-sauio/supplyanduseandinput-outputtablesforireland2011/

reputation in export markets, by adjusting prices and increasing advertising activity which might also increase domestic demand for the product. Furthermore, the constant parameters are constructed with an implicit assumption of constant returns to scale i.e. that a doubling of output requires a doubling of input, which may not hold in practice. This may be due to increasing returns to scale at the firm or industry level, or decreasing returns perhaps due to capacity constraints. A third drawback of I-O tables is that they are concerned with gross output rather than value added. Thus, they overestimate the real impact on the economy. A fourth related drawback is that the multipliers when taken across the entire economy include significant double counting. Thus, a one unit increase in the demand for output from one sector also results in increased inputs from other sectors with the multiplier measuring not just the one unit increase but also the resultant increased production of intermediate inputs required to produce that additional unit of output.

The analysis of the effects of a nuclear accident focus on the direct impact within three sectors: agriculture, food and tourism. Tourism is not a single sector within the accounting framework of National Accounts and Input-Output tables, but rather comprises a proportion of activities in a number of sectors, principally Accommodation and Restaurants (NACE sectors 55-56) and Travel and Tourism services (NACE sector 79).[14] Other sectors that encompass some tourism activities include land, sea and air transport (NACE sectors 49-52), Cultural and Sporting services (90-92) and Recreation services (93). Our analysis focuses on the NACE categories 55-56 and 79. Here we assume that the intermediate linkages of the tourism sector are well represented by the Accommodation and Restaurants and the Travel and Tourism sectors, with the former accounting for significantly more activity.

The main domestic intermediate inputs into the Agriculture, Forestry and Fishing sectors are produced using other output from Agriculture, Forestry and Fishing sector, Wholesale trade, Repair and Installation of Machinery and Equipment and Electricity and Gas, which account for over 75% of domestic inputs. The sector also uses significant inputs from the Chemical and Chemical Products sector and Petroleum, Furniture and Other Manufacturing which however contain significant proportions of imports. The Food, Beverage and Tobacco sector produces more goods for final consumption (78.5%) of which almost 90% are accounted for by exports rather than intermediate inputs which account for just 21.5% of output from this sector.

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[14] Some of Accommodation and Restaurants services are used for domestic non-tourism consumption and some travel and tourism services relate to services that facilitate Irish residents to travel abroad (tourism imports).

The I-O tables also identify how an extra unit of final output is distributed across Imports of goods and services, Product taxes less subsidies, Compensation of employees, Net operating surplus, Consumption of fixed capital and Other Taxes less Subsidies on production, after accounting for all the intermediate input effects. For example, the I-O tables show that a €1 million increase in output in the Agriculture, Forestry and Fishing sector has the following implications for the level of output in other sectors: Imports are increased by €507,000, output in the Food, Beverages and Tobacco sector increases by €561,000, Accommodation and Food increase by €177,000 and Travel and Tourism increase by €142,000. The last example shows how the Tourism sector is less import intensive.

The focus of the analysis in this report is on domestic impacts and we use the I-O tables in order to identify the indirect effects through supply linkages. In order to avoid double counting the direct and reputational effects of a change in demand or final production these are netted out which identifies the indirect multiplier for the sectors. These differ significantly with that for Agriculture, Forestry and Fishing being 0.459, that for Food, Beverages and Tobacco 0.456, Accommodation and Restaurants 0.303 and Travel and Tourism services 0.074.[15] Thus, a reduction in the demand for Food, Beverage and Tobacco products by €1 million reduces demand for intermediate products by €456,000 while a similar reduction in the output of the tourism sector (Accommodation and Restaurants; Travel and Tourism services) reduces demand for intermediates by €284,000. These intermediates include products or services produced by the own sector. For example, of all the intermediate inputs used in the Agriculture, Forestry and Fishing sector over 40% are sourced from the Agriculture, Forestry and Fishing sector.

[15] The weighted average for the Tourism sector is 0.285.

3. Scenarios

The scenarios used in this report were designed to provide a spectrum of hypothetical outcomes across different seasons. They are not intended to be specific to a nuclear accident at either a particular location or facility. While an accident in north-western Europe may have an impact on Ireland, accidents at much further distance could also have an impact, as was the case with Chernobyl. The level of impact will depend not only on the location of the accident, but also on the scale and type of accident, as well as the prevailing weather conditions. In the event of a nuclear accident, advice provided by the Department of Agriculture, Food and the Marine (DAFM), the Food and Safety Authority of Ireland (FSAI) and others may vary from the guidance described in these scenarios. The largest variation in advice in the event of an accident will relate to the agriculture and food sectors and will naturally depend on the time of year the accident occurs. The two study dates selected for the scenarios in this report are possibly the time of the year when a nuclear accident would cause the greatest impact.

