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Nordic Nuclear Accident Consequence Analysis (NORCON): Final Report

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Abstract

The NORCON project involved a comparative partial consequence analysis conducted within the Nordic region for a release of radioactivity from a nuclear power reactor(s) located within the region or in a nearby region of potential significance for the purpose of identifying methodological or procedural disparities between the participating countries with respect to the generation of the information used to direct post-accident responses over the short to long term. The project ranged from source term evaluation, to detailed dispersion/transport modelling and long term consequence assessment. The aims of the project included assessment of the potential for disparities and fractures in the assessment of impacts from a nuclear accident due to the implementation of systems for the estimation of dispersion of contamination and the behaviour of contaminants in the environment in years following an accident. The results of the project indicate that the main potential source of divergence in assessing the potential impacts of a nuclear accident between the countries of the Nordic region lies within the routines and procedures implemented during assessment of late phase impacts.

Key words

Nuclear accident, consequence, impact assessment, dispersion, transfer

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Final Report from the NKS-B Project NORCON (Contracts: AFT/B(14)1 and AFT/B(15)2).

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1.0 Introduction

1.1 Background.

The NORCON project involved a comparative partial consequence analysis conducted within the Nordic region for a release of radioactivity from a nuclear power reactor(s) located within the region or in a nearby region of potential significance for the purpose of identifying methodological or procedural disparities between the participating countries with respect to the generation of the information used to direct post-accident responses over the short to long term. The project ranged from source term evaluation, to detailed dispersion/transport modeling and long term consequence assessment. The majority of countries in the Nordic region have conducted or have the capacity to conduct consequence analyses of a range of types and at varying levels of complexity for nuclear accidents in relation to either their own reactors, those in neighboring countries or reactors farther afield and in this regard have, collectively, significant experience in this field. These analyses have focused on some or all of a range of "end points" including effects on humans, socioeconomic factors and the environment. The results of these analysis form, in most cases, the basis for decision making and the provision of advice to affected members of the public.

Recent events, such as those that occurred as a result of the accident in Japan, have demonstrated the need for regional level response in relation to a number of aspects that include, but are not limited to, contaminant transport predictions, potential human/environmental impacts, countermeasures and remediation. This demonstration reinforces earlier experiences in relation to regional level response in the aftermath of the Chernobyl accident. While the specificities of the responses of individual countries to accidents in terms of recommendations, counter measures etc. may differ in a variety of ways, a common understanding on the regional level of the basis upon which decisions are being made by individual countries aids in the establishment of coherent, robust and holistic responses to nuclear accidents. The impacts of divergent responses from countries as closely linked as those in the Nordic region, to individual incidents, can generate uncertainty and confusion which can be propagated through various media and ultimately pose a significant challenge at a time when resources are better spent on other activities. The Nordic countries have, in particular over the past two decades, been proactive in establishing and maintaining the foundations of regional level response, work in this direction having been precipitated by the Chernobyl accident. This is amply evidenced by initiatives such as "The Nordic Manual" (Co-operation, Exchange of Information and Assistance between Nordic Authorities in

Nuclear or Radiological Incidents and Emergencies) of 2006, the agreement upon recommendations for Nordic Intervention Criteria for Nuclear or Radiological Emergencies of 2001, the Nordic “flag books” and the existence of a range of “Nordic Groups” under the umbrella of nuclear emergency management. Parallel to these concrete initiatives exist a number of informal arrangements and contacts between the Nordic countries on a number of different levels. While the previously listed initiatives aimed specifically at addressing potential weaknesses highlighted by responses in the wake of the Chernobyl accident, the events in the days and weeks following the more recent Fukushima accident provided a further opportunity for reflection upon Nordic response to nuclear emergencies. A distillation of the Nordic experience held at Stockholm in January of 2013 produced a range of observations of relevance regarding regional level responses, two of which are the related to objectives of this proposal – improvements in the exchange of assessments and related information between nuclear safety experts and addressing the situation whereby a major accident occurs in or very close to the Nordic region itself.

1.2 Objectives

The objectives of the NORCON project were to improve the ability of the Nordic region as a whole to coherently assess the consequences of a major accident within the Nordic region, to improve the exchange of assessment information and results between the Nordic countries and to identify vulnerabilities and divergences between individual nation’s consequence assessment methodologies in relation to regional response.

1.3 Realisation

The objectives were to be realised by the participants performing independent consequence analyses for an accident scenario(s) using a common source term(s) - all the countries conducting their analysis from the same start point and using the systems or procedures as would be employed in the aftermath of a significant accident. The complexity of the foundation upon which the objectives of NORCON were anchored necessitated a fairly complex approach whilst incorporating a degree of flexibility such that the materials with which NORCON was concerned could be generated and analysed despite the disparity of systems and approachs employed by the various participants. It was decided at an early stage that it would be advisable to split the activity into two distinct parts – dispersion modelling and ecosystem/foodchain transfer. For the purposes of dispersion modelling it was decided that a series of modelling runs would be made assuming releases according to the source terms as described previously at various specified time points for which pertinent meteorological data would be employed. These dates were October 17th of 2014 and 25th of March 2015. The data generated by these modelling runs was then used for intercomparison purposes and for the purposes of comparing transfer and uptake as is detailed later in this report. Deviation from these dates and precautions implemented to ameliorate any subsequent effects are described where appropriate in the text body. Intercomparison was conducted as described within the relevant sections of this report and during expert discussion at four meetings over the project duration.

2.0 Source Terms

In accordance with the objectives of NORCON, two source terms were developed as part of the project – the first to be one within the Nordic area, the second to be outside of the area but of relevance with respect to potential consequences. The primary purpose of these source terms was to provide a hypothetical but fundamentally sound basis for further stages of the NORCON work. The source terms were developed over a series of meetings held within the NORCON project during 2014. The main criteria for development of the source terms were that they be of such a magnitude that they facilitated useful comparisons during later phases of the project, that they were detailed enough to facilitate thorough analysis of consequences and that they were technically defensible. Source terms have been previously described in earlier deliverabler reports as part of the NORCON project and are presented here for convenience.

Figure 1. Location of the Brokdorf and Ringhals facilities.

2.1 Brokdorf

The first source term was developed for the Brokdorf PWR facility in Germany (53°51´03˝N 9°20´41˝E) (see Figure 1) and was derived from technical information and analyses as described within "*Aktualisierung der Quelltermbibliothek des Entscheidungshilfesystems RODOS für Ereignisse im Leistungsbetrieb*" (Löffler, H., Mildenberger, O., Sogalla, M., Stahl, T., Gesellschaft für Anlagenund Reaktorsicherheit (GRS) GmbH, 2010). The Brokdorf plant is a pressurized water reactor (PWR) with uranium dioxide fuel elements of 1.9%, 2.5% and 3.5% enrichment. It also uses some MOX fuel. There are 193 fuel assemblies in the reactor, with a total heavy-metal weight of 103 tons. The power station has a thermal output of 3765 MW, and an electrical output of 1440 MW. The Brokdorf nuclear power plant is located about 10 kilometres to the north-west of Glückstadt in Schleswig-Holstein on the banks of the River Elbe. The reactor was commissioned in 1986 and is due for decommissioning in 2021. The source term used within NORCON is presented in Table 3.

2.2 Ringhals

The source term presented within NORCON is based on a recent Level 2 Probabilistic Safety Assessment (PSA) study made for the 2011 uprated Ringhals 4 (3300 MWth). The R4 reactor is one of four at the Ringhals site situated in Sweden (57°15´35˝N 12°6´39˝E). The R4 reactor is a 3-loop 1115 MWe PWR reactor that commenced commercial generation in 1983. The objective for a Level 2 PSA is to study the impact on the containment and its related systems and the characteristics of possible radiological releases from severe core damage accidents. Input to the Level 2 PSA is the Level 1 PSA event trees attributed with a core damage consequence. Events with similar accident progression are grouped into a number of Plant Damage States (PDS) also considering some operator actions and phenomenological aspects. The PDS:s are the starting points for the containment event tree (CET) analysis of the accident progression after the onset of the core melt. The outcome from the CET analysis is an extensive set of accident sequences emerging from different initial events with different availabilities of different systems and with different boundary conditions and related to a certain frequency. In order to interpret and present the vast amount of information, accident sequences are grouped together into different release categories (RC) depending on the characteristics of the fission product releases to the environment (magnitude, timing etc). The source terms for each release category are obtained by calculations made with the software

MAAP (Modular Accident Analysis Program) for representative accident scenarios. The MAAP software simulates most of the important severe accident phenomena. The selected scenario in this study is a steam generator tube rupture release category. The initiating event is a tube rupture in one of the steam generators with several systems unavailable which leads to severe core damage after approximately 35 hours. The scenario is also representative for some sequences where the Steam Generator initially is intact, but fails due to creep rupture (SAI-SGTR - Severe Accident Induced Steam Generator Tube Rupture). In all these sequences with failed tubes there is a potential for releases of fission products to reach the environment through different pathways in the secondary system (e.g. safety- and relief valves). SGTR-sequences in the R4 PSA L2 study constitute less than 1% of the frequency of core melt sequences, but expressed as source term risk for Cs (frequency multiplied with release fraction) they constitute more than 50% of the total source term risk for Cs.

The MAAP result indicates a source term of approximately 25% of the noble gas inventory, 3% of the cesium and iodine inventory, together with smaller amounts of other fission products which is released to the atmosphere at a supposed release height of 20 m. The release onset is after approximately 36 hours with a 64 hours duration. The MAAP release fractions for different release groups (see Table 1) have to be converted into released activity in Bq. For most of the 26 radionuclides considered in the study, the core inventory is multiplied with the release fractions for the MAAP group (an approximation since the MAAP result is presented in mass release fraction).

Since MAAP by definition assumes all iodine to form CsI it can be deduced that appr. 10% of the Cs originates from the CsI group (group 2), while the remaining originates from the CsOH group (group 6). The core inventory and the mapping for each radionuclide are presented in Table 2. The source term for Ringhals within the NORCON project is presented in Table 4. Note that the release fractions from MAAP do not take into account radioactive decay and ingrowth between scram and starting time for each release time interval.

Group 1	Nobles (Xe + Kr)
Group 2	CsI + RbI
Group 3	TeO_2
Group 4	SrO
Group 5	MoO_2+RuO_2+TcO_2
Group 6	CsOH + RbOH
Group 7	BaO
Group 8	La_2O_3+Pr_2O_3+Nd_2O_3+Sm_2O_3+Y_2O_3+ZrO^2+NbO^2
Group 9	CeO^2+ NpO^2 + PuO^2
Group 10	Sb
Group 11	Te^2
Group 12	UO^2

Table 1. *The MAAP release groups.*

Nuclide	**Core inv [Bq]**	**MAAP release group**	**Nuclide**	**Core inv [Bq]**	**MAAP release group**
^{87}Kr	1.70E+18	Group 1	^{106}Ru	1.64E+18	Group 5
^{88}Kr	2.28E+18	Group 1	^{131m}Te	6.23E+17	Group 3
^{133}Xe	6.52E+18	Group 1	^{132}Te	4.68E+18	Group 3
^{135}Xe	1.77E+18	Group 1	^{134}Cs	5.68E+17	(0.1*Group 2)+(0.9*Group 6)
^{131}I	3.26E+18	Group 2	^{136}Cs	1.67E+17	(0.1*Group 2)+(0.9*Group 6)
^{132}I	4.79E+18	Group 2	^{137}Cs	3.66E+17	(0.1*Group 2)+(0.9*Group 6)
^{133}I	6.74E+18	Group 2	^{140}Ba	5.81E+18	Group 7
^{134}I	7.58E+18	Group 2	^{140}La	6.11E+18	Group 8
^{135}I	6.43E+18	Group 2	^{144}Ce	4.00E+18	Group 9
^{90}Sr	2.68E+17	Group 4	^{238}Pu	1.23E+16	Group 9
^{95}Zr	5.71E+18	Group 8	^{241}Pu	4.15E+17	Group 9
^{99}Mo	6.14E+18	Group 5	^{242}Cm[1]	1.26E+17	Group 8
^{103}Ru	5.05E+18	Group 5	^{244}Cm[1]	1.83E+16	Group 8

[1] Assumed to behave similarily to those in Group 8.

Table 2. *The core inventory and the MAAP mapping for the selected radionuclides.*

	Start	0.00000										
FKA	Abs time(h)	0.59449	1.38889	2.44167	2.96555	3.94083	6.51111	9.72222	12.50000	15.27780	18.0556	20.8333
	Nuclide											
Time(min)		35.6694	47.664	63.1668	31.4328	58.5168	154.2168	192.6666	166.6668	166.668	166.668	166.662
	Kr-87	6.64E+14	7.77E+13	1.18E+14	2.96E+12	1.37E+11	5.18E+10	1.02E+10	1.56E+10	2.17E+10	1.95E+10	2.06E+10
	Kr-88	6.03E+15	7.22E+14	1.17E+15	3.70E+13	2.64E+14	9.98E+13	1.96E+13	3.00E+13	4.18E+13	3.77E+13	3.97E+13
	Xe-133	4.08E+17	6.29E+16	1.65E+17	1.12E+16	2.44E+17	9.35E+16	1.88E+16	2.93E+16	4.17E+16	3.85E+16	4.15E+16
	Xe-135	1.10E+17	1.66E+16	4.23E+16	2.80E+15	6.01E+16	2.27E+16	4.48E+15	6.83E+15	9.52E+15	8.58E+15	9.05E+15
	I-131	3.39E+16	5.49E+15	1.92E+16	2.81E+15	1.64E+16	5.24E+15	7.76E+14	5.85E+15	4.41E+15	8.21E+15	5.73E+15
	I-132	4.45E+16	7.19E+15	2.51E+16	3.65E+15	2.12E+16	6.74E+15	9.90E+14	7.39E+15	5.52E+15	1.02E+16	7.05E+15
	I-133	3.91E+16	6.18E+15	2.09E+16	2.95E+15	1.68E+16	5.32E+15	7.71E+14	5.68E+15	4.19E+15	7.62E+15	5.20E+15
	I-134	3.46E+14	4.26E+13	8.62E+13	4.68E+12	8.66E+08	2.73E+08	3.96E+07	2.91E+08	2.14E+08	3.90E+08	2.65E+08
	I-135	1.07E+16	1.54E+15	4.48E+15	5.40E+14	2.74E+15	8.65E+14	1.25E+14	9.22E+14	6.78E+14	1.23E+15	8.39E+14
	Sr-90	7.71E+12	8.54E+12	2.22E+13	6.66E+10	2.68E+14	2.86E+14	3.97E+13	2.24E+13	4.95E+13	6.48E+13	4.79E+13
	Zr-95	1.53E+09	2.00E+09	8.55E+09	1.31E+10	5.64E+14	7.90E+14	3.86E+12	1.40E+05	2.17E+05	1.59E+05	1.12E+05
	Mo-99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.36E+07	1.77E+08	2.45E+07	2.43E+06	2.54E+06	3.02E+06	4.26E+06
	Ru-103	8.26E+09	1.74E+10	5.48E+10	1.11E+08	1.61E+09	6.65E+08	5.53E+07	2.76E+01	2.07E+01	1.06E+01	6.25E+00
	Ru-106	2.10E+09	4.41E+09	1.39E+10	2.82E+07	4.09E+08	1.69E+08	1.41E+07	7.06E+00	5.31E+00	2.73E+00	1.61E+00
	Sb-137	1.10E+11	9.98E+09	8.25E+08	2.73E+08	2.98E+13	1.21E+14	5.01E+13	1.82E+13	8.44E+12	8.31E+12	7.08E+12
	Te-132	3.70E+16	6.81E+15	1.64E+16	2.30E+15	2.07E+16	2.38E+15	7.40E+14	8.68E+15	8.61E+15	2.57E+15	8.03E+14
	Cs-134	3.32E+15	5.22E+14	2.00E+15	3.02E+14	1.72E+15	4.37E+14	9.74E+13	7.12E+14	4.37E+14	8.76E+14	6.02E+14
	Cs-137	2.85E+15	4.48E+14	1.71E+15	2.59E+14	1.48E+15	3.74E+14	8.35E+13	6.10E+14	3.75E+14	7.51E+14	5.16E+14
	Ba-140	2.22E+14	2.46E+14	6.39E+14	1.91E+12	7.67E+15	8.14E+15	1.13E+15	6.32E+14	1.39E+15	1.81E+15	1.33E+15
	La-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E+13	2.96E+13	7.85E+11	7.34E+10	2.66E+10	9.07E+03	6.76E+03
	Ce-144	9.81E+08	1.28E+09	5.48E+09	8.42E+09	3.62E+14	5.06E+14	2.48E+12	8.99E+04	1.39E+05	1.02E+05	7.20E+04
	Pu-238	1.08E+06	1.40E+06	6.01E+06	9.24E+06	3.97E+11	5.56E+11	2.72E+09	9.88E+01	1.53E+02	1.13E+02	7.94E+01
	Pu-241	7.66E+07	9.99E+07	4.28E+08	6.57E+08	2.82E+13	3.95E+13	1.94E+11	7.03E+03	1.09E+04	8.02E+03	5.64E+03
	Cm-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E+11	3.46E+11	9.20E+09	8.64E+08	3.14E+08	1.08E+02	8.06E+01
	Cm244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.67E+09	1.38E+10	3.66E+08	3.44E+07	1.25E+07	4.29E+00	3.21E+00
	Height (m)	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000
	I aerosol	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000

Abs time(h)	23.30560	26.3889	29.1667	31.9444	34.72222	37.5	40.2778	43.0556	45.8333	48.6111	50	Abs time(h)		3850.00	MwT
Nuclide														GRS 358	
Time(min)	148.338	184.998	166.668	166.662	166.6692	166.6668	166.668	166.668	166.662	166.668	83.334	Total		Inventory	Fraction
Kr-87	1.93E+10	2.95E+10	2.86E+10	2.90E+10	2.75E+10	2.66E+10	2.65E+10	2.70E+10	2.57E+10	2.69E+10	1.30E+10	8.63E+14	Kr-87	2.02E+18	4.27113E-04
Kr-88	3.71E+13	5.68E+13	5.51E+13	5.58E+13	5.30E+13	5.13E+13	5.10E+13	5.20E+13	4.95E+13	5.17E+13	2.51E+13	9.03E+15	Kr-88	2.82E+18	3.20256E-03
Xe-133	3.97E+16	6.23E+16	6.22E+16	6.48E+16	6.34E+16	6.33E+16	6.52E+16	6.88E+16	6.80E+16	7.39E+16	3.70E+16	1.82E+18	Xe-133	7.63E+18	2.38933E-01
Xe-135	8.46E+15	1.29E+16	1.26E+16	1.27E+16	1.21E+16	1.17E+16	1.16E+16	1.19E+16	1.13E+16	1.18E+16	5.72E+15	4.15E+17	Xe-135	1.66E+18	2.50217E-01
I-131	7.71E+15	1.61E+16	2.58E+16	3.98E+16	4.23E+16	5.03E+16	2.87E+15	3.08E+15	3.92E+15	3.94E+15	2.37E+15	3.06E+17	I-131	3.66E+18	8.36336E-02
I-132	9.41E+15	1.94E+16	3.09E+16	4.71E+16	4.95E+16	5.82E+16	3.29E+15	3.49E+15	4.39E+15	4.36E+15	2.60E+15	3.72E+17	I-132	5.35E+18	6.95654E-02
I-133	6.83E+15	1.39E+16	2.17E+16	3.25E+16	3.35E+16	3.86E+16	2.13E+15	2.21E+15	2.71E+15	2.62E+15	1.53E+15	2.73E+17	I-133	7.67E+18	3.55699E-02
I-134	3.48E+08	7.05E+08	1.10E+09	1.64E+09	1.69E+09	1.94E+09	1.07E+08	1.11E+08	1.35E+08	1.30E+08	7.59E+07	4.79E+14	I-134	8.27E+18	5.79794E-05
I-135	1.10E+15	2.23E+15	3.48E+15	5.21E+15	5.36E+15	6.16E+15	3.39E+14	3.51E+14	4.29E+14	4.13E+14	2.40E+14	5.00E+16	I-135	7.16E+18	6.97913E-03
Sr-90	3.17E+13	1.93E+13	5.33E+12	1.78E+12	2.15E+04	1.93E+04	1.66E+04	2.22E+11	1.07E+04	7.99E+03	3.33E+03	8.75E+14	Sr-90	2.22E+17	3.94088E-03
Zr-95	8.09E+04	6.39E+11	3.00E+04	2.48E+04	2.23E+04	2.10E+04	1.65E+04	1.33E+04	1.14E+04	6.32E+11	3.51E+03	1.36E+15	Zr-95	6.45E+18	2.10819E-04
Mo-99	4.83E+06	9.28E+06	9.79E+06	1.07E+07	8.21E+06	8.24E+06	5.59E+06	4.45E+06	3.25E+06	5.65E+06	2.46E+06	3.00E+08	Mo-99	7.71E+12	3.89399E-05
Ru-103	4.10E+00	2.95E+00	1.42E+00	5.43E+07	1.08E+00	5.41E+07	8.64E-01	7.00E-01	5.37E+07	4.29E-01	1.78E-01	8.30E+10	Ru-103	5.65E+18	1.46949E-08
Ru-106	1.06E+00	7.62E-01	3.67E-01	1.41E+07	2.82E-01	1.41E+07	2.26E-01	1.84E-01	1.41E+07	1.13E-01	4.71E-02	2.11E+10	Ru-106	1.41E+18	1.49660E-08
Sb-137	6.48E+12	1.00E+13	9.42E+12	9.51E+12	7.29E+12	7.61E+12	5.27E+12	4.75E+12	3.81E+12	6.02E+12	2.73E+12	3.16E+14	Sb-137	3.23E+17	9.79595E-04
Te-132	8.27E+14	1.25E+15	1.74E+15	2.06E+15	1.70E+15	1.91E+15	2.03E+15	2.42E+15	1.89E+15	2.63E+15	1.81E+15	1.27E+17	Te-132	5.24E+18	2.42812E-02
Cs-134	8.14E+14	1.61E+15	2.47E+15	3.69E+15	4.79E+15	4.78E+15	2.59E+15	3.76E+14	4.46E+14	4.66E+14	2.77E+14	3.34E+16	Cs-134	3.54E+17	9.42163E-02
Cs-137	6.98E+14	1.38E+15	2.12E+15	3.17E+15	4.11E+15	4.10E+15	2.22E+15	3.23E+14	3.82E+14	4.00E+14	2.38E+14	2.86E+16	Cs-137	3.54E+17	8.07568E-02
Ba-140	8.75E+14	5.29E+14	1.45E+14	4.81E+13	5.79E+05	5.17E+05	4.43E+05	5.87E+12	2.80E+05	2.09E+05	8.66E+04	2.48E+16	Ba-140	6.47E+18	3.83411E-03
La-140	5.14E+03	6.53E+10	1.30E+10	3.23E+10	1.79E+03	1.77E+03	1.68E+03	1.27E+10	2.53E+10	1.26E+10	3.49E+09	4.51E+13	La-140	6.86E+18	6.57149E-06
Ce-144	5.21E+04	4.11E+11	1.93E+04	1.60E+04	1.44E+04	1.35E+04	1.07E+04	8.60E+03	7.37E+03	4.09E+11	2.27E+03	8.71E+14	Ce-144	4.14E+18	2.10480E-04
Pu-238	5.74E+01	4.54E+08	2.13E+01	1.77E+01	1.59E+01	1.50E+01	1.18E+01	9.53E+00	8.17E+00	4.54E+08	2.52E+00	9.57E+11	Pu-238	4.54E+15	2.10734E-04
Pu-241	4.08E+03	3.23E+10	1.52E+03	1.26E+03	1.13E+03	1.07E+03	8.39E+02	6.78E+02	5.81E+02	3.23E+10	1.79E+02	6.80E+13	Pu-241	3.33E+17	2.04307E-04
Cm-242	6.15E+01	7.84E+08	1.57E+08	3.92E+08	2.18E+01	2.16E+01	2.07E+01	1.57E+08	3.13E+08	1.56E+08	4.34E+07	5.26E+11	Cm-242	7.87E+16	6.68440E-06
Cm244	2.45E+00	3.13E+07	6.25E+06	1.56E+07	8.69E-01	8.63E-01	8.25E-01	6.25E+06	1.25E+07	6.25E+06	1.74E+06	2.09E+10	Cm244	3.13E+15	6.68123E-06
Height (m)	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000				
I aerosol	100.00000	100.00000	100.00000	100.00000	100.00000	##########	100.00000	100.00000	100.00000	100.00000	100.00000				

	Start	0.00000										
FKA	Abs time(h)	0.59449	1.38889	2.44167	2.96555	3.94083	6.51111	9.72222	12.50000	15.27780	18.0556	20.8333
	Nuclide											
Time(min)		35.6694	47.664	63.1668	31.4328	58.5168	154.2168	192.6666	166.6668	166.668	166.668	166.662
	Kr-87	3.45E+14	4.04E+13	6.10E+13	1.54E+12	7.11E+10	2.69E+10	5.30E+09	8.08E+09	1.13E+10	1.02E+10	1.07E+10
	Kr-88	3.13E+15	3.75E+14	6.07E+14	1.92E+13	1.37E+14	5.18E+13	1.02E+13	1.56E+13	2.17E+13	1.96E+13	2.06E+13
	Xe-133	2.12E+17	3.27E+16	8.56E+16	5.82E+15	1.27E+17	4.86E+16	9.76E+15	1.52E+16	2.17E+16	2.00E+16	2.16E+16
	Xe-135	5.70E+16	8.61E+15	2.20E+16	1.46E+15	3.12E+16	1.18E+16	2.33E+15	3.55E+15	4.94E+15	4.46E+15	4.70E+15
	I-131	1.76E+16	2.85E+15	9.99E+15	1.46E+15	8.52E+15	2.72E+15	4.03E+14	3.04E+15	2.29E+15	4.26E+15	2.98E+15
	I-132	2.31E+16	3.74E+15	1.30E+16	1.90E+15	1.10E+16	3.50E+15	5.14E+14	3.84E+15	2.87E+15	5.30E+15	3.66E+15
	I-133	2.03E+16	3.21E+15	1.08E+16	1.53E+15	8.75E+15	2.76E+15	4.00E+14	2.95E+15	2.17E+15	3.96E+15	2.70E+15
	I-134	1.80E+14	2.21E+13	4.48E+13	2.43E+12	4.50E+08	1.42E+08	2.05E+07	1.51E+08	1.11E+08	2.02E+08	1.38E+08
	I-135	5.56E+15	8.00E+14	2.33E+15	2.80E+14	1.43E+15	4.49E+14	6.51E+13	4.79E+14	3.52E+14	6.41E+14	4.36E+14
	Sr-90	4.01E+12	4.44E+12	1.16E+13	3.46E+10	1.39E+14	1.48E+14	2.06E+13	1.16E+13	2.57E+13	3.37E+13	2.49E+13
	Zr-95	7.95E+08	1.04E+09	4.44E+09	6.83E+09	2.93E+14	4.10E+14	2.01E+12	7.27E+04	1.13E+05	8.28E+04	5.82E+04
	Mo-99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.07E+06	9.22E+07	1.27E+07	1.26E+06	1.32E+06	1.57E+06	2.21E+06
	Ru-103	4.29E+09	9.03E+09	2.85E+10	5.77E+07	8.35E+08	3.45E+08	2.87E+07	1.43E+01	1.07E+01	5.50E+00	3.24E+00
	Ru-106	1.09E+09	2.29E+09	7.24E+09	1.47E+07	2.13E+08	8.80E+07	7.33E+06	3.67E+00	2.76E+00	1.42E+00	8.36E-01
	Sb-137	5.72E+10	5.18E+09	4.29E+08	1.42E+08	1.55E+13	6.31E+13	2.60E+13	9.44E+12	4.38E+12	4.31E+12	3.68E+12
	Te-132	1.92E+16	3.54E+15	8.52E+15	1.19E+15	1.07E+16	1.24E+15	3.84E+14	4.51E+15	4.47E+15	1.34E+15	4.17E+14
	Cs-134	1.73E+15	2.71E+14	1.04E+15	1.57E+14	8.95E+14	2.27E+14	5.06E+13	3.70E+14	2.27E+14	4.55E+14	3.13E+14
	Cs-137	1.48E+15	2.33E+14	8.91E+14	1.34E+14	7.67E+14	1.94E+14	4.34E+13	3.17E+14	1.95E+14	3.90E+14	2.68E+14
	Ba-140	1.16E+14	1.28E+14	3.32E+14	9.91E+11	3.99E+15	4.23E+15	5.85E+14	3.28E+14	7.20E+14	9.38E+14	6.90E+14
	La-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.48E+12	1.54E+13	4.08E+11	3.81E+10	1.38E+10	4.71E+03	3.51E+03
	Ce-144	5.10E+08	6.65E+08	2.85E+09	4.37E+09	1.88E+14	2.63E+14	1.29E+12	4.67E+04	7.23E+04	5.32E+04	3.74E+04
	Pu-238	5.59E+05	7.29E+05	3.12E+06	4.80E+06	2.06E+11	2.89E+11	1.41E+09	5.13E+01	7.96E+01	5.86E+01	4.12E+01
	Pu-241	3.98E+07	5.19E+07	2.22E+08	3.41E+08	1.47E+13	2.05E+13	1.01E+11	3.65E+03	5.66E+03	4.17E+03	2.93E+03
	Cm-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.71E+10	1.80E+11	4.78E+09	4.49E+08	1.63E+08	5.59E+01	4.19E+01
	Cm244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.46E+09	7.14E+09	1.90E+08	1.79E+07	6.50E+06	2.23E+00	1.67E+00
	Height (m)	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000
	I aerosol	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000	100.00000

													Therma	2000.00	MwT
Abs time(h)	23.30560	26.3889	29.1667	31.9444	34.72222	37.5	40.2778	43.0556	45.8333	48.6111	50	Abs time(h)			
Nuclide															
Time(min)	148.338	184.998	166.668	166.662	166.6692	166.6668	166.668	166.668	166.662	166.668	83.334	Total			
Kr-87	1.00E+10	1.53E+10	1.49E+10	1.50E+10	1.43E+10	1.38E+10	1.38E+10	1.40E+10	1.33E+10	1.40E+10	6.76E+09	4.48E+14	Kr-87		
Kr-88	1.93E+13	2.95E+13	2.86E+13	2.90E+13	2.75E+13	2.66E+13	2.65E+13	2.70E+13	2.57E+13	2.69E+13	1.30E+13	4.69E+15	Kr-88		
Xe-133	2.06E+16	3.24E+16	3.23E+16	3.37E+16	3.30E+16	3.29E+16	3.38E+16	3.57E+16	3.53E+16	3.84E+16	1.92E+16	9.47E+17	Xe-133		
Xe-135	4.39E+15	6.72E+15	6.53E+15	6.61E+15	6.28E+15	6.08E+15	6.05E+15	6.16E+15	5.87E+15	6.13E+15	2.97E+15	2.16E+17	Xe-135		
I-131	4.01E+15	8.34E+15	1.34E+16	2.07E+16	2.20E+16	2.61E+16	1.49E+15	1.60E+15	2.04E+15	2.05E+15	1.23E+15	1.59E+17	I-131		
I-132	4.89E+15	1.01E+16	1.60E+16	2.45E+16	2.57E+16	3.02E+16	1.71E+15	1.81E+15	2.28E+15	2.26E+15	1.35E+15	1.93E+17	I-132		
I-133	3.55E+15	7.20E+15	1.13E+16	1.69E+16	1.74E+16	2.00E+16	1.11E+15	1.15E+15	1.41E+15	1.36E+15	7.95E+14	1.42E+17	I-133		
I-134	1.81E+08	3.66E+08	5.71E+08	8.54E+08	8.78E+08	1.01E+09	5.56E+07	5.75E+07	7.03E+07	6.78E+07	3.94E+07	2.49E+14	I-134		
I-135	5.73E+14	1.16E+15	1.81E+15	2.71E+15	2.78E+15	3.20E+15	1.76E+14	1.82E+14	2.23E+14	2.15E+14	1.25E+14	2.60E+16	I-135		
Sr-90	1.65E+13	1.00E+13	2.77E+12	9.22E+11	1.12E+04	1.00E+04	8.64E+03	1.15E+11	5.53E+03	4.15E+03	1.73E+03	4.54E+14	Sr-90		
Zr-95	4.20E+04	3.32E+11	1.56E+04	1.29E+04	1.16E+04	1.09E+04	8.57E+03	6.91E+03	5.91E+03	3.28E+11	1.82E+03	7.06E+14	Zr-95		
Mo-99	2.51E+06	4.82E+06	5.09E+06	5.55E+06	4.27E+06	4.28E+06	2.90E+06	2.31E+06	1.69E+06	2.94E+06	1.28E+06	1.56E+08	Mo-99		
Ru-103	2.13E+00	1.53E+00	7.35E-01	2.82E+07	5.63E-01	2.81E+07	4.49E-01	3.64E-01	2.79E+07	2.23E-01	9.27E-02	4.31E+10	Ru-103		
Ru-106	5.50E-01	3.96E-01	1.91E-01	7.34E+06	1.47E-01	7.34E+06	1.17E-01	9.54E-02	7.34E+06	5.87E-02	2.45E-02	1.10E+10	Ru-106		
Sb-137	3.37E+12	5.22E+12	4.89E+12	4.94E+12	3.79E+12	3.95E+12	2.74E+12	2.46E+12	1.98E+12	3.13E+12	1.42E+12	1.64E+14	Sb-137		
Te-132	4.30E+14	6.52E+14	9.02E+14	1.07E+15	8.85E+14	9.91E+14	1.06E+15	1.26E+15	9.79E+14	1.36E+15	9.40E+14	6.61E+16	Te-132		
Cs-134	4.23E+14	8.36E+14	1.29E+15	1.92E+15	2.49E+15	2.48E+15	1.34E+15	1.95E+14	2.32E+14	2.42E+14	1.44E+14	1.73E+16	Cs-134		
Cs-137	3.63E+14	7.17E+14	1.10E+15	1.64E+15	2.13E+15	2.13E+15	1.15E+15	1.68E+14	1.99E+14	2.08E+14	1.23E+14	1.49E+16	Cs-137		
Ba-140	4.54E+14	2.75E+14	7.54E+13	2.50E+13	3.01E+05	2.68E+05	2.30E+05	3.05E+12	1.45E+05	1.08E+05	4.50E+04	1.29E+16	Ba-140		
La-140	2.67E+03	3.39E+10	6.75E+09	1.68E+10	9.30E+02	9.19E+02	8.75E+02	6.60E+09	1.31E+10	6.54E+09	1.81E+09	2.34E+13	La-140		
Ce-144	2.70E+04	2.14E+11	1.00E+04	8.32E+03	7.46E+03	7.03E+03	5.53E+03	4.47E+03	3.83E+03	2.12E+11	1.18E+03	4.53E+14	Ce-144		
Pu-238	2.98E+01	2.36E+08	1.11E+01	9.20E+00	8.25E+00	7.78E+00	6.13E+00	4.95E+00	4.24E+00	2.36E+08	1.31E+00	4.97E+11	Pu-238		
Pu-241	2.12E+03	1.68E+10	7.88E+02	6.54E+02	5.87E+02	5.53E+02	4.36E+02	3.52E+02	3.02E+02	1.68E+10	9.31E+01	3.53E+13	Pu-241		
Cm-242	3.20E+01	4.07E+08	8.15E+07	2.04E+08	1.13E+01	1.12E+01	1.07E+01	8.13E+07	1.63E+08	8.13E+07	2.26E+07	2.73E+11	Cm-242		
Cm244	1.27E+00	1.62E+07	3.25E+06	8.12E+06	4.52E-01	4.48E-01	4.29E-01	3.25E+06	6.50E+06	3.25E+06	9.03E+05	1.09E+10	Cm244		
Height (m)	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000	30.00000				
I aerosol	100.00000	100.00000	100.00000	100.00000	100.00000	##########	100.00000	100.00000	100.00000	100.00000	100.00000				

Table 3. Detailed decription of the Brokdorf source term. Values in Bq.