- Early February. The majority of livestock are still housed indoors with some uncontaminated[16] animal feedstuffs available. With livestock indoors the risk of livestock contamination is lowest but with winter feedstuffs almost exhausted the management of risk in the weeks after the accident is problematic but feasible.
- Mid-May. The majority of livestock are outdoors and uncontaminated animal feedstuffs are in short supply. With livestock mostly outdoors and sourcing uncontaminated feedstuffs in the immediate aftermath of the accident very difficult, DAFM's guidance actions for farmers to manage contamination risk will differ from that in February.

In the event of a nuclear accident food/agriculture protective actions taken would depend on the time of year and prevailing weather conditions (in the first instance); and these actions would be adjusted (and eventually lifted) based on the type of radioactivity released in the accident, actual contamination levels measured, the sectors impacted and the effectiveness of the initial actions taken. The timely introduction of appropriate agricultural management actions and food controls has been shown to be very effective in controlling radioactivity levels in foods for sale. Potential actions include housing of livestock and use of uncontaminated silage/hay, delaying slaughter times in conjunction with clean feeding or the use of specific feed additives or fertilisers. While these measures are very effective at reducing or eliminating the transfer of fallout into the food chain, they can have significant socio-economic implications and costs. Decisions on which actions to

[16] Uncontaminated feedstuffs refer to animal feedstuffs that are below the maximum permitted levels of radioactive contamination of feedstuffs. See Council Regulation (Euratom) 2016/52 of 15 January 2016 laying down maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency.

implement will depend on the circumstances of the accident and the level of impact on Ireland. Some examples of the type of protective actions are described in the European Food Handbook (Euranos, 2009). The durations of specified actions in the scenarios below are for the purposes of this report and may vary in the event of an accident. In each of the four scenarios considered it is assumed that there are no direct health impacts on the human population within Ireland, which is consistent with the accident scenarios studied in RPII (2013).

Regardless of the scale of a nuclear accident, monitoring the radiological impact on Ireland would be necessary particularly for public reassurance on the scale of impact. The level of monitoring required would vary by scenario type but in all instances are likely to include:

- High sensitivity monitoring of airborne particulates using laboratory-based gamma spectrometry of gamma-emitting radionuclides performed on a 24 hour basis during the release period and in the weeks afterwards.
- Monitoring of raw milk samples for gamma-emitting radionuclides, particularly isotopes of iodine and caesium. An enhanced sampling and measurement programme would be put in place. We have assumed it would be performed on a daily basis until the results have stabilised.

It is envisaged that the screening of samples for levels of radionuclides would be conducted across the country through the national radiation monitoring network. This process would include:

- Monitoring the results of measurements of online instruments (gamma dose rates, aerosol particulates); and
- Laboratory measurements of gamma-emitting radionuclides in glass fibre and charcoal filters from low volume air samplers (LVAS) and in rainwater samples (to assess the levels of deposited radionuclides). This sampling would be performed every two to three days initially before returning to the normal weekly basis several weeks after the release phase had ended.

For more severe releases, drinking water would be sampled and screened on a nationwide basis as a priority with targeted follow-up monitoring in subsequent weeks and months. Grass and soil samples from suspected higher deposition areas would be measured to assess the spatial distribution of the levels of deposited radionuclides.

For the purposes of this analysis we have assumed that radiological depositions are uniform across the country, without any regional variations. Accordingly, the scenario analysis undertaken here is at national level by economic sector.

Scenario 1 – Nuclear accident but no radiological impact on Ireland

This nuclear accident scenario is assumed to have no radiological impact on Ireland. However, there will be significant global media attention covering the accident, the protective actions at the nuclear site (e.g. evacuation of site staff) or in the area local to the nuclear site, as well as speculation on contamination risks. This attention leads to a perception of Ireland being contaminated, which has associated economic impacts with respect to tourism and Irish food products.

The guidance and actions below are hypothetical and for the purpose of this scenario analysis only. In the event of an actual nuclear accident official guidance and protective actions may vary from that outlined below and will depend on the circumstances of the accident and its impact on Ireland. Please refer to "The National Emergency Plan for Nuclear Accidents" (NEPNA) at www.environ.ie, which is intended specifically to cater for a major emergency at a nuclear installation abroad that could result in radioactive contamination reaching Ireland.