RT4_	Abs time(h)	3.505022	7.013483	14.02716	28.03583	30.03683	32.03694	34.03722	36.03897	38.04061	40.04411	42.04642	45.04642	50.06683	55.00625	60.00625	65.08958	70.00625	75.00625	80.00625	85.00625	90.00625	95.00625	100
	Nuclide																							
Time(min)		210.3013	210.5077	420.8207	840.5203	120.06	120.0067	120.0167	120.105	120.0983	120.21	120.1383	180	301.225	296.365	300	305	295	300	300	300	300	300	299.6267
	Kr- 87	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.05E+15	3.01E+17	6.45E+16	1.21E+15	2.02E+15	6.67E+15	5.10E+15	5.23E+15	5.32E+15	5.08E+15	5.03E+15	4.88E+15	4.74E+15	4.60E+15	4.44E+15	4.25E+15
	Kr- 88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.45E+15	4.04E+17	8.65E+16	1.63E+15	2.70E+15	8.94E+15	6.84E+15	7.01E+15	7.13E+15	6.81E+15	6.75E+15	6.55E+15	6.36E+15	6.16E+15	5.95E+15	5.70E+15
	Xe-133	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E+16	1.15E+18	2.47E+17	4.65E+15	7.73E+15	2.56E+16	1.96E+16	2.01E+16	2.04E+16	1.95E+16	1.93E+16	1.87E+16	1.82E+16	1.76E+16	1.70E+16	1.63E+16
	Xe-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.34E+15	3.13E+17	6.72E+16	1.26E+15	2.10E+15	6.94E+15	5.31E+15	5.45E+15	5.54E+15	5.28E+15	5.24E+15	5.08E+15	4.94E+15	4.79E+15	4.62E+15	4.43E+15
	I-131	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E+09	5.84E+16	2.29E+16	4.05E+14	2.34E+15	8.86E+15	5.71E+15	2.22E+15	4.83E+14	2.68E+14	4.01E+14	4.11E+14	3.44E+14	2.67E+14	1.93E+14	1.40E+14
	I-132	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E+09	8.59E+16	3.37E+16	5.95E+14	3.44E+15	1.30E+16	8.40E+15	3.26E+15	7.09E+14	3.94E+14	5.89E+14	6.03E+14	5.05E+14	3.92E+14	2.84E+14	2.05E+14
	I-133	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.61E+09	1.21E+17	4.74E+16	8.37E+14	4.84E+15	1.83E+16	1.18E+16	4.59E+15	9.98E+14	5.55E+14	8.29E+14	8.49E+14	7.10E+14	5.52E+14	3.99E+14	2.89E+14
	I-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.31E+09	1.36E+17	5.34E+16	9.42E+14	5.44E+15	2.06E+16	1.33E+16	5.16E+15	1.12E+15	6.24E+14	9.33E+14	9.55E+14	7.99E+14	6.21E+14	4.49E+14	3.25E+14
	I-135	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.35E+09	1.15E+17	4.53E+16	7.99E+14	4.62E+15	1.75E+16	1.13E+16	4.38E+15	9.52E+14	5.29E+14	7.91E+14	8.10E+14	6.78E+14	5.27E+14	3.81E+14	2.76E+14
	Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.17E+07	2.01E+14	2.95E+14	5.36E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Zr-95	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.09E+03	2.08E+14	2.42E+14	3.96E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Mo-99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.43E+09	4.56E+16	1.49E+14	1.90E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ru-103	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.29E+09	3.75E+16	1.23E+14	1.56E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ru-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E+09	1.22E+16	3.99E+13	5.07E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Te-131m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E+09	7.86E+15	4.40E+15	1.11E+14	8.87E+12	4.58E+13	2.83E+13	1.20E+13	5.45E+12	4.85E+12	2.70E+12	1.62E+10	8.10E+09	3.74E+09	1.87E+09	1.25E+09
	Te-132	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E+10	5.90E+16	3.30E+16	8.33E+14	6.67E+13	3.44E+14	2.13E+14	8.99E+13	4.09E+13	3.65E+13	2.03E+13	1.22E+11	6.08E+10	2.81E+10	1.40E+10	9.36E+09
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E+08	8.58E+15	3.67E+15	5.37E+13	6.70E+13	2.44E+14	1.44E+14	6.54E+13	2.92E+13	2.62E+13	3.01E+13	3.00E+13	2.47E+13	2.06E+13	1.66E+13	1.27E+13
	Cs-136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.32E+07	2.52E+15	1.08E+15	1.58E+13	1.97E+13	7.19E+13	4.23E+13	1.92E+13	8.57E+12	7.70E+12	8.84E+12	8.81E+12	7.27E+12	6.05E+12	4.89E+12	3.73E+12
	Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.04E+08	5.53E+15	2.36E+15	3.46E+13	4.31E+13	1.57E+14	9.26E+13	4.21E+13	1.88E+13	1.69E+13	1.94E+13	1.93E+13	1.59E+13	1.33E+13	1.07E+13	8.17E+12
	Ba-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.08E+08	1.29E+16	4.13E+15	5.40E+13	1.92E+10	1.92E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	La-140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E+03	2.23E+14	2.58E+14	4.23E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Ce-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.72E+00	1.44E+15	1.59E+15	1.19E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Pu-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.14E-02	4.44E+12	4.89E+12	3.66E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Pu-241	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E-01	1.50E+14	1.65E+14	1.23E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cm-242	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.02E+01	4.59E+12	5.33E+12	8.73E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Cm-244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E+01	6.67E+11	7.74E+11	1.27E+09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Assumption for diffuse release	Height (m)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Assumption	I aerosol	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 4. Detailed decription of the Ringhals source term. Values in Bq.

3.0 Dispersion Modelling

A key aspect of the NORCON project was the comparison of ouputs of the various countries dispersion modelling systems in terms of geographic dispersal, activity predictions etc. in sofar as these predictions may impact upon decision making later in the process. In the following section the background to this aspect of the project is presented along with more detailed descriptions of how the participants conduct such procedures in their own countries.

3.1 Forecasting and Prognoses

The modelling of atmospheric dispersion is a simulation of the dispersion of air pollutants in the atmosphere. These simulations are conducted on computers and incorporate weather data and source term information as input to the model. Depending on the simulations complexity, the weather data may range from simple observations to global numerical weather prediction data. Simple data may yield a rapid estimate of the local level dispersion over a short time, complex models simulating dispersion over a country or continent over a time period that may extend out to several days. The source term is a parameterised description of the release itself, including information such as the location of the release, the release time and duration, and the amount of material released. The Nordic countries all use atmospheric dispersion modelling for simulation of the atmospheric dispersion of radioactive material from a source. The capabilities are typically available as cooperative efforts between the national meteorological institutes and the relevant radiation protection authorities. Meteorological institutes provide the model and the numerical weather predictions, the radiation protection authorities being the main users and having the expert knowledge to specify the source term and interpret the results.

3.1.1. Source Term

The source term is a description of the amount of radioactive material released from a nuclear accident and contains the starting time of the release and how much activity (in Becquerel) is released of each isotope, per time unit. It may also describe other parameters which are important for simulating the release, such as instance geographical coordinates of the location and the height at which the release occurs. Knowledge of the source term is important from a crisis management perspective because it can help to understand the actual or potential consequences of a release, and use this to plan which actions to take.

The location of the source is information that is usually available either through the operator or from different services such as the IAEA PRIS database or by simply searching for the source on the internet. For moving sources such as nuclear powered submarines and icebreakers, the exact geographic location may be more difficult to determine in the early phase, yet this information is usually available after some time. For surface ships the information will be available from the coastguard.

The starting time of a release will normally be well defined if the release has actually occurred although this does depend on if it is a controlled release or not. If it is a controlled release, the operator will be able to provide this information. If the release is not controlled, as was the case for Fukushima and Chernobyl, the time of the explosion or other destructive initiating event may be employed as the starting point. If a release is foreseen in the future, the release can be modelled by considering several releases over the coming hours and analysing the stability.

The amount of radioactive material released into the environment is without doubt the most difficult parameter to determine but also a very important one because it is required for the assessment of radiological consequences. The theoretical total amount, referred to as the reactor inventory, can be calculated based on the reactor type, fuel type, degree of enrichment and fuel lifecycle. The UNSCEAR report on the Fukushima accident (UNSCEAR, 2013) refers to two different approaches in determining the amount of radioactivity released into the environment. The first method is using advanced reactor simulation codes. Such codes require information regarding the status of the plant and actual or postulated events that have occurred during the progression of the accident. Results from these codes typically exhibit high uncertainty, largely because of lack of exact information about what has happened at plant. This information is even more difficult to get hold of with increasing problems at the site.

The second approach UNSCEAR refers to is to assess the amount released based on actual measurement data. The estimates from an existing dispersion prognosis can then be compared to one or more measurements (i.e. dose rate, air concentration or deposition) at different locations. Estimated and measured values are used as input to simple or complex methods for optimisation of the source term. A simple method is by adjusting the release to fit the measurements. Ultimately this will reduce differences for each location when the prognosis is re-run with a new source term, and assumes that values for non-measured locations are more correct. This method is only applicable if an actual release has occurred and measurement data are available. In addition, simple optimisation methods do not take into account uncertainties in meteorology, dispersion models or measurement data.

To summarise, the source term is, unfortunately, not known with any degree of certainty during a serious accident, and early estimates can vary by orders of magnitudes.

3.1.2 Meteorological Uncertainty

Uncertainty in dispersion modelling arises from uncertainties in the meteorology in addition to those of the source term as mentioned previously. In simple terms, uncertainties in meteorology can affect the direction the plume is assumed to take, the spatial extent of the plume and subsequent contamination, and the consequences derived from the amount of radioactive material in the plume.

The dispersion calculation will normally use data from an advanced Numerical Weather Prediction (NWP) model, the NWP model calculating a matrix of meteorological data for every 1 or 3 hours for the following 2-5 days, the one hour model resolution normally giving a more precise calculation close to the release point where sea- and land breeze is present. The dispersion model will use, amongst other parameters, the wind speed, rain and temperature. The best model employed in Scandinavia provides a horizontal resolution of 3-15 km in up to 50 vertical layers describing the atmosphere up to a height of 40km. If the high-resolution NWP model is initialized with high resolution monitoring data from satellites, meteorological towers etc. a high resolution NWP model will normally produce better quality results in complex terrain and complex land, sea areas. The NWP models are updated every 6 or 12 hours. For every NWP run a new forecast is produced. Using 6 and 12 hours data will normally produce different results.

Up until recently, quantifying uncertainty in meteorological forecasting has not been possible, but recent developments in numerical weather prediction includes methods which make this possible. NKS project MUD (Sørensen et.al. 2013, 2014) has investigated the application of such methods for modelling of a nuclear release. To explain the uncertainty in the meteorological forecast, the ensemble forecasting system with up to 25 slightly different forecasts was tested in the project. Depending on the meteorological situation, the uncertainties can be large, up to a factor of ten for certain meteorological conditions. The project aimed to make this method available for operational use which will include visualisation of the uncertainty. Without a dedicated tool for assessing the uncertainty, meteorological predictions should be used and accepted as they are. But all dispersion products should be controlled by a meteorologist who is capable of comparing the dispersion with the weather condition and prognoses at the site, and determine if the dispersion is plausible or not.

3.1.3 Visual presentation of Dispersion Results

There are several ways to visualise the atmospheric dispersion of a radioactive plume. Graphical presentation may reflect one or more of the quantities that a dispersion prognosis can output, for example spatial extent, time, concentrations and dose. Quantities with a value range can be visually enhanced by displaying this range through colour scales for each grid cell or contour lines for different threshold levels.

Trajectories are the simplest way for visualization of a dispersion prognosis being a line made by releasing one particle and tracking the path it follows when it is transported in the model. It only requires the location and time of release and no release rate information. This makes it suitable for an early estimate of the plume direction and speed but no information is provided as to the spatial extent and the visualization is not amenable for illustrating a prolonged release where wind conditions change at the release point.

An example of trajectories made with the ARGOS Decision Support System (Hoe et.al. 1999) is displayed in Figure 2. Each line represents different release heights above ground level, and the circles indicate the progress with time. Visualising the dispersion of a plume as opposed to a trajectory provides a picture of the spatial extent and radiological consequences if a plausible source term is applied. It can display several different quantites. Direct output from the model may include air concentration (in Bq/m^3), time integrated air concentration $Bq{*}s/m^3$, ground deposition (Bq/m^2) and time of arrival. From this other quantities can be derived, i.e. effective dose, dose rate or operational intervention levels. What type of model used also affects the output. Most common are puff models for short and medium range models (<500 - 1000 km) and particle model for medium and long range (up to global). Figure 3 shows direct output from two models of both types. Particle models tend to be patchier at the edge of the plume.

Figure 2. *An example of trajectories made using the ARGOS DSS. Each trajectory represents a specific release height.*

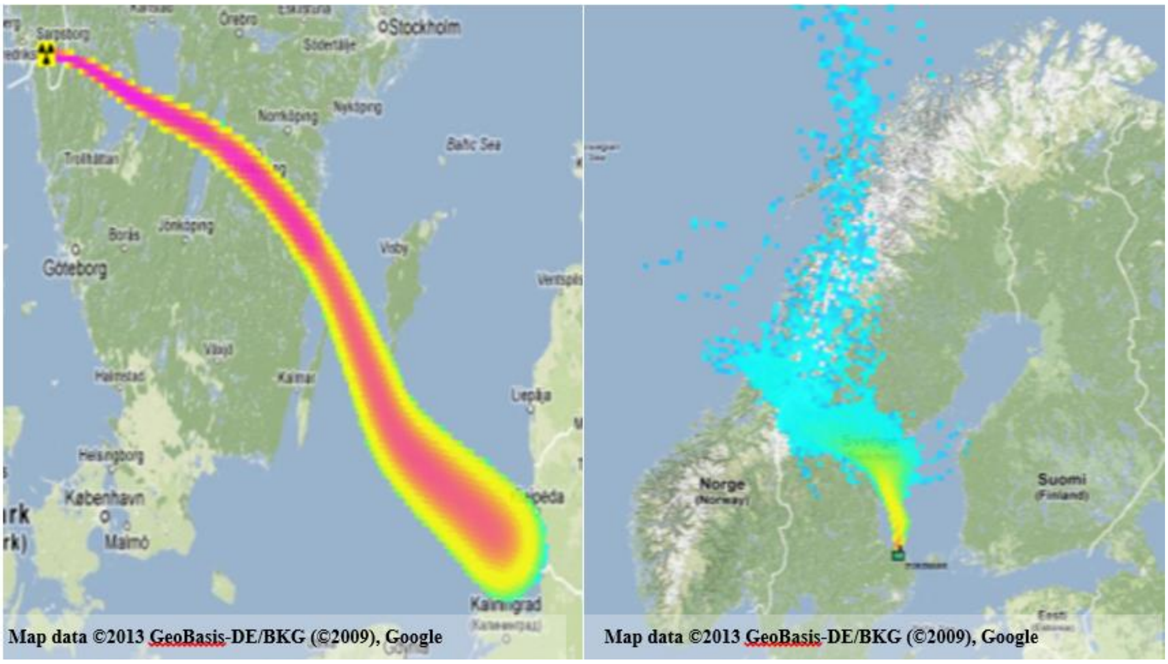

Figure 3. *Output from two different types of dispersion models. Left is Norwegian long range model SNAP (particle model). Right is Danish medium range model RIMPUFF (puff model). Both shows output as time integrated air concentration with unit Bq*h/m^3.*

A third type of dispersion model result is the time of arrival plot, an example of which is shown in Figure 4. It is in essence the same as the integrated air concentration plots, but with contour lines that displays where the plume is after *n* hours relative to the release time. It can be considered a hybrid between a plume and a trajectory since it does not require a source term to make, but still shows the spatial extent. If all information about time is left out, only the extent of the plume will show.

Figure 4. *Time of arrival plot.*

3.2 Individual Countries

As part of NORCON each participant/country was required to conduct a series of dispersion prognoses. The following section outlines the resources brought to bear by each country within NORCON with examples of outputs for demonstrative purposes.

Country 1: Norway

NRPA employs the ARGOS decision support system which is integrated with the long range dispersion model SNAP (Bartnicki et al., 2013) developed and hosted by the Norwegian Meteorological Institute. SNAP is a Lagrangian particle model, and it runs operationally on the latest weather forecast up to 66 hours. The ARGOS version of SNAP was improved as part of the NORCON project, in order to handle more nuclides and more time steps compared to the old version thereby facilitating the more complex source terms employed within NORCON. To further facilitate NORCON, the model was moved to a new and faster server.

Some modifications were made to the Brokdorf source term. SNAP cannot handle time intervals that are shorter than 60 minutes and less time steps than the numbers used in the original source term. To overcome this, some of the shorter time steps where merged with the previous or next step. The effect of this is was that some steps had lower release rates (Bq/s) for that period, but the total amount released remained constant. A selection of results, in the form of visual representations, from the Norwegian dispersion modelling for the chosen source terms are provided below as examples of outputs.

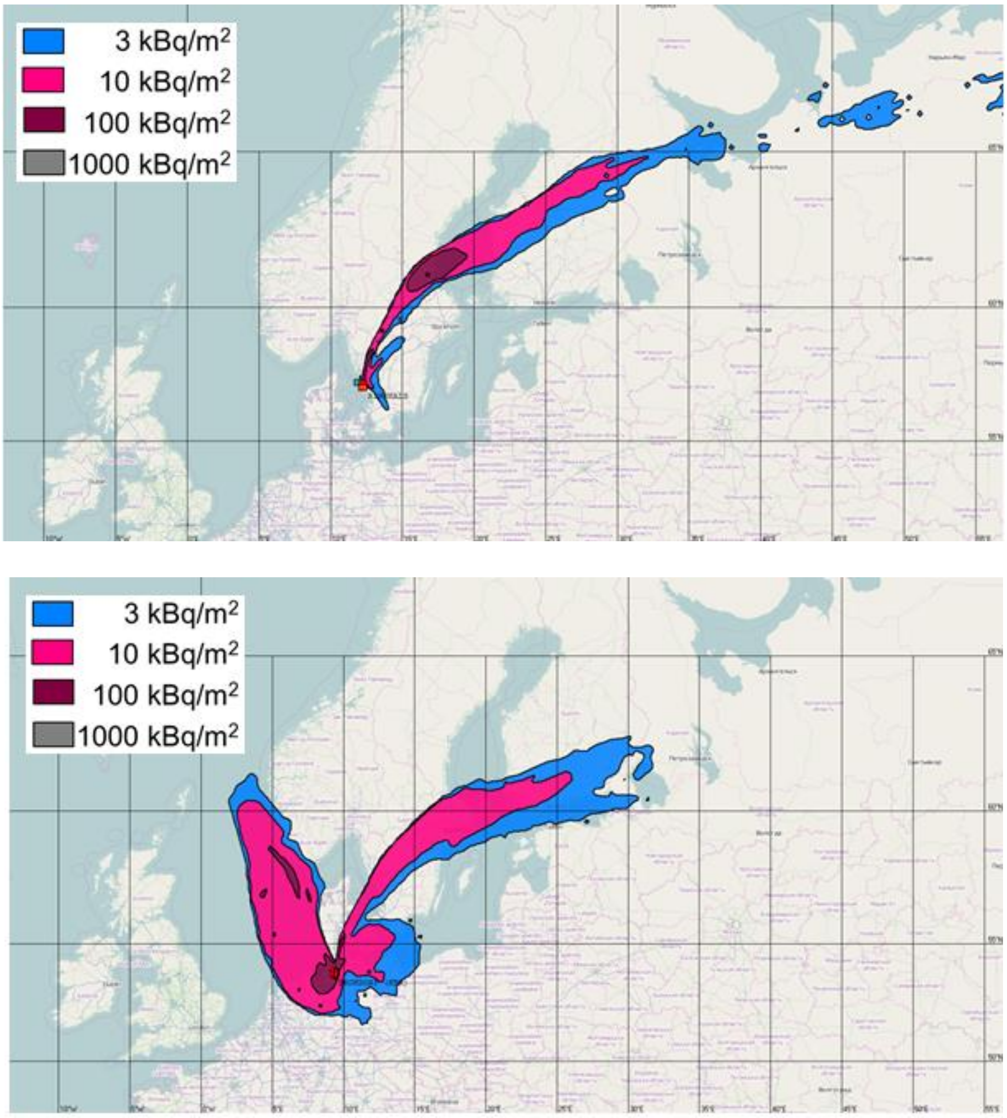

Figure 5. *Depiction of the deposition of ^{137}Cs from the Ringhals source term (top) and Brokdorf source term (bottom) based upon the common release conditions.*

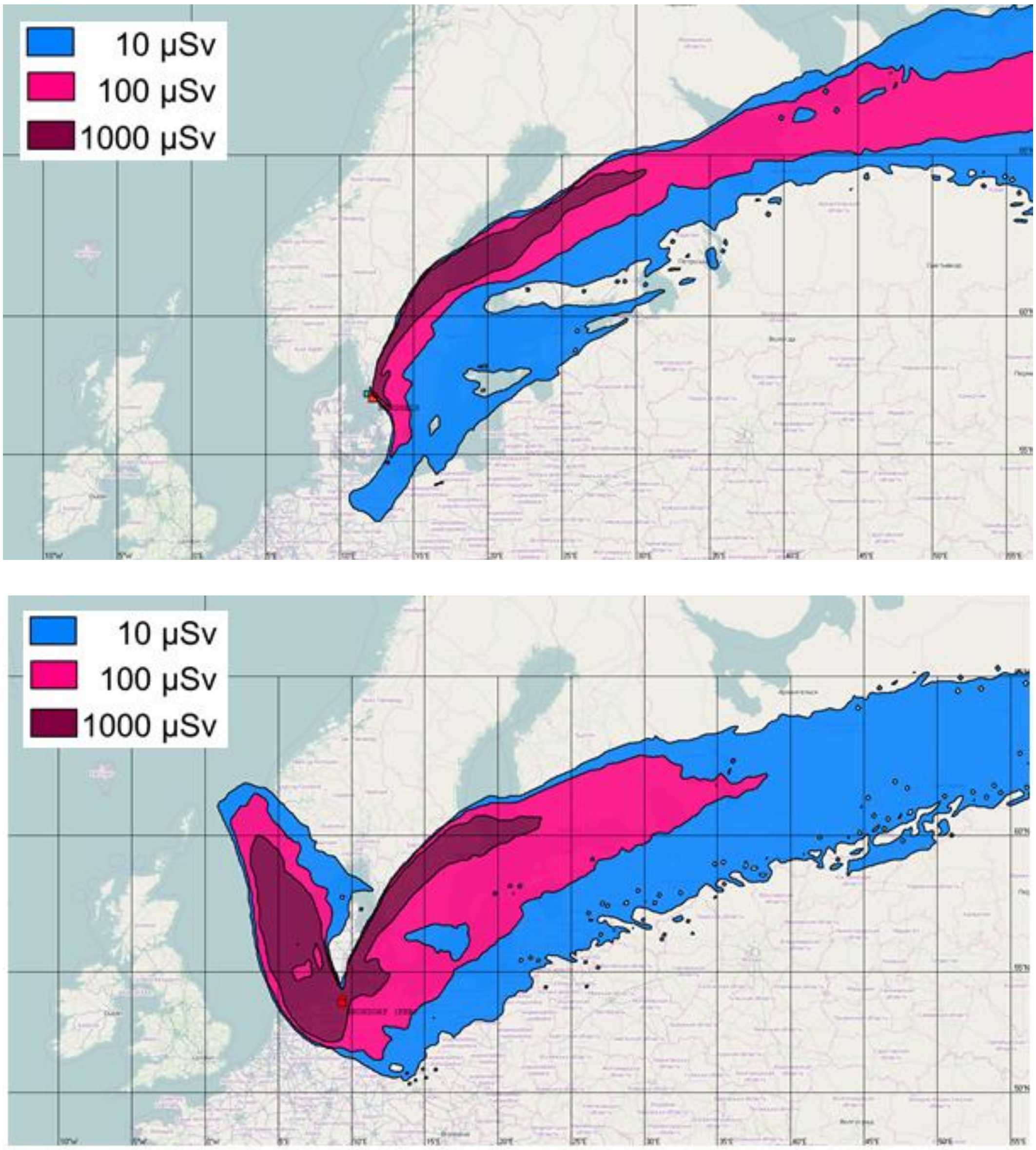

Figure 6. *Depiction of the total effective dose outdoors one year after release for the Ringhals source term (top) based upon the common release conditions and similarily fro the Brokdorf source term (bottom).*

Country 2: Denmark

The ARGOS system in DEMA has access to 3 different dispersion models: URD, RIMPUFF and DERMA. The URD is an urban dispersion model and is not relevant for the NORCON project. RIMPUFF (RIso MsoscalePUFFmodel) is a dispersion model used for atmospheric dispersion from 1-500 km and in not to complex conditions at larger distances. In the NORCON project RIMPUFF is used with NWP (Numerical Weather Prediction) data from DMIs (Danish Meteorological Institute) HIRLAM-model and, for some scenarios, also RADAR precipitation data.

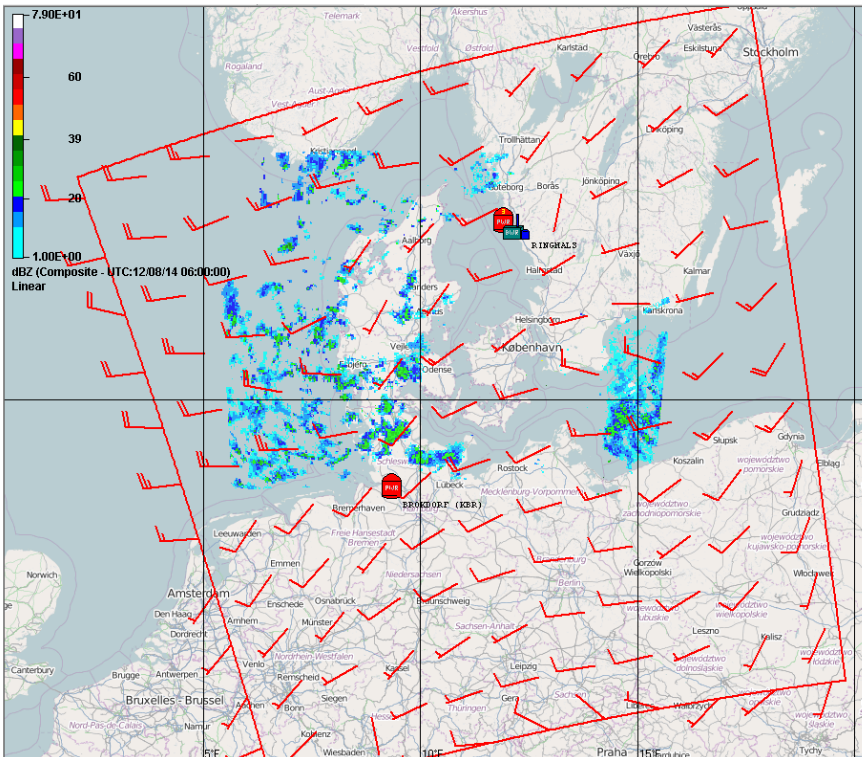

Figure 7. *HIRLAM SKA area used by ARGOS/RIMPUFF in Denmark, wind vectors and RADAR data from the 7th November 2014 is shown inside the area.*

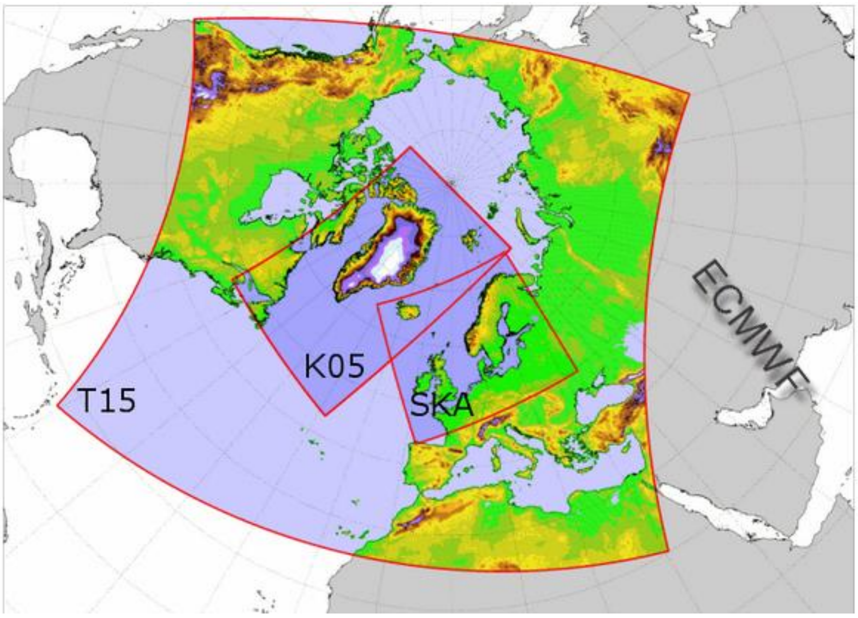

Figure 8. *NWP model used by DEMA: SKA 3km horizontal resolution, 65 horizontal layers and 60h prognoses length – T15 16km horizontal resolution, 40 horizontal layers and 60h prognoses length – K05 5 km horizontal resolution 40 horizontal layers and 48h prognoses length – ECMWF extract from global model with 5 days prognoses length and approximately 50km resolution. All models are updated every 6 h.*

The horizontal resolution of the HIRLAM-model used in NORCON is 3 km with 33 layers covering the atmospheres up to nearly 2800m. The normal model forecast length is 54 h, resulting in minimum 48h forecast of wind and precipitation – the model is updated every 6h. The RIMPUFF model can calculate nuclide specific air concentrations, deposition (wet and dry), doses and dose rates from ground and plume (3D calculation), decay and build up from decay product is included. Based on results from RIMPUFF ARGOS can then add additional dose values and combinations of these. ARGOS can also calculated doses from ingestion with the AgriCP-model.

The DERMA model is a long-range dispersion model developed and operated by DMI (Danish Meteorological Institute). ARGOS can use the model with user interaction at DMI. The model can be used from 50 km up to global scale. DERMA will run on all NWP area when initiated from ARGOS. The DERMA model can calculate air nuclide specific concentrations and deposition (wet and dry) and the model includes radioactive decay but not daughter build-up. The source is released from a column ranging from from the ground up-to the top of the mixing-layer. All dose values are calculated by ARGOS – the plume dose with a semi-infinite model. Doses and some depositions values calculated with RIMPUFF and DERMA will be different due to different plume dose calculations models and the lack of build up in DERMA. The DERMA model will normally disperse more due to the release from a column with a variable height. The selected source term for the NORCON project are complex long lasting releases 50.07 h and 65.95 h. The duration of the NORCON source term made it impossible to finish the calculations with the prognoses length of the NWP models except for the DERMA model using the ECMWF forecast models.

To compare results from the DSS models 2 different methods were available.

- Forecast comparison:

The calculation runs as long as there are NWP data and stops.

- Analyzed comparison

The calculation starts when the dispersions has stopped, in the DEMA setup, forecast data is replaced by analyze data (the first 6 h of the prognoses) when they are available. The analyzed data will be very close to the actual observed weather. For RIMPUFF it is possible to use RADAR precipitation data to give a more correct wet deposition. The NORCON project, after the first phase, has identified complications running with realistic source terms in the early phase of an accident, and the need for improved guides for the operations of DSS.

The calculations with realistic (long duration, many nuclides) took too long time (hours) for the first consequence estimation, and some of the dispersion models underestimated the doses – running with a limit set of nuclides and simpler model setup can give first use guess of the consequences. The limited forecast length of the high-resolution NWP prognoses length, will underestimate the effect of the potential accident- in DEMA the coarse NWP model can compensate for this. The participating model-chains produced comparable and useful results, for the Nordic Countries.