Assumptions underlying this scenario

- Date of Accident: Mid-May
- Government and State Agencies issue information to the public providing reassurance of no radiological impact on Ireland
- Assumed that there are no direct health impacts on human population within Ireland
- Food/agriculture protective actions lifted after sufficient time for monitoring/analysis to confirm no impact (assumed a few days in this scenario)
    - Assumed advice to farmers is to keep livestock indoors for up to 2 days
- Enhanced monitoring for food and environment samples put in place to provide reassurance of no contamination to public and export markets. Assumed duration 2 weeks
    - Assumed that restrictions on trade in food produce will remain in place for 2 weeks
- Increase in demand from exporters for certification of products for export outside the EU expected. Assumed duration, 3 months

Scenario 2 – Nuclear accident with low-level contamination in Ireland

In this scenario it is assumed that a nuclear accident leads to some low-level contamination of the environment and food in Ireland. Food controls and agriculture protective actions are put in place for several days until it is proven that the levels of radioactive contamination are very low and of no health concern and do not warrant any protective actions. The significant global media attention covering the accident is assumed to lead to a higher level of reputational damage, as other countries respond to the presence (however minimal) of contamination in Ireland.

The guidance and actions below are hypothetical and for the purpose of this scenario analysis only. In the event of an actual nuclear accident official guidance and protective actions may vary from that outlined below and will depend on the circumstances of the accident and its impact on Ireland. Please refer to "The National Emergency Plan for Nuclear Accidents" (NEPNA) at www.environ.ie, which is intended specifically to cater for a major emergency at a nuclear installation abroad that could result in radioactive contamination reaching Ireland.

Assumptions underlying this scenario

- Date of Accident: Mid-May
- Government and State Agencies issue information to the public providing reassurance of no radiological risk to health
- Assumed that there are no direct health impacts on human population within Ireland
- Food/agriculture protective actions assumed to be in place for up to 3 weeks, allowing sufficient time for monitoring/analysis to confirm impact
    - Assume that farmers advised to keep livestock indoors for up to 4 days
    - Feed animals uncontaminated feedstuffs (where available) and water
    - Assumed that tillage is unaffected by this type of accident
    - Intensive pigs and poultry production is unaffected
    - Meat and dairy produce in shops at the time of the accident is uncontaminated and safe for consumption
- Enhanced monitoring for food and environment put in place to provide reassurance of food safety for public and export markets. Assumed duration 9 months
    - Curtailment of exports of Irish food produce to EU countries assumed to remain in place for 9 months
    - Curtailment of exports of Irish food produce to non-EU countries assumed to remain in place for 9 months
- Increase in demand from exporters for certification of products for export outside the EU expected. Assumed duration 7 years.
- Assumed that increased demand for certification will require expansion in EPA's testing capacity

Scenario 3 – Nuclear accident leading to moderate contamination in Ireland

In this scenario it is assumed that a nuclear accident leads to moderate contamination of the environment and food in Ireland. While no population-related protective actions (such as recommendations on staying indoors) are necessary, the levels of contamination are found to warrant food controls and agriculture protective actions for a number of months, as without them food would not comply with EU regulations on radioactivity content.

> The guidance and actions below are hypothetical and for the purpose of this scenario analysis only. In the event of an actual nuclear accident official guidance and protective actions may vary from that outlined below and will depend on the circumstances of the accident and its impact on Ireland. Please refer to "The National Emergency Plan for Nuclear Accidents" (NEPNA) at www.environ.ie, which is intended specifically to cater for a major emergency at a nuclear installation abroad that could result in radioactive contamination reaching Ireland.

Assumptions underlying this scenario

- Date of Accident: Early February
- Information issued to the public on the event – reassurance of no radiological risk to health
- Assumed that there are no direct health impacts on human population within Ireland
- Food/agriculture protective actions assumed to be in place for up to 10 months duration
    - Assume that farmers advised to keep livestock indoors for up to 8 weeks
    - Feed animals uncontaminated feedstuffs (where available) and water
    - Need to import animal feedstuffs (possibly from outside Europe) as a substitute for contaminated grass. Assumed a lead time of 6-8 weeks is likely for imported feedstuffs
    - Assumed an increased reliance on concentrates to feed animals for 8 weeks
    - Where animals are subject to temporary contamination through the consumption of contaminated feedstuffs the following was assumed: Dairy cows need to eat uncontaminated feedstuffs for several days for their milk to be below contamination limits. Sheep and cattle need to eat uncontaminated feedstuffs for several weeks to ensure their meat is below contamination limits
    - Assumed that increased levels of pre-slaughter screening required
    - Where there is contamination of pasture land assumed that farmers are advised to cut, remove and dispose of grass to remove contaminated material from food chain
    - Assumed that feedstuff imports are required to substitute for losses associated with contaminated silage/hay for following winter
    - Intensive pigs and poultry production is unaffected
    - Meat and dairy produce in shops at the time of the accident is uncontaminated and safe for consumption
    - Assumed that outdoor fruit and vegetable production is lost
- Enhanced monitoring for food and environment put in place to provide reassurance of food safety for public and export markets. Assumed duration 10 years
    - Curtailment of exports of Irish food produce to EU countries assumed to remain in place for 1 year
    - Curtailment of exports of Irish food produce to non-EU countries assumed to remain in place for 5 years