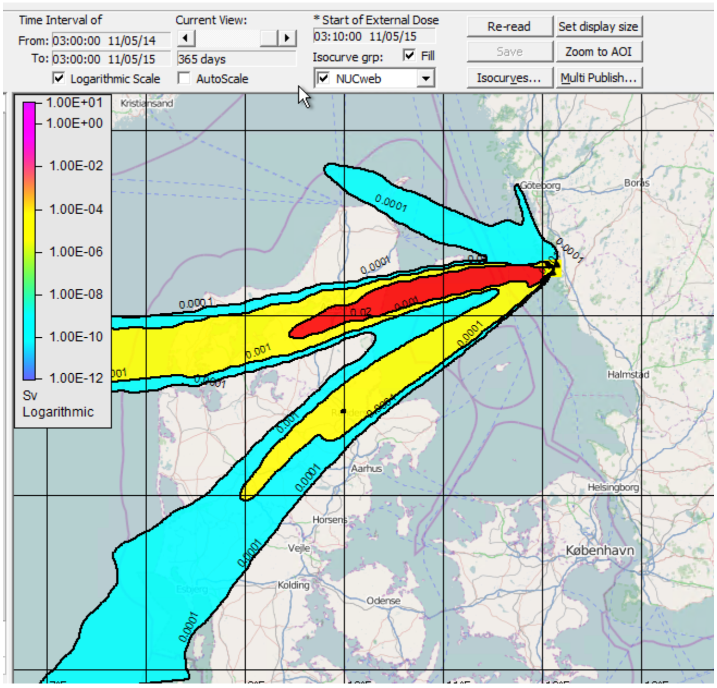

Figure 9. *Example of RIMPUFF used on the Ringhals source term case affecting Denmark 5 November 2014 – total dose over first year.*

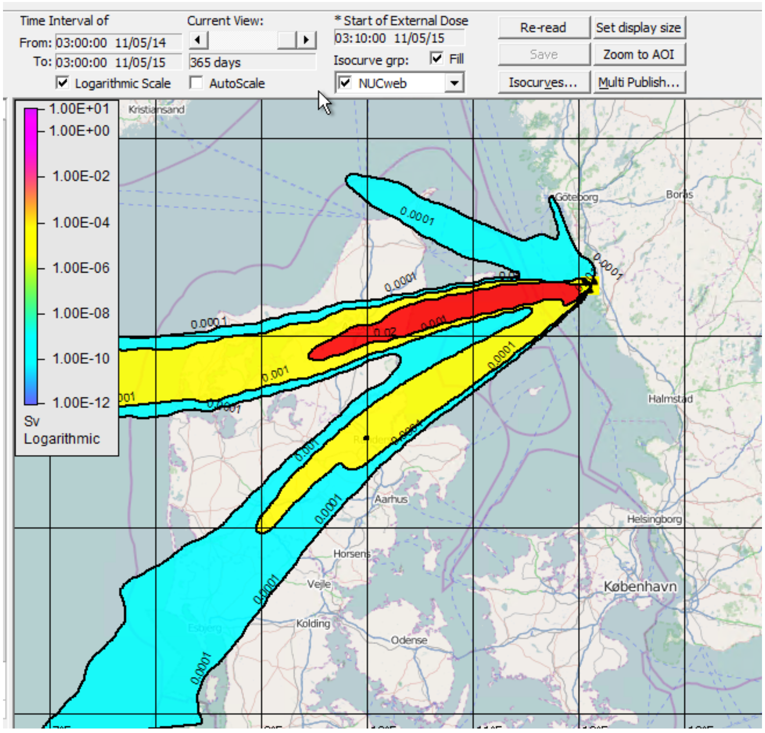

Figure 10. *Example of RIMPUFF used on the Ringhals source term case affecting Denmark 5 November 2014 – total dose over first year.*

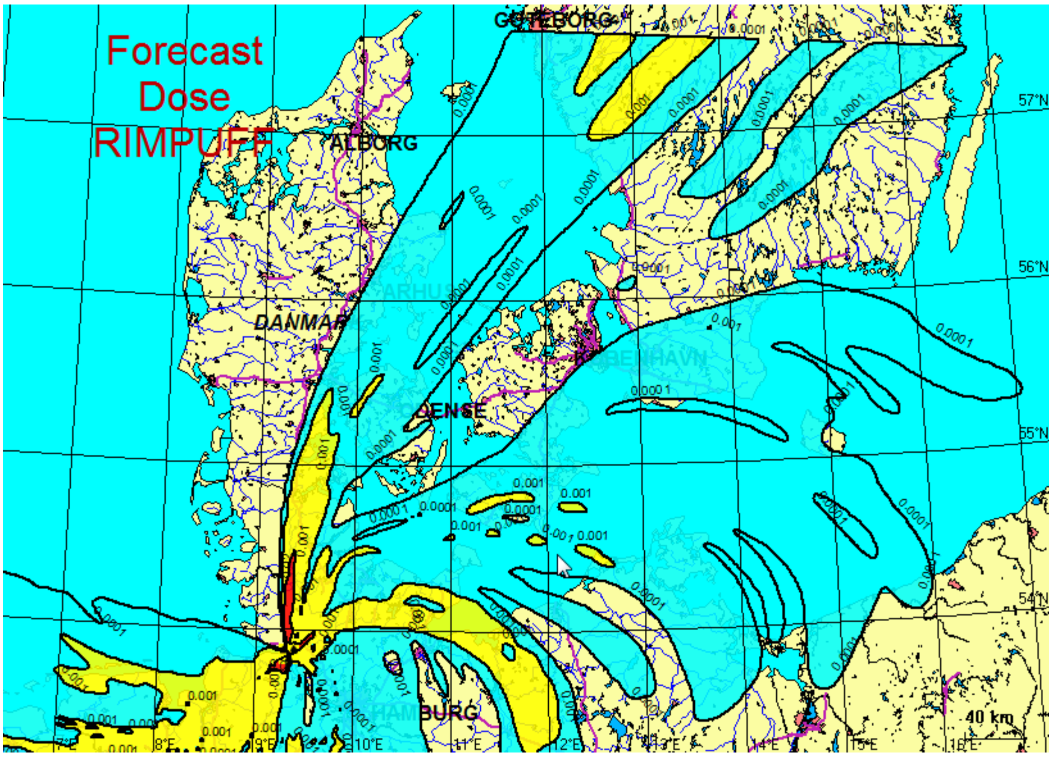

Figure 11. *Example of RIMPUFF for the Brokdorf Case- 30 October 2014 14:00 UTC Forecast 30 day total dose.*

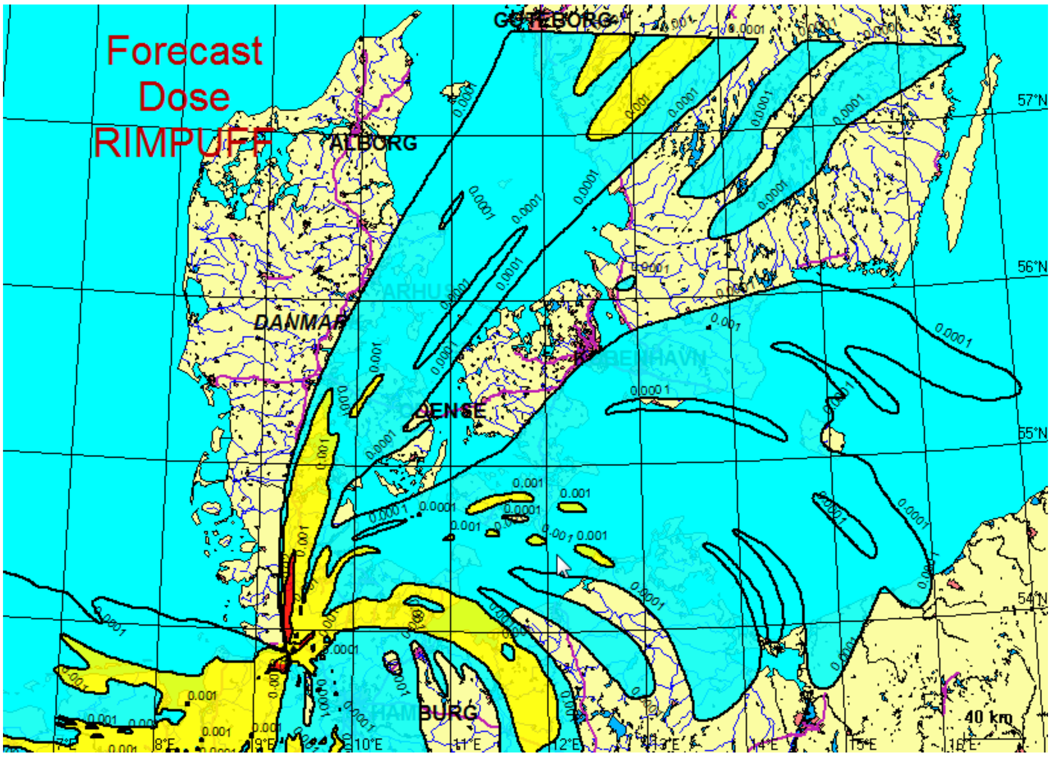

Figure 12. *Example of RIMPUFF for the Brokdorf Case- 30 October 2014 14:00 UTC Forecast 30 day total dose.*

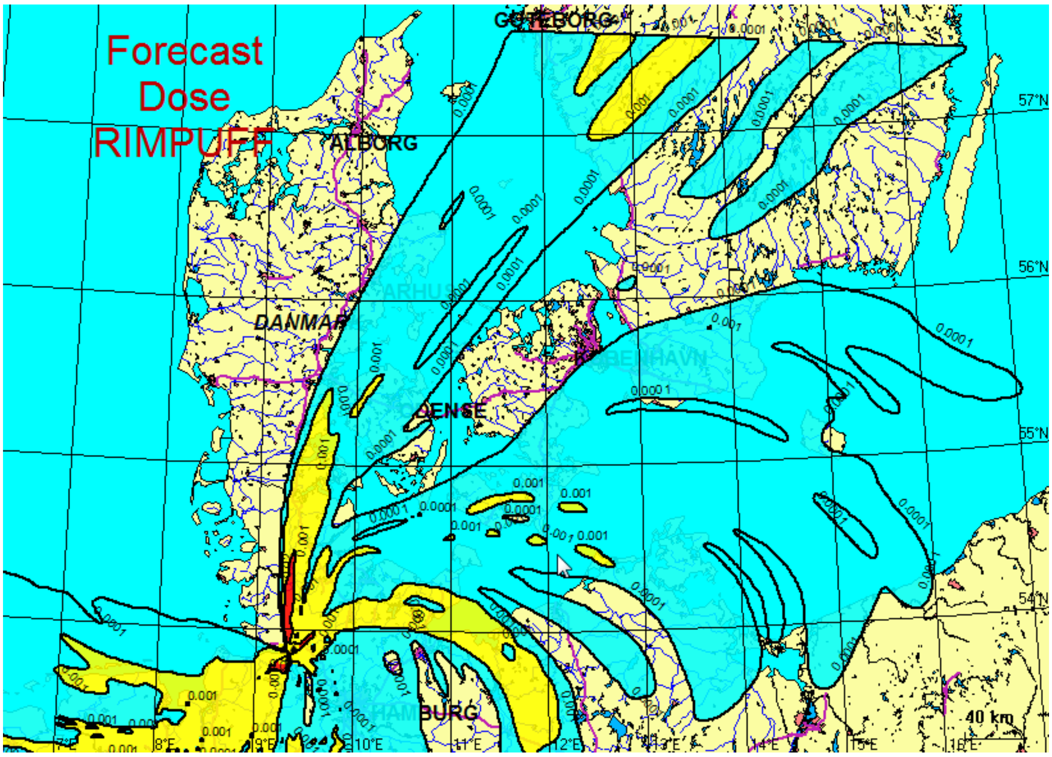

Figure 13. *Example of RIMPUFF for the Brokdorf Case- 30 October 2014 14:00 UTC Forecast 30 day total dose.*

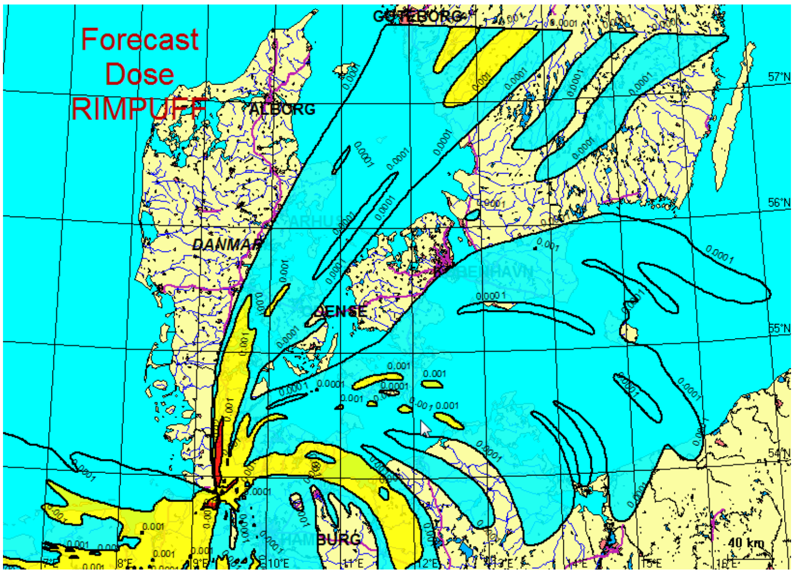

Figure 14. *Example of RIMPUFF for the Brokdorf Case- 30 October 2014 14:00 UTC Forecast 30 day total dose.*

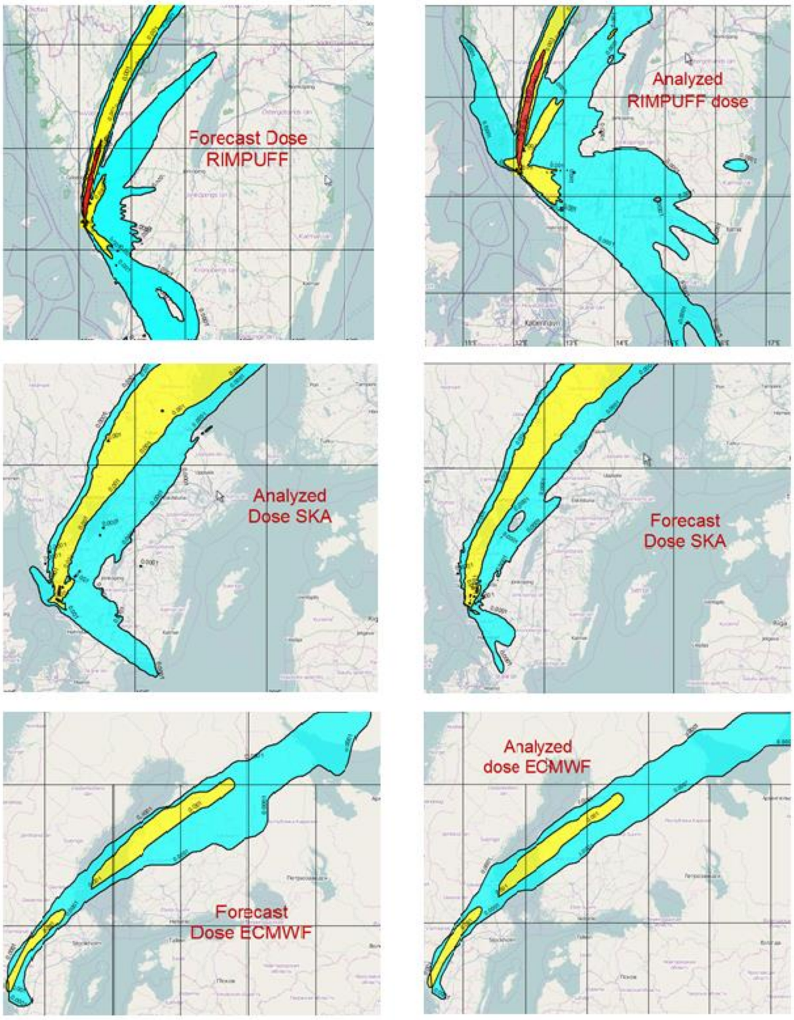

Figure 15. *Examples of putput data for the Ringhals source term - 30 October 2014 14:00 UTC.*

Country 3: Iceland

Within the NORCON project, the Icelandic Meteotological Office (IMO) started to use numerical tools for simulating the dispersal of radionuclides in the atmosphere originating from nuclear power plants located in Europe. The main aim was to produce a tool that could be used, in case of necessity, for estimating the potential impact of a nuclear cloud to Iceland. IMO is able to run two codes that are suitable for modelling the dispersal in atmosphere of radionuclides: NAME (Numerical Atmospheric-dispersion Modelling Environment) (Jones A. R. et al. 2007) and CALPUFF (EarthTech, 2002). Both codes are installed at IMO and can be run on demand for nuclear accident purposes. In standard use, they run by using meteorological data provided by ECMWF with a spatial resolution of 0.125 degrees and a temporal resolution of one hour. IMO runs NAME under a research license agreement and public use of NAME results are agreed with the UK Metoffice. CALPUFF is an open-source code. Several improvements could be done in using these codes for simulating impact on Iceland due to radionuclides releases from abroad countries. In particular, different kind of quantities in outputs could be provided, e.g. deposition and doses. For the NORCON common run during October 2014, IMO used NAME for producing preliminary results of radionuclide cloud movements and its deposition on the ground for the chosen source terms. NAME is a Lagrangian model designed to predict the atmospheric transport and deposition to the ground surface of airborne substances, and treats both gaseous and particulate materials. NAME is used for a wide range of activities that include emergency-response modelling, routine forecasting applications, scientific research and policy support work.

NAME was originally developed as a nuclear accident model in response to the Chernobyl nuclear disaster in 1986, and it continues to have an important operational role within UK and international frameworks for responding to radiological incidents (e.g. RIMNET, RSMC, CTBTO). Over the years, the radiological capabilities of NAME have been further enhanced, including the relatively recent additions of decay-chain modelling and cloud gamma dose calculations. However NAME has also evolved in a much broader sense as a general-purpose atmospheric dispersion model with developments such as an atmospheric chemistry scheme.

An overview of model details is provided in Table 5.

Physical processes described by the model	
Advection and diffusion	Three-dimensional random-walk techniques of varying levels of sophistication. Diffusive scheme (computationally efficient) and Langevin-type scheme. Puff approach for short range applications
Turbulence schemes	Turbulence and meander scales treated independently within the boundary layer. Constant-magnitude free tropospheric turbulence applied above the boundary layer
Dry deposition	General surface resistance/deposition velocity based scheme. Land-surface dependent dry deposition scheme for certain gas species
Wet deposition	Rain out (in-cloud removal) and wash out (below-cloud removal by rain impaction)
Particle sedimentation	Based on Stokes flow with Cunningham correction applied for small particle sizes
Plume rise	Represents buoyancy and momentum driven releases. Based on conservation equations of mass, momentum and heat (development on Briggs formulae)
Radiological decay	Simple half-life decay of one radionuclide, decay chains, cloud gamma dose assessments
Physical decay	Decay of biological agents and vector-borne species
Chemistry	Comprehensive sulphur/nitrogen/hydrocarbon chemistry scheme
Source terms	
Source geometry	Point, line, area and volume
Source shape	Cuboid, Ellipsoid or Cylindroid with Gaussian or Uniform distribution cross-section
Composite sources	Most source configurations can be represented as composites of above source types
Species characteristics	Multi-species per particle with different physical and chemical characteristics
Output quantities	
Model outputs	Two-dimensional fields, location-specific time series, particle trajectory information
Output quantities	Standard dispersion quantities: air concentration, deposition, cloud gamma dose Meteorological and flow variables Chemistry: gridded fields Other quantities: particle numbers, travel times, plume depth, etc.
Statistical processing	Time averaging/integrating; ensemble averaging; percentiles and probabilities
Data formats	Plain text ASCII file format with user-configured flexible layout Offline conversion to GRIB and NetCDF
Graphical products	Offline IDL and Python (IRIS) utilities to create ps, png, gif images Offline GIS products (ArcView)

Table 5. *Overview of the NAME model*.

NAME was run simulating a release of ^{137}Cs radionuclides from the two nuclear power plants as selected in NORCON: Ringhals (Sweden) and Brokdorf (Germany). The release started hypothetically on 17 October 2014 and lasted 48 hours. Cs-137 was released with an intensity of 2.0E+08 Bq/hr from Ringhals and 8.0E+15 Bq/hr from Brokdorf. The dispersal was simulated and the maps shown here are indicative of the type of results generated (see Figure 16). For Brokdorf, the results are summarized in Figure 17.

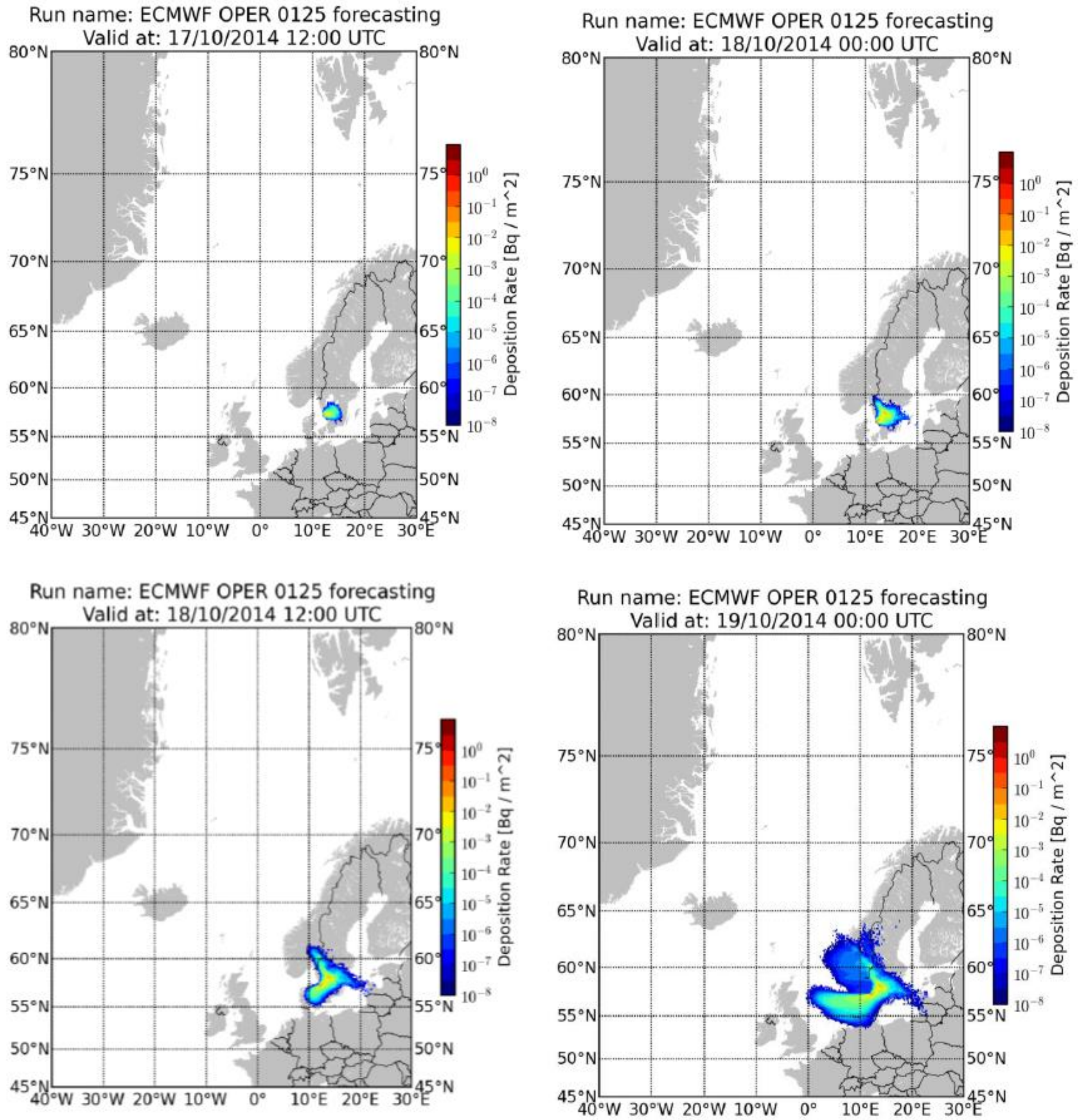

Figure 16. *Deposition on the ground of ^{137}Cs for 12 hour increments as simulated for the Ringhals source term.*

The computation was perfomed on a spatial grid of 560x280 cells with a step of 0.125 degree. Each run, per species per source, took about 55 minutes for executing both the dispersal modelling and the post-processing. The results were made available on a public page, where Geislavarnir Ríkisins could visualize the single frames and the animation, that is brunnur.vedur.is/aska/vi/na_runs. This page should be considered temporary as of time of writing and it will be improved over the courseof NORCON.

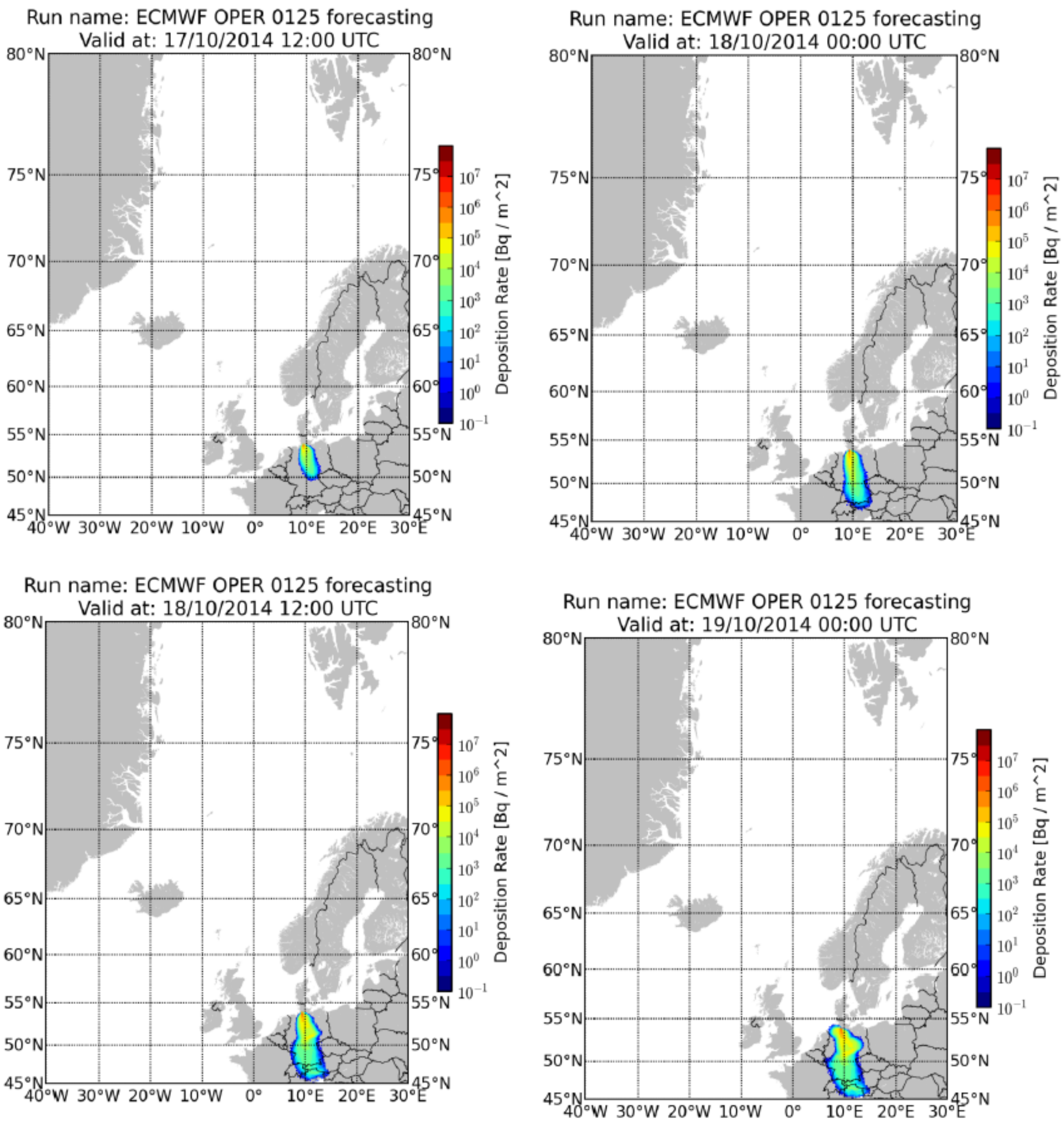

Figure 17. Deposition on the ground of ^{137}Cs for 12 hour increments as simulated for the Brokdorf source term.

Country 4: Sweden

JRODOS is a java based software which has been developed from the older version of RODOS (Real-time On-line Decision Support) under the 6th Framework EC RTD EURANOS. Many European emergency preparedness organisations (e.g. BsF (Germany) and ENSI (Switzerland)) use JRODOS to evaluate the immediate consequences of an unplanned radioactive release. Depending on the outcome, decisions on appropriate countermeasures in an emergency situation can be made. Among the models included in the JRODOS platform are RIMPUFF, ATSTEP, LASAT and MATCH for atmospheric dispersion calculations, ERMIN for simulating countermeasures in inhabited areas and FDMT for terrestrial food chain calculations. Additional models, including aquatic dispersion (HDM), countermeasures in agricultural areas (AgriCP) and forest food chain calculations (FDMF) are also incorporated in the software. Many of the models are similar in the decision support system ARGOS.

The most recent version of RIMPUFF, within the JRODOS system, can be used for distances as far as 800 km from the release point. The accuracy for a single calculation at larger distances (more than about 100 km from the release point) may not be as good as the accuracy obtained using MATCH. However, since many runs are made with different weather parameters, the average result using RIMPUFF is not expected to deviate substantially from the average results that would be obtained using MATCH. (see for example DETECT – "Design of optimised systems for monitoring of radiation and radioactivity in case of a nuclear or radiological emergency in Europe" (Contract No. 232662 under the European Commission's 7th framework program) WP1).

In the latest version of the software there is the possibility to do batch runs with prognostic weather data, i.e. to run for example 365 different times of the release (one release per day during one year). The time during the day (HH:MM) for when the release occurred is chosen randomly by JRODOS. The selected results are written into text-files (data per timestep and gridpoint) to enable statistical analysis in a post-processing stage. The default parameters in JRODOS are for central European conditions and many of the parameters that are used in the terrestrial food-chain model (FDMT, based on the ECOSYS model) are region-dependent. The database for region specific data has recently been updated by Vattenfall to represent more realistic input data to for Sweden and to some extent, the neighboring Nordic countries. Focus has been on the three key elements (Cs, I and Sr) and distinction is now made for different soil types in Sweden. The country has been divided into four different radioecological regions and the Nordic countries Denmark, Norway and Finland have been allocated a region related to a Swedish region. The parameterisation is mainly based on the information given in the report from Danish DTU Nutech (former Risö) (Andersson, 2013a) and its addendum (Andersson, 2013b). The landuse and soil type is updated with Swedish data. Vattenfall within the NKS NORCON project used JRODOS for the dose assessment.

SSM employed ARGOS throughout the NORCON project, example results being depicted in Figures 18 and 19.

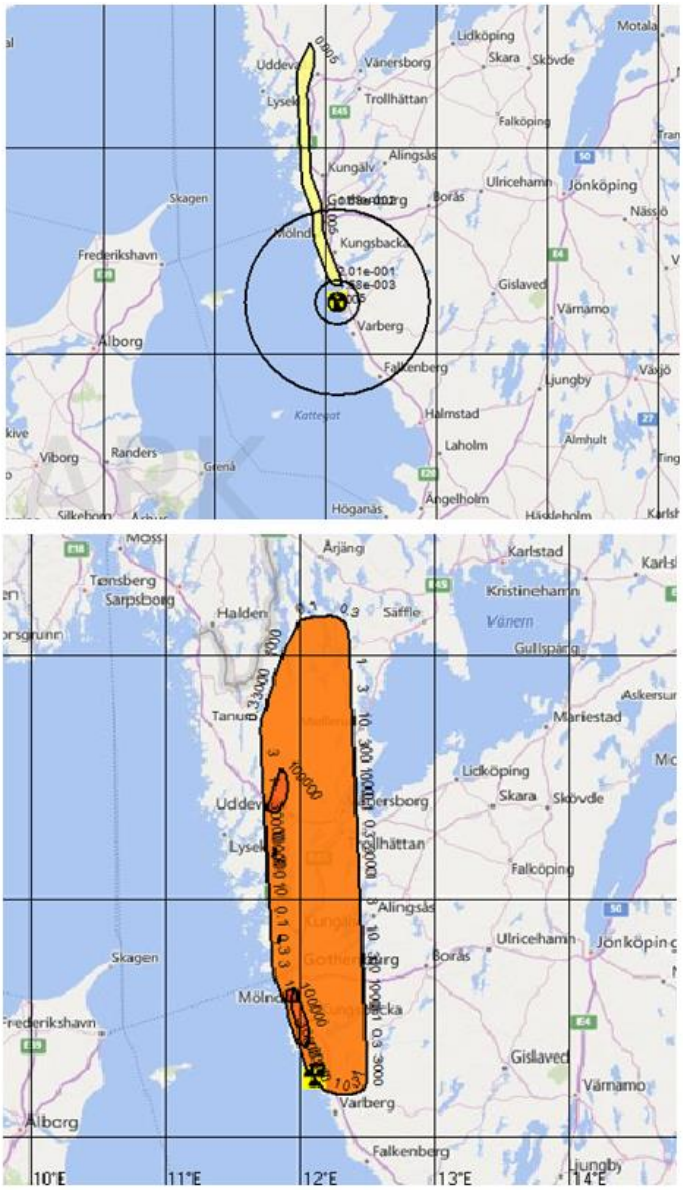

Figure 18. *Total effective dose (7-days) and deposited ^{137}Cs for the Ringhals source term.*