- Increase in demand from exporters for certification of products for export outside the EU expected. Assumed duration 10 years
- Assumed that increased demand for certification will require expansion in EPA’s testing capacity

Scenario 4 – Nuclear accident leading to high levels of contamination in Ireland

In this scenario it is assumed that a nuclear accident leads to significant contamination of the environment and food in Ireland. In anticipation of potentially higher radiation doses in the short term, people are advised to remain indoors as much as possible for up to 48 hours. While people remaining outdoors are not at significant health risks, this advice is issued as a precaution due to lack of available data following a severe accident but also as an effective way of reducing potential radiation doses. The levels of contamination are found to warrant food controls and agriculture protective actions for a number of years after the accident, as without them there is a long term risk that food would not comply with EU regulations on radioactivity content. In summary, from an agriculture perspective international demand for Irish produce will be subject to significant decline.

The guidance and actions below are hypothetical and for the purpose of this scenario analysis only. In the event of an actual nuclear accident official guidance and protective actions may vary from that outlined below and will depend on the circumstances of the accident and its impact on Ireland. Please refer to "The National Emergency Plan for Nuclear Accidents" (NEPNA) at www.environ.ie, which is intended specifically to cater for a major emergency at a nuclear installation abroad that could result in radioactive contamination reaching Ireland.

Assumptions underlying this scenario

- Date of Accident: Mid-May
- Information issued to the public on the event – people are recommended to remain indoors as much as possible during the passage of the plume (24 to 48 hours). Assumed a loss of three working days due to sheltering advice and heightened public concerns
- Assumed that there are no direct health impacts on human population within Ireland
- Food/agriculture protective actions expected to be in place for an extended period
    - A rendering/slaughter process of contaminated animals is established
    - Assumed that domestic fruit and vegetable production (outdoors) is condemned in year of accident
    - Assumed that tillage production lost in year of accident
    - In the years subsequent to the accident any food production is for the domestic market only, as food import restrictions from Ireland are in place. Domestic consumption will rely heavily on food imports
    - Assumed that additional ploughing and application of fertilizer as radiation mitigating actions are undertaken
- Enhanced monitoring for food and environment put in place to provide reassurance of food safety to public and export markets. Assumed duration 30 years
    - Curtailment of exports of Irish food produce to EU countries assumed to remain in place for 3 years
    - Curtailment of exports of Irish food produce to non-EU countries assumed to remain in place for 15 years
- Increase in demand from exporters for certification of products for export (both food and non-food products), assumed duration 60 years
- Increased demand for certification will require expansion in EPA’s testing capacity

Table 3 summarises some of the primary assumptions underpinning the four scenarios, including the assumed value of the parameter t_{ie}, which is the time period when reputational loss is fully recovered that varies across scenarios.

Table 3: Summary of Scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Date	Mid-May	Mid-May	Early February	Mid-May
Radiological Impact	None	Minimal	Substantial	Severe
Advice for people to remain indoors	-	-	-	2 days
Loss of working days	-	-	-	3 days
Advice to keep livestock indoors	2days	4 days	8 weeks	-
Food/Environment Monitoring	2 weeks	9 months	10 years	30 years
Export Certification	-	7 years	10 years	60 years
Food import restrictions from Ireland				
- EU	2 weeks	9 months	1 year	3 years
- Non-EU	2 weeks	9 months	5 years	15 years
Reputational damage duration - tourism	6 months	1 year	6 years	15 years
Duration of reputational damage post EU import restriction rescinded	6 months	1 year	2 years	6 years
Reputational damage duration - domestic consumers	6 months	1 year	2 years	6 years
Duration of reputational damage post non-EU import restriction rescinded	6 months	1 year	10 years	15 years

4. Data

Unless specified otherwise, we have used published data sources and where possible rely on data published by the Central Statistics Office (CSO). For detailed enterprise specific data on the agriculture sector Teagasc's 2013 National Farm Survey is used. The data sources are listed in Table 4. In all cases, the most recent data available was used and inflated to a common base using the CSO's consumer price index (CPI). Costs and losses are discounted to the base period using a discount rate of 5%, which is the current rate advised by the Department of Public Expenditure and Reform.[17]

Table 4 - Data Sources

Source	Data	Period
Central Statistics Office (CSO)	StatBank Ireland Database	most recent year available
	Census of Agriculture	2010
	Household Budget Survey (HBS)	2010
Teagasc	National Farm Survey	2013
Environmental Protection Agency (EPA)	Estimates of environment and food monitoring cost	2015

5. Scenario Impacts

This section outlines the potential economic impacts of the four nuclear accident scenarios. Our methodological approach has been conservative in terms of the scope of impacts and only focuses on a number of specified economic impacts. Any potential accident would also include wider losses to society, which have not been covered.