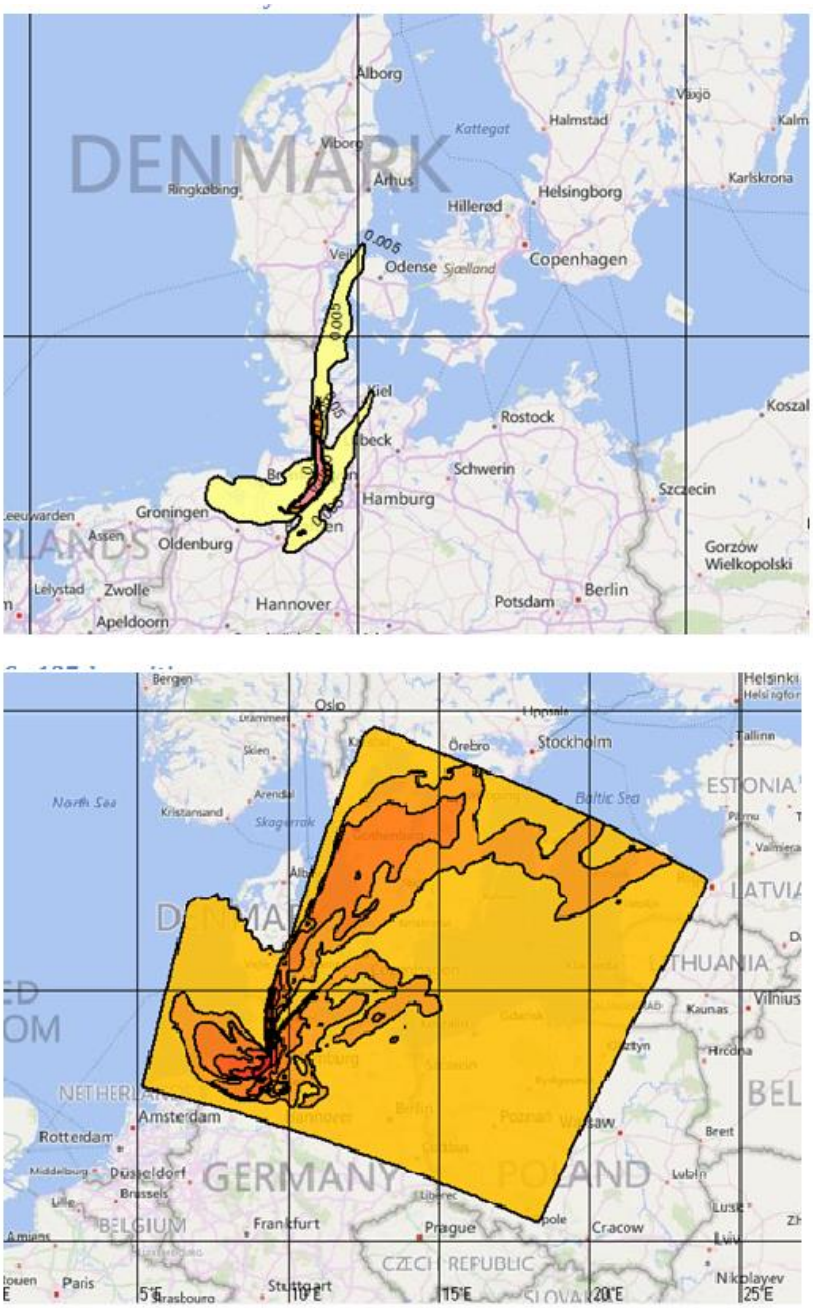

Figure 19. *Total effective dose (7-days) and deposited ^{137}Cs for the Brokdorf source term.*

4.0 Foodchains and Transfer

4.1 Scenario Development

For the purpose of comparing how different participants estimate the transfer of deposited radionuclides through foodchains – assuming the participants conduct such activities as part of their emergency response activities and do not rely solely on empirical data for decision making – a basic set of parameters were laid out governing how the participants would conduct their assessment. After some discussion within the consortium it was agreed that each participant should pick two locations in their countries within the data generated by the 17th of October 2014 prognoses. These locations were be picked within the contours corresponding to 100000 Bq m^2 and 1000000 Bq m^2 based on their dispersion models. The locations were to be based on ^{137}Cs data and the values of the other isotopes would then be determined for the locations. "Consequences" would then be determined at each of these locations to simulate two seasons as represented hypothetically by the dates 1 March and 17 October. The first period for which consequences would be calculated was 7 days after the end of the release. The second period would be 3 months, the third period 1 year after and the fourth period was two years. The following was to be calculated by whatever means each country would normally use for each of the isotopes assuming, again, that such estimates would be derived by the participating country.

- Soil values in Bq/kg over the top 10 cm.
- Grass Bq/kg
- Cow – meat and milk, Bq/kg and Bq/l
- Blueberry Bq/kg
- Mushroom Bq/kg
- Leafy Vegetables Bq/kg
- Root vegetable Bq/kg

The methodologies employed by the countries participating are described in the following sections.

4.2 Methodology – Norway

The first two periods (up to 3 months) defined in the scenarios used for assessing the estimation of transfer could be modelled using a variant of the FASTer model (see Brown et al., 2003; UNSCEAR (2014), a brief description of which is given in the text below. The 3rd and 4th period (1 year and 2 years) could be modelled using the generic equilibrium transfer factors presented in IAEA (2009) and IAEA (2010) for agricultural produce and IAEA (2014) for food products from semi-natural ecosystems. The modelling methodology used many of the same approaches applied in the ECOSYS-87 model (Muller, H.; Pröhl, G., 1993) but differed, importantly, with regards to the way in which transfer from grass to animal products was simulated. Furthermore, the approach adopted to simulate interception by vegetation was simplified to reflect the highly generic nature of the scenario provided (i.e. no information provided on antecedent conditions including rainfall). These points will be elaborated upon in more detail below.

In view of the available data, it was most appropriate to split the modeling into transfer to vegetation (grass, blueberry, leafy vegetables and root vegetables) and animals (cows). Transfer to mushrooms required the application of a simpler (equilibrium-based) approach using aggregated transfer factors. Employing a variant of the methodology provided in UNSCEAR (2014), the activity concentration in vegetation/crops could be derived from the total deposition using an expression accounting for interception by foliage, direct deposition onto soil, weathering losses of radionuclides from vegetation and uptake from soil to plant.

In the case of an acute deposition the radionuclide content on vegetation at time 't', accumulated via direct deposition from the air, can be calculated (as outlined in Brown et al., 2003) as:

$$C^{air}_{flora,r} = \frac{f_{flora} \cdot D_{tot,r}}{b_{flora}} \cdot [e^{(-(\lambda_{flw,r}+\lambda_r)\cdot t)}] \qquad [1]$$

where

$C_{flora,r}$ is the radionuclide activity concentration in flora from air deposition (Bq kg^{-1} f.w.)

f_{flora} is the interception fraction for a given flora (dimensionless)

$D_{tot,r}$ is the total deposition of radionuclide 'r' (Bq m^{-2})

$\lambda_{flw,r}$ is the weathering constant for a given flora for radionuclide r(d-1)

λ_r is the decay constant for radionuclide r (d^{-1})

b is standing biomass of the flora(kg m^{-2})

t is time (d)

For the same acute deposition, at time ‘t’, there is also a component of contamination that arises from soil to plant transfer. In this case an assumption is made that for this fraction of the contamination in the plant attributable to root uptake, equilibrium exists between the activity concentration in the plant and the soil.

$$C^{soil}_{flora,r} = \left[\frac{D_{tot,r} \cdot \left[(1 - f_{flora}) + f_{flora} \cdot (1 - e^{-\lambda_{flw,r} t}) \right] \cdot e^{-\lambda_r t}}{\rho_{soil} \cdot d_{soil}} \right] . CR_{flora,r} \qquad [2]$$

where

ρ_{soil} is the dry soil density (kg m^{-3} d.m.)

d_{soil} is the depth of soil within which radionuclide r has become mixed (m)

$CR_{flora,r}$ is the soil to plant concentration ratio for radionuclide r (dimensionless)

All other parameters are as described above in equation [1]. Application of this model also allowed for time varying deposition rates to be considered. For this more complex situation, the problem could be solved numerically. Because the scenario being modelled started from 2 points in time, both the interception fraction ‘f’ and the biomass of the vegetation ‘b’ needed to be changed accordingly to account for this. For the start of the growing season, both biomass and interception fraction will be relatively low whereas at the end of the growing season both biomass and interception fraction will be relatively high.

Data compilations for agricultural systems in relation to the parameter ‘f’ (IAEA, 2010), indicate that the interception fraction depends on whether dry or wet deposition is occurring, the stage of development of the plant and plant type in question, the capacity of the canopy to retain water, elemental properties of the radionuclide, and other factors such as amount and intensity of rainfall in the case of wet deposition and particle sizes of the deposited material. Many of these processes are included in the ECOSYS-87 model and in later versions of the model adapted for other conditions (Nielsen & Andersson, 2010). The approach taken here was, therefore, arguably simplistic but in view of the numerous uncertainties involved (reflecting a lack of scenario information on rainfall etc.) should at least provide an indication of contamination levels in food-chains following deposition of contamination and at least constitutes an attempt to model the dynamics of interception and loss from vegetation in contrast to approaches considering soil to plant transfer only. The interception fractions used in the model for the various vegetation (and radionuclide) categories are summarized below (Table 7).

The interception fraction, f, for Cs and grass varies from 0.84 (dry deposition) to 0.027 (wet deposition heavy rain) (IAEA, 2010). A default at the end of the growing season (October) of 0.43 was selected for this analysis simply based on the value falling midpoint between the maximum and minimum values reported above. Owing to the lack of specific information on shrubs (berry plants), the same default value as grass have been used. As noted by Tømmervik et al. (2009), the shrub layer for a location in Finnmark had a biomass of a similar order of magnitude to the field layer in mid growing season. Although leaf area and surface roughness etc. might be expected to be different between grasses and shrubs the similarity purely in terms of above ground mass available to intercept contaminants render the assumption of similar mass interception fractions a reasonable one. The differences in interception between different elements reflect their different valencies. Plant surfaces are negatively charged and thus may be considered as analogous to a cation exchanger (IAEA, 2009). Therefore, the initial retention of anions such as iodide is less than for polyvalent cations, which seem to be very effectively retained on plant surface. For analyses of data for Chernobyl deposition in Germany, the mass interception factors increase in the order ^{106}Ru, ^{131}I, ^{137}Cs, ^{140}Ba, with these radionuclides having been deposited during the same rainfall event (IAEA, 2009). The highest values were observed for ^{140}Ba, which behaves similarly to strontium. Barium is a bivalent cation, and seems to be more strongly retained on the negatively charged plant surface than the monovalent caesium cation. In addition to the interception fraction, biomass, which clearly relates to the stage of development of the plant, also requires further consideration as an important model parameter.

Tømmervik et al. (2009) report a biomass of 4.13 tonnes/hectare for a ‘Field layer’ (forbs and grasses) in Northern Finland. This understory biomass would appear to be fairly typical for many other categories of shrub and bottom (moss and lichen) layers in mountain birch forests and mountain heaths in this region:.Tømmervik et al. (2009) report 1.5 to 5.35 tonnes/hectare for such categories from northern Fenno-scandinavia, including Finnmark). Although these data are for northern Norway, the indicative biomass of 0.4 kg/m^2 provides a reasonable value for Blueberry-Shrub for application in our model. Furthermore, Schino et al. (2003) studied grasslands in mountainous areas of central Italy, the work provides an indication of variations in grass biomass that can arise from seasonality and the presence of different species. The recorded range of grass biomass in this aforementioned study was approximately 60 to almost 700 g m^{-2} providing a useful context for our selection of an appropriate biomass value for Grass and for shrubs.

Growth dilution may play an important role in determining vegetation activity concentrations as the considered period of deposition, in the spring, normally corresponds to substantial increases in vegetation biomass. Műller and Pröhl (1993) provide information for grass yield at various calendar dates and for a studied area in (the environs of Munich) Germany. From the data available, it would seem that changes in grass biomass after mid-May for the given country are not substantial. Because of its colder climate we know that the growing season in Norway will be delayed by a few weeks compared to locations in more southerly European countries. Information from Skaugen and Tveito (2004) suggest that the growing season for the southern coastal areas of Norway we are interested in begins in Mid-April. We potentially only introduce a small error into the calculation by assuming that the deposition (on May 1st) coincides with the start of the growing season and then simply introducing a time lag of 1.5 months into the data of Műller and Pröhl, (1993) as shown in Table (6).

Date	**01.05 (15.03)**	**01.07 (15.05)**	**31.10**	**Reference**
Grass	0.05	1.5	1.5	Műller and Pröhl, (1993)
Leafy vegetables	0.03*	3	3	IAEA(2010)*; Richardson (2012)**

*Second lowest value for Chinese cabbage taken from Table 4 in IAEA (2010) to be consistent with grass value and interception fraction used (early in the growing season)

**Based on Richardson (2012) – see main text for clarification

Table 6. *Change in biomass with season (original dates for grass for Germany from Műller and Pröhl, (1993) in parentheses): Yield (kg m^{-2} f.w.)*

According to Richardson (2012), yields of cabbage in parts of the Bahamas can attain levels of close to 40 Tonnes/ha. In view of the less suitable conditions for growth in southern Norway for this type of crop a yield corresponding to 75 % of this value (i.e. 3 kg m^{-2}) has been provided as a crude estimate for leafy vegetables for our model. Although the biomass reported in Table 6 for leafy vegetable falls at the lower end typical for Norwegian condition (Http://www.agropub.no/id/6780), the value has been retained because it provides a conservative value for activity concentration in model output. The process of growth dilution was modelled for the deposition scenario starting on May 1st but not for the deposition scenario starting on 17th October at the end of the growing season.

For root vegetables, the same parameters for interception, and biomass dilution as for leafy vegetables were used. In view of the considerable biomass of crops like potato above ground this assumption is considered to be a reasonable one. The only difference introduced is in relation to how much of the activity is translocated from the above ground part of the vegetation to the below ground crop. The translocation factor is defined as the ratio of the activity, on a ground area basis, of the edible part of a crop at harvest time (Bq m^{-2}) to the foliage activity of the crop at the time of deposition (Bq m^{-2}). Information is available and has been taken from IAEA (2010) and is given in Table 7 below.

Weathering rates for grass were derived from the extensive analyses of data undertaken elsewhere (IAEA, 1996). Mitchell (2001) provides an overview of models concerning the transfer radionuclides to fruits. In order to model weathering of radionuclides on plant surfaces, an effective retention half-time was derived for use in the FARMLAND model. A single value of 11 d gave the best fit to experimental data giving a radionuclide independent rate constant of 6.3×10^{-2} d^{-1}. The similarity of this value with those applied for grass has led to the application of the same default values for the berry/shrub category. There are very few data available on weathering rates in IAEA (2010). Essentially for Cs, we have information for cereals (based on 1 data point) and grasses (n=4). In view of the lack of data for other plant categories, the weathering rates for vegetables (leafy and root) have been set to the grass value.