Scenario 1 – Nuclear accident but no radiological impact on Ireland

Under this scenario it is assumed that there is no radiological impact on Ireland and consequently there are no significant direct costs or losses to Ireland. It is assumed that the nuclear accident would generate significant media attention. It is also expected that reputational losses would arise because of Ireland's proximity to the accident site due to the perception of Ireland as being contaminated. As outlined in the scenarios, the reputational losses are assumed to primarily occur with respect to food exports and tourism. For instance, it is reasonable to assume that international

[17] See http://www.per.gov.ie/en/project-discount-inflation-rates/

food markets will source product from suppliers further distant from the accident site and tourists are likely to travel to destinations other than north-west Europe as precautionary measures.

Our assumptions, as outlined earlier, indicate that tourism and exports will suffer reputational losses. In the case of tourism we project a loss of over 2 million visitors, approximately 40% from the UK, and 35% from elsewhere in Europe. The associated loss in tourism revenue is €1 billion, as reported in Table 5.[18]

Table 5 - Scenario 1 - Tourism Reputational Loss

Visitor Origin	Reputational Loss (€m)	Tourists (Million)
UK	423	0.9
Rest of Europe	356	0.8
Rest of World	230	0.5
Total	**1,009**	**2.2**

Reputational losses in Ireland's export markets are reported in Table 6. In this scenario it was assumed that the losses would be short-lived and markets would recover to pre-accident levels within 6 months. The total value of export losses is projected to be €3.1 billion. Meat and dairy produce account for 57% of the total losses.

[18] The estimates of direct costs and losses, including reputational losses, are based on the methodology outlined in section 2.

Table 6 - Scenario 1 – Exports Reputational Loss

	Reputational Loss (€m)
Livestock	138
Meat Products	1,144
Dairy Produce	631
Seafood	181
Cereals & cereal production	120
Fruit & Vegetables	89
Animal feedstuffs	82
Other Food Produce	666
Other Goods	81
Total	**3,133**

The indirect impacts under this scenario are likely to be limited to those arising in the tourism sector, as it is difficult to adjust production in agriculture in the short run (e.g. crops already planted). The impact on the tourism sector will impact on other sectors also and this impact is captured in the I-O multipliers. The indirect losses to the rest of the economy total €287 million (estimated by applying the I-O multipliers). Although there are no radiological impacts within Ireland in this scenario it is likely that additional health costs will arise, as people engage with the health services to ensure that they have not been adversely affected. An assessment of additional health costs has not been undertaken.

The total sum of losses under scenario 1 is €4.4 billion.

Scenario 2 – Nuclear accident with low-level contamination in Ireland

In this scenario it is assumed that the nuclear accident leads to some low-level contamination of the environment. Food controls and agriculture protective actions are put in place for several days until it is proven that the levels of radioactive contamination are very low, are of no health concern and do not warrant any protective actions. Similar to scenario 1, global media attention covering the accident is likely to be significant, leading to a perception that Ireland is highly contaminated. It is also likely that additional health costs will arise, as people engage with the health services to ensure that they have not been adversely affected. An assessment of additional health costs has not been undertaken.

As contamination occurs there are direct costs associated with this accident scenario, such as additional radiation monitoring. As contamination levels are very low these costs are primarily confined to laboratory and monitoring costs without any requirement to implement radiation remediation actions. These costs are estimated to be just over €6 million.

This scenario assumes that there will be a restriction on imports from Ireland for 9 months, which results in direct losses to food and other exporters. The effect of the trade restriction extends beyond the period of the import restriction itself, as it takes time to recover market share. In this scenario we assume that the reputational losses associated with the import restriction are recovered within one subsequent year. Table 7 reports the direct export losses associated with the import restriction and also the subsequent reputational losses, totalling almost €13 billion. In addition to a reduction in foreign demand for Irish produce, it is also expected that there is a reduction in domestic demand with consumers switching to imported produce. It is impossible to assess to what extent this might occur but for the purposes of this scenario we assume that the additional cost to domestic consumers is initially equivalent to 2.5% of their food bill and that this declines as over time as the reputational losses associated with food of Irish origin diminishes. Under those circumstances the cost of foodstuffs for domestic consumers will be €54m higher compared to the situation with no accident occurring.

Table 7 - Scenario 2 – Export Losses

	Direct Loss (€m)	Reputational Loss (€m)	Total (€m)
Livestock	302	263	565
Meat Products	2,499	2,179	4,678
Dairy Produce	1,378	1,202	2,580
Seafood	396	346	742
Cereals & cereal production	263	229	491
Fruit & Vegetables	195	170	365
Animal feedstuffs	178	155	334
Other Food Produce	1,454	1,268	2,722
Other Goods	177	154	331
Total	**6,841**	**5,967**	**12,808**

In the case of tourism there will be about 4 million fewer tourist visitors because of the accident with an associated loss in revenue of roughly €2 billion, as reported in Table 8

Table 8 - Scenario 2 - Tourism Reputational Loss

Visitor Origin	Reputational Loss (€m)	Tourists (Million)
UK	846	1.8
Rest of Europe	712	1.5
Rest of World	461	1.0
Total	**2,018**	**4.3**

Under this scenario production of agricultural and food products is likely to adjust resulting in reductions in the demand for intermediate products which will have a wider impact on the economy. There will also be indirect impacts from the losses in the tourism industry, resulting in lower demand for intermediate inputs from this sector. The estimate of the total indirect impact from the Input-Output analysis is €3.5 billion.

The sum of direct and indirect loses in scenario 2 is €18.4 billion.

Scenario 3 – Nuclear accident leading to moderate contamination in Ireland

In this scenario a nuclear accident leads to moderate environmental contamination. The levels of contamination are found to warrant food controls and agriculture protective actions for a number of months, as without them food would not comply with EU regulations on radioactivity content. No protective actions for people, such as recommendations on staying indoors, are necessary. Another aspect in which scenario 3 differs from the others is that the timing of the accident is assumed at the start of February. With the majority of animals indoors the direct impact on livestock is minimal but pastures will be contaminated. At this time winter feedstuffs will be in short supply and farmers will find it difficult and expensive to source uncontaminated feedstuffs for their animals.

Though this scenario specifically says that there are no protective actions necessary for people and that the food controls and agriculture protective actions will prevent long term health risks, nonetheless there are likely to be substantial additional health costs. The perception of a radiological risk will mean that people are likely to engage more frequently with the health services than would otherwise be the case. An assessment of additional health costs has not been undertaken.

Because of the level of contamination, plus the associated uncertainty, we assume that outdoor fruit and vegetable crops, as well as tillage are lost for the year. The value of the lost production is just less than €2 billion, as shown in Table 9. Production in subsequent years is expected to resume.

This is the first of the four scenarios in which there are significant direct costs and losses in the agriculture sector. There will also be additional costs related to radiation sample testing and monitoring plus remediation measures, which are listed in Table 9. Additional feedstuff costs total €174 million, whereas it is assumed that the Department of Agriculture, Food and the Marine would incur additional monitoring costs of €9m. Grass pastures at the time of the accident are contaminated and it is assumed that this grass will be removed to avoid entry to the food chain. Fresh growth grass should not pose the same food chain contamination risk. Our assessment of the cost of grass removal is €1.25 billion. This estimate is based on silage cutting costs but we have not estimated the cost of disposal of this contaminated material.

It is assumed that the work of the Environmental Protection Agency (and other national authorities) will increase considerably in the event of an accident, with an estimated cost of roughly €25 million. This is due to the duration and scale of increased sample testing which will require expansion of laboratory operations nationally to accommodate the increased demand for testing.

Table 9 - Scenario 3 – Direct Costs and Losses

	Total (€m)
Lost Produce	
Tillage, fruit & vegetables	1,963
Extra Costs Incurred	
Concentrates & Feed Purchased	174
DAFM Monitoring Costs	9
Contaminated Grass Removal	1,253
EPA Costs Incurred	
Lab and Monitoring costs	15
Food & Environment Monitoring	4
Product Certification	5
Total	**3,423**

Due to radiation contamination, Irish produce will incur considerable losses in export markets, both direct losses due to import restriction and also reputational losses. For this scenario we assume that the EU will prohibit imports of Irish produce for one year, whereas other international markets impose 5 year restrictions. Reputational losses continue after the import restrictions are rescinded, 2 years for EU markets and 10 years for international markets. Table 10 lists the losses across the production categories with the total export losses in excess of €43 billion.

Table 10 - Scenario 3 – Export Losses

	Direct Loss (€m)	Reputational Loss (€m)	Total (€m)
Livestock	975	940	1,915
Meat Products	8,070	7,776	15,847
Dairy Produce	4,450	4,288	8,738
Seafood	1,280	1,233	2,513
Cereals & cereal production	848	817	1,665
Fruit & Vegetables	630	607	1,237
Animal feedstuffs	575	554	1,130
Other Food Produce	4,695	4,524	9,219
Other Goods	570	550	1,120
Total	**22,095**	**21,290**	**43,384**

In total there are almost 23 million fewer international tourist visitors to the country over a 6 year horizon. On average 3.8 million visitors less per annum, though the losses are greater immediately after the accident. Across the 6 years the total discounted loss in the tourism sector is almost €10 billion, as reported in Table 11.

Table 11 - Scenario 3 - Tourism Reputational Loss

Visitor Origin	Reputational Loss (€m)	Tourists (Million)
UK	4,125	9.5
Rest of Europe	3,468	8.0
Rest of World	2,245	5.2
Total	**9,838**	**22.7**

Irish households will also spend more on foodstuffs by switching to imported produce.[19] It is difficult to gauge how households will actually respond and for the purposes of this scenario we assume that the additional costs to domestic consumers is initially equivalent to 5% of their food bill and that this declines as over time as the reputational losses associated with food of Irish origin diminishes. The increase in the cost of foodstuffs for domestic consumers is €336 million.

The indirect impacts through the rest of the economy in this scenario amount to €22.6 billion. This loss includes the indirect impact of the loss of fruit, vegetable and tillage crops for one year and the associated demand for intermediate inputs.

The sum of direct and indirect loses in scenario 3 is €79.6 billion. This is considered to be a conservative lower bound estimate of the potential total loss. This estimate excludes costs associated with disposal of contaminated or condemned materials, as well as any losses or additional healthcare costs, or wealth or migration flows that might arise in the event of such an accident.

[19] All food placed on the market will need to satisfy food safety guidelines.

Scenario 4 – Nuclear accident leading to high levels of contamination in Ireland

High levels of nuclear contamination would be economically catastrophic for Ireland and particularly so for the food sector. In this scenario, concerns for the health of the population become a primary focus. Levels of contamination are such to warrant food controls and agriculture protective actions for a number of years after the accident, as without them food would not comply with EU regulations on radioactivity content. International demand for Irish produce will completely collapse, while animal production systems need to start over. The cost of such a scenario is far from being just economic or financial, as it will have a substantial cost on societal well being. However, within this report we focus on a narrow range of economic costs.

As in scenario 3, although food controls and other protective actions should prevent long term health risks it is likely that the perception of a radiological risk will mean more engagement with the health services than would otherwise be the case. It is difficult to assess either the level of additional health service engagement or its associated cost but it likely to be quite substantial. No estimate of the additional health costs that might arise under this scenario is provided.

The impact of such high levels of contamination will also be long-lived. For example, our scenario assumes that radiation monitoring and product certification by the EPA will continue for 60 years after the accident, which alone will cost almost €50 million. Other direct costs are listed in Table 12. Similar to scenario 3 the cost of contaminated grass disposal is not estimated, nor is the cost of disposal of contaminated livestock (or livestock for which there is no market). The cost of livestock disposal could potentially be multiples of the value of lost agricultural produce, which itself is valued at €5 billion. It is also likely that in this scenario (and to a lesser extent in scenario 3) that there may be substantial outward migration and capital withdrawal from the economy. Significant emigration and wealth shocks could have a substantial impact on the productive capacity and aggregate demand within the economy causing a serious fiscal-erosion of the tax base. The magnitude of such impacts has not been assessed.

Agricultural production is essentially lost in the first three years after an accident. The scenario assumes that EU markets will open to Irish produce after that time but that it will take a further 12 years before international markets open up to Irish produce. We have not included an estimate of the cost of re-establishment within agriculture (e.g. rebuilding livestock herds). We have assumed that the duration of reputational losses are of 6 and 15 years durations for the EU and Non-EU respectively. The total value of loss of export markets is some €84 billion, with meat and dairy produce alone accounting for over €47 billion, as shown in Table 13.

Table 12 - Scenario 4 – Direct Costs and Losses

	Total (€m)
Lost Produce	
Livestock, tillage, fruit & vegetables	5,138
Extra Costs Incurred	
DAFM Monitoring Costs	47
Contaminated Grass Removal	1,253
Soil Remediation Actions	2,968
EPA Costs Incurred	
Lab and Monitoring costs	23
Food & Environment Monitoring	6
Product Certification	14
Total	**9,449**

Table 13 - Scenario 4 – Export Losses

	Direct Loss (€m)	Reputational Loss (€m)	Total (€m)
Livestock	2,450	1,158	3,608
Meat Products	20,268	10,469	30,737
Dairy Produce	11,177	5,773	16,950
Seafood	3,214	1,660	4,874
Cereals & cereal production	2,129	1,100	3,229
Fruit & Vegetables	1,583	817	2,400
Animal feedstuffs	1,445	746	2,191
Other Food Produce	11,791	6,090	17,881
Other Goods	1,433	740	2,173
Total	**55,489**	**28,554**	**84,043**

The tourism market would also suffer substantial losses. Our model suggests that there would be approximately 57 million fewer tourist visitors to Ireland over a 15 year period, amounting to over €21 billion in lost revenue.

Table 14 - Scenario 4 - Tourism Reputational Loss

Visitor Origin	Reputational Loss (€m)	Tourists (Million)
UK	9,003	23.7
Rest of Europe	7,571	20.0
Rest of World	4,899	12.9
Total	**21,473**	**56.6**

For most Irish households the direct impact will relate to their purchased food. Supplies of domestic food produce will dwindle and for the first few years post accident most food will be imported. This will increase the cost of foodstuffs supplied in the Irish market plus there are likely to be supply restrictions and price increases associated with the accident elsewhere in Europe. The magnitude of these increased costs is impossible to assess but we have conservatively assumed that the additional costs to domestic consumers is equivalent to 10% of their food bill immediately after the accident and that this declines over time as the reputational losses diminish. The increased cost of foodstuffs for domestic consumers under those assumptions is over €1.8 billion. The total indirect impact to the rest of the economy is estimated to total €44 billion.

The sum of direct and indirect loses in scenario 4 is €161.2 billion. Similar to the other scenarios this is a conservative lower bound estimate of the potential total loss. For instance, it excludes costs associated with disposal of contaminated or condemned materials, as well as any losses or additional healthcare costs, or wealth or migration flows that might arise in the event of such an accident. It also excludes the cost of livestock disposal, which could potentially be many multiples of the value of lost agricultural produce.

Summary

Across the four scenarios we have assessed some of the potentially larger economic impacts of a nuclear accident. It has not been possible to assess all the impacts and from that perspective the figures presented here should be considered as conservative lower bound estimates. This is particularly the case for scenarios 3 and 4. The figures are intended to be illustrative of the scale of potential losses for accidents of varying severity rather than quantify a definitive loss resulting from an accident of very low probability with an uncertain outcome.

6. Summary

This report assesses some specific economic costs facing Ireland in the event of a nuclear accident. This information will inform national positions on policy and legislative developments in Europe and internationally with respect to the nuclear risks and management. The report also seeks to provide supporting data on assessing whether it is in Ireland's interests to become a signatory with respect to treaties and conventions. Ireland is already a signatory to a number of Emergency Preparedness & Response conventions but could, in the future, consider becoming a signatory to one of the existing nuclear liability conventions if it were appropriate.

Table 15 summarises the scale of losses across the four scenarios, combining the direct agricultural, tourism, export and domestic consumption impacts and indirect losses in the wider economy. Two points are immediately striking. A nuclear accident in north-western Europe could potentially have a severe impact on the economy; the discounted cost of the most severe accident scenario is roughly equal to the economy's annual GDP. The second point is that where a nuclear accident does occur but with no radiological deposition occurring on Ireland there is still a substantial though more manageable economic impact.

Table 15 – Summary of Losses – Scenarios 1 to 4

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	€billion			
Direct Costs & Losses (incl. reputation losses) to agriculture, food, and tourism sectors	4.1	14.9	57.0	116.8
Indirect Losses (rest of economy)	0.3	3.5	22.6	44.4
Total	**4.4**	**18.4**	**79.6**	**161.2**

To quantify the economic effects of such hypothetical, unprecedented events is extremely difficult. The impacts are likely to be discrete rather than marginal and consequently it is especially difficult to assess indirect effects. The methodology employed in this report is intended to be illustrative of the scale of impacts and does not purport to be an exhaustive assessment of all potential effects and guidance which would be experienced in the event of an accident. To the contrary, we have taken a conservative approach by focusing on the direct impacts within three key areas: the agriculture and food sectors and tourism (incl. exports). We then used data on the interdependence of the sectors within the economy to assess the indirect impacts on the wider economy. Accordingly, the estimates represent lower bound estimates of the potential economic impacts of the scenarios examined. The analysis has not attempted to estimate the costs associated with disposal of contaminated or condemned materials, as well as any losses or additional healthcare costs, or wealth or migration flows that might arise in the event of such an accident. A nuclear accident is likely to have wider social impacts and though not considered within this report could potentially be very large in magnitude.

Even a nuclear accident somewhere in northwest Europe that has no physical radiation impact within Ireland is likely to have a negative economic impact on the Irish economy. Our heavy reliance on tourism and export markets for food produce means that even the perception of Ireland suffering nuclear contamination will lead to a relatively significant economic impact. In the least severe of the accident scenarios considered (i.e. no radiological impact) the reputational losses amount to over €4 billion. The impact of such an event on Ireland would be confined within a relatively short period. However, the duration of impact in the most severe scenario considered extends to 60 years. The magnitude of the assessed losses in that scenario are roughly equivalent to one year's GDP but this represents a conservative lower bound estimate of the impact. The full impacts would be substantially higher.

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