Parameter	Dependencies	Value	Units and notes	References
Interception fraction (f)	Grass Cs, May Cs, October Sr, May Sr, October	 0.05 0.43 0.08 0.66	(Unitless) A relatively low interception factor was applied in modelling deposition to vegetation early in the growing season following the Fukushima accident (Unitless) f varies from 0.84 (dry deposition) to 0.027 (wet deposition heavy rain) (IAEA, 2010) Bivalent Sr-90 will have a higher f than monovalent Cs (derived by simply multiplying f for Cs (May) by the ratio of f Sr/Cs for October Bivalent Sr-90 will have a higher f than monovalent Cs	UNSCEAR (2014) IAEA, 2010 IAEA (2009) IAEA (2009) and Hosseini et al. (in prep. : K-27 report (Part II))
	Blueberry-Shrub, Cs, May Cs, October Sr, May Sr, October	 0.43 0.43 0.66 0.66	As for grass in October	
	Leafy vegetables, Cs, May Cs, October Sr, May Sr, October	 0.59 0.87 0.59 0.87	Second lowest value for Chinese cabbage taken from Table 4 in IAEA (2010) to be consistent with grass value and interception fraction used (early in the growing season) Highest value for Chinese cabbage taken from Table 4 in IAEA (2010) to be consistent with grass value and interception fraction used (early in the growing season) As for Cs – the values from IAEA (2010) for leafy vegetables pertain to a “mixture of radionuclides”	IAEA (2010) IAEA (2010) IAEA (2010)
	Root vegetables, Cs, May Cs, October Sr, May Sr, October	 0.59 0.87 0.59 0.87	 As for leafy vegetables As for leafy vegetables As for leafy vegetables As for leafy vegetables	
weathering constant ($\lambda_{flw,r}$)	Wild grasses Cs Sr	 0.05 0.05	 d^{-1}, Table VIII, p.37 (IAEA, 1996)	IAEA (1996)
	Shrub Cs Sr	 0.05 0.05	 d^{-1}, As for grass d^{-1}, As for grass	
	Leafy vegetables Cs Sr	 0.05 0.05	 d^{-1}, As for grass d^{-1}, As for grass	
	Root vegetables, Cs, Sr	 0.05 0.05	 d^{-1}, As for grass d^{-1}, As for grass	
Translocation factor (ftr)	Root vegetables, Cs Sr	 0.05 5×10^{-3}	Unitless, See definition in main text. Table 10 in IAEA (2010) a value of 4.6 % is given for root vegetables and tubers Unitless, See definition in main text. Table 10 in IAEA (2010) a value of 0.5 % is given for root vegetables and tubers	IAEA (2010)

Table 7. *Parameters in the model which are dependent upon radionuclide.*

The interception fraction of ^{90}Sr has been taken to be a factor based upon the ratio of mass interception fraction of ^{140}Ba to ^{137}Cs (i.e. 1.7/1.1 = 1.54) for Chernobyl from IAEA (2009). According to Andersson et al. (2011), there are no clear differences between the weathering rates for grass that can be attributed to radioceasium and radiostrontium. From this observation the same default value was used for both radionuclides. The parameters have been assigned different default values as shown in Table 7. Two categories of flora –wild grass/grasses, and shrubs – taken to be representative of berry plants such as *Vaccinium spp.*. It should be noted that the compilation in IAEA (2014) for CR values has been made for the generic category "shrub" of which berry plants will only form a (potentially) small subset. However, the application of transfer data for a generic group to a more specific group may in many cases be a reasonable approximation. For example, in a comparison of Cs and Sr transfer data (i.e. CRs) for broadleaf and coniferous trees, inter alia, there were no statistically significant differences in the geometric means of these groups (Wood et al., 2003). The implication would be that using a generic tree transfer value, for these specific radionuclides, would provide a reasonable indication of transfer for particular subcategories of tree. Although extrapolation of such findings to our particular case are not presently substantiated, the use of a generic shrub value provides a conservative estimate of transfer and is based upon a much larger dataset than that applied for berries in IAEA (2010).

Parameter	Dependencies : flora, radionuclide	Value	Units and notes	References
ρ_{soil}		1300	kg m^{-3}	UNSCEAR (2014)
Soil depth (d_{soil})		0.05	m, Assumed depth of initial contamination following a deposition event	
Biomass (b)	Grass,			
	May	0.05	Biomass early in the season	Műller and Pröhl, (1993), UNSCEAR (2014)
	October	1.5	Biomass late in the season	Műller and Pröhl, (1993), UNSCEAR (2014)
	Blueberry-Shrub			
	May	0.4		Tømmervik et al. (2009), Hosseini et al. (in prep)
	October	0.4		Tømmervik et al. (2009), Hosseini et al (in prep)
	Leafy vegetables			IAEA(2010); Richardson (2012)
	May	0.03		
	October	3		
	Root vegetables			
	May	0.03	As for leafy vegetables	
	October	3		

Table 8. *Parameters in the model which are independent of radionuclide type.*

Limitations to the use of concentration ratios[2], CRs, arise from an incompatibility of the application of empirical data based on the long term post depositional conditions to the period directly following an accident. The CR values used (Table 9) are based on empirical datasets from field investigations collated to avoid inclusion of data pertaining to the period directly following depositional events (global fallout and Chernobyl accident deposition for some radionuclides such as Cs, Pu, Sr and Am) and thus should omit values pertaining to surface contamination of vegetation (Beresford et al., 2008). These default CR data are generally assumed to correspond to, and thus are applicable for, a contaminated soil depth of 10 cm. There is thus an inconsistency with the observed distributions of radionuclides shortly following deposition. Using the Fukushima accident by way of example, Kato et al., (2012) reported that greater than 86% of total radiocaesium and 79% of total ^{131}I were absorbed in the upper 2.0 cm in a soil profile from a relatively contaminated cultivated area sampled, at the end of April 2011, in proximity to (< 50 km distant, in a northeasterly direction) the Fukushima Dai-ichi site. A default value of 5 cm has been used for the calculations undertaken in the current assessment. Furthermore, bioavailability of radiocaesium has been observed to decrease with time following its introduction to soils (Vidal et al., 1995) with the implication that CRs based upon long term post depositional datasets might not reflect the transfer occurring in the early phase depositional environment appropriately. Indeed this contention is evidenced by reviews of published information on ^{137}Cs in the soil-plant system shortly after the Chernobyl accident (Fesenko et al., 2009). Finally, soil type, as defined by various soil properties, strongly influences transfer of radionuclides to plants (IAEA, 2010) and there will undoubtedly be differences in the soil types upon which the default data are based and the soil types for which the transfer parameters are applied. Since the scenario provides no information on this latter consideration, this could not be explored further under this modelling exercise.

Although some information exists on soil to grass transfer for the short term after accidents (Fesenko et al., 2009) these data are, by the author's own admission, insufficient for adequate (CR) estimation. This coupled to the knowledge that, with the model constructed and parameterized in its current configuration, direct contamination by fallout dominates the total activity concentration in vegetation in the initial weeks of simulation renders the application of highly uncertain CR values relatively unimportant.

[2] Concentration ratio = activity concentration in whole organism divided by activity concentration in soil

Element	Vegetation	CR (Bq kg^{-1} f.w. per Bq kg^{-1} d.w)	Reference and notes
Cs	Grass	0.05	IAEA (2010) Table 17 - mean value, pasture, all soil types (meadow fescue used for d.m. content=20%)
Sr	Grass	0.26	IAEA (2010) Table 17 - mean value, pasture, all soil types (meadow fescue used for d.m. content =20%)
Cs	Blueberry-Shrub	2.3	IAEA (2014)
Sr	Blueberry-Shrub	0.5	IAEA (2014)
Cs	Leafy vegetables	7.2E-3	IAEA (2010) : Table 17 – based on AM value for All soil types (12 % d.m. for cabbage)
Sr	Leafy vegetables	0.09	IAEA (2010) : Table 17 – based on AM value for All soil types (12 % d.m. for cabbage)
Cs	Root vegetables	8.8E-3	IAEA (2010) : Table 17 – based on AM value for All soil types (21 % d.m. for potato)
Sr	Root vegetables	0.15	IAEA (2010) : Table 17 – based on AM value for All soil types (21 % d.m. for potato)

Table 9. *CRs for agricultural and semi-natural terrestrial ecosystem– arithmetic mean values.*

The output data for shrubs has been used as input to the assessment of ingestion doses for humans by assuming that shrub contamination levels provide a reasonable proxy for edible berries. Finally, for mushroom, calculations were made using aggregated transfer factors. A value for Cantharellus (cibarius, lutescens, pallens, tubaeformis), selected because it has a relatively high Tag and the fact that it is a popular edible mushroom in Norway, was used in the calculation from IAEA (2010). The approach is far from ideal because little consideration is made for the rapidly changing dynamic nature of the system. A value of 0.3 m^2 kg–1, dry weight was used**.**

For mammals, examples of (bio)kinetic model for terrestrial environments have been published in the open literature and one of these, the so-called FASTer model, has been selected for further application (Brown et al., 2003; Beresford et al., 2010). For herbivorous mammals, the input data used can be those specifying the activity concentrations in grass as expressed above. Details are required regarding biokinetic parameters for various representative animals/fauna as described below in equation [4]:

$$\frac{dC_{r,a}}{dt} = \sum_{i=1}^{i=n}\left(x_i . AE_{r,i} . {FMI}/{M} . C_{r,i}\right) - C_{r,a} . \lambda_{r,a} \qquad [4]$$

where :

x_i is the fraction of the diet associated with dietary component ‘‘i’’;

$AE_{r,i}$ is the assimilation efficiency(dimensionless) for radionuclide “r” within dietary component “i”;

FMI/M is the ingestion rate per unit mass of animal (kg f.w. day^{-1} per kg f.w.);

$C_{r,i}$ is the activity concentration of radionuclide “r” in dietary component ‘‘i’’ (Bq kg^{-1} f.w.);

$C_{r,a}$ is the ‘‘whole-body’’ activity concentration of radionuclide “r” in the animal (Bq kg^{-1} f.w.); and

$\lambda_{r,a}$ is the effective loss rate of radionuclide “r” from animal(day^{-1}) incorporating both excretion rate and physical decay of the radionuclide.

This model was then applied to determine the transfer to the herbivorous mammal – cow. Fresh matter ingestion rates (FMI) were derived using allometric relationships of the form given in equation [5] as shown in Table 10. Although selecting a representative mass for an adult cow is not uncontentious, because of uncertainties associated with seasonal changes and differences between the sexes and whether we are considering beef or dairy cattle, a value of 400 kg, based on a high percentile value from the work of Lofgreen et al.(1962) was selected. The following allometric relationship could then be applied:

$$FMI = a.M^b \qquad [5]$$

where:

a is the multiplication constant in the allometric relationship for fresh matter intake for animal [kg d^{-1}]

b is the exponent in the allometric relationship for fresh matter intake for animal [relative units] M is mass of the animal (kg).

Similarly, $\lambda_{r,a}$ the effective loss rate of radionuclide "r" from animal, a, could be derived using allometric relationships (Table 11) using the animal masse specified below (Table 10). The various parameters required in the model runs are thus specified in Table 12.

Organism	FMI (kg/d)	Comments and references
herbivorous mammal - cow	8.6	Mass = 400 kg FMI for herbivores (kg d^{-1}) = $0.1995M^{0.628}$ from Nagy (2001)

Table 10. *Fresh matter ingestion rate, FMI, for the herbivorous mammal – cow*.

Radionuclide	Allometric equations
Cs	$\lambda_{r,a} = \dfrac{\ln 2}{18.36 M^{0.24}}$
Sr	$\lambda_{r,a} = \dfrac{\ln 2}{645 M^{0.26}}$

Table 11. *Allometric equations used to derive effective loss rates (d^{-1}) for studied animals from mass of animals (kg) (Brown et al., 2003)*.

Parameter	Dependencies	Value	Units	Notes (references)
x_i	Grass Cow	1	dimensionless	Assumption that the cow is feeding entirely on contaminated grass
AE	Cow Cs Sr	 0.8 0.11	 dimensionless dimensionless	Table 24 of IAEA (2010) – mean value for ruminants Table 24 of IAEA (2010) – mean value for ruminants
FMI/M	Cow	2.15E-02	kg f.w. day^{-1} per kg	(FMI/M)
$\lambda_{r,a}$	Cow, Cs Sr	 9.0E-03 2.3E-04	 d^{-1} d^{-1}	 Table 6; Mass = 400 kg Table 6; Mass = 400 kg
f_{soft}	Cow Sr	 0.09	 unitless	 Brown et al. (2003)

Table 12. *Parameters used in dynamic model runs for cow*.

It should be noted that the FMI for cow appears to be substantially underestimated with regards to information published elsewhere. For example in Smith and Beresford (2005) a value of 7.2 kg/day dry weight for ingestion of feed by beef cattle was considered appropriate. This would convert to a FMI (assuming 20 % dry matter) of >35 kg/day. Even higher ingestion rates for milk cattle are often applied. Nonetheless, the value was not adjusted for the time being as the model has been set up to incorporate allometric parameters and further testing/analysis is considered necessary before changes of this type are made. The model as it was set up had an output as the whole body activity concentration in a selected mammal. For the case of radiocaesium the whole body activity concentration was considered to be a reasonable surrogate for the beef activity concentration – thus no modification to the output value needs to be made. This is not the case for Sr which tends to become primarily associated with bone once the element is assimilated within the body of mammals. A further factor therefor needs to be applied to account for this when calculating activity concentrations in beef. For this purpose a value of 0.09 (representing the fraction of total activity in the soft tissues) has been used from the original set up of the FASTer model (Brown et al., 2003).

Determining activity concentrations in milk requires further attention because whole body activity concentrations only provide indirect information about this measurement endpoint. The classical way to derive activity concnetrations in milk, as well as meat, is to use transfer coefficients which relate the activity concentration ingested by a given farm animal (Bq per day) to the activity concentration in the animal at equilibrium (Bq L^{-1} or Bq/ kg^{-1}) hence the associated and slightly obscure, unit for this parameter of L day^{-1} or kg $day^{-1,}$(IAEA,2010) . An alternative method for quantifying transfer from herbage to animal products is also presented in the form of a concentration ratio, CR. This parameter is defined as the equilibrium ratio of the radionuclide activity concentration in the food product (fresh weight) divided by the radionuclide concentration in the feed (dry matter).The CR has the advantage in field studies that dietary dry matter intake does not need to be calculated or, as is more often the case, have a value assumed for it. The relative magnitude of these CRs for beef and dairy cattle may be used for the conversion of the whole body activity concentrations derived from the model to activity concentrations in milk. This is arguably a crude conversion owing to the large uncertainties involved in using datasets with different provenance (i.e. the concentration ratios reported in IAEA (2010) for beef and for milk will pertain to different herds sampled in different areas under different conditions) the value will at least provide an indication of the differences that might be expected in activity concentrations associated with beef and milk products from the same area. A summary of additional parameters used in the modelling is given in Table 13.

Parameter	Dependencies	Value	Units	Notes (references)
CR_{milk}	Cow Cs	0.11	Bq L^{-1} (milk) per Bq kg^{-1} d.w. feed	IAEA 2010 (Table 29)
CR_{beef}	Cow Cs	0.23	Bq kg^{-1} (beef) per Bq kg^{-1} d.w. feed	IAEA 2010 (Table 36)
Conv	Cow Cs	0.5	Dimensionless, CR_{milk}/ CR_{beef}	Conversion factor whole body to milk

Table 13. *Additional parameters used to convert whole body activity concentrations to milk activity concentrations and for the sake of comparison*.

The model was set up and run using the software tool ECOLEGO (Avila et al., 2005). Ecolego is a flexible software tool for creating dynamic models and performing deterministic or probabilistic simulations. The software has specialised databases and other add-ons designed for the field of radiological risk assessment. The graphical user interface helps the user to define and manage building blocks, parameters, species and simulation settings. Ecolego also helps to create reports, to plot simulation results, to perform probabilistic simulations and sensitivity analysis.

4.3 Methodology – Sweden

For the purpose of the transfer estimation component of NORCON, Vattenfall used the functionality of the RODOS system for which some details are provided here. One cell with deposition of more than 1E5 Bq/m^2 ^{137}Cs in Sweden (for Ringhals source term – no values are above 1E6 Bq/m^2 in Sweden) was selected and used as the basis for estimation. The selected output data included activity concentrations as a function of time in raw feedstuff (grass intensive) and food (leafy vegetables, root vegetables, cows milk, cow beef and berries). The top 10 cm soil deposition was only calculated for the prognosis time although nuclide specific ground dose data is available for longer time periods. No data was available for mushrooms, blueberries.

4.4 Methodology – Iceland

The nuclear power plant nearest to Iceland is in the United Kingdom, more than 1000 km away so the radioactive fallout has some distance and time to travel before reaching Iceland. In case of an accident in a nuclear power plant in one of our neighboring countries, IRSA would contact the Icelandic Met. office to model the dispersion. Currently IRSA has not put transfer coefficient in their model (NAME) to estimate what will happen with the radioactive fallout. IRSA would either estimate the transfer by hand using the appropriate transfer coefficient (transfer coefficient for Nordic countries if available) or try to implement them in the models at the Icelandic Met. office. Because of the distance and time the primary concern would most likely be ^{137}Cs and IRSA has been monitoring ^{137}Cs for a long time in the environment and agriculture in Iceland. If the aftermath of an accident in a nuclear power plant would affect Iceland then most of the countermeasures would be based on measurements.

4.5 Methodology – Denmark

No methodology description was provided.

5.0 Results

5.1 Dispersion Modelling

During the project, an exercise was conducted with the aim of comparing dispersion results from the different partner countries. The concept was to simulate a situation where the national competent authorities (NCA) are notified about an event and a potential release that is likely to take place at a given time. With every NCA having completed a run, NORCON observed how the results compared to each other, to see if the basis (with respect to the information generated by this stage of an analysis) for a decision is more or less the same, or if there are differences that could lead to different assessments. This exercise was comparable to the initial release phase of a NPP accident where the countries do not have any measurements, but still need to assess potential consequences outside planning zones. The only factor that varies are which combination of dispersion model and numerical weather prediction (NWP) model was used, and how the operator configured the model to best reproduce the given scenarios. In summary, this exercise was not an evaluation of dispersion models, but to compare the results NCAs are in possession of after they have done a model run based on relevant internal procedures . In a real situation, the NCA should contact their meteorological institute for a quality check of the result.

Each country executed one or more dispersion calculations for each of Brokdorf and Ringhals NPP using the developed source terms. For both reactors the release started at 10:00 UTC on 25. March 2015 and lasted for 24 hours (see Table 14). Release height was set to 20 meters for Ringhals and 30 meters for Brokdorf.

Isotope	**Total release from Ringhals 4 (Bq)**	**Total release from Brokdorf (Bq)**
^{134}Cs	1.6E+16	1.8E+16
^{137}Cs	1.3E+16	1.5E+16
^{131}I	1.6E+17	1.9E+17
^{133}I	3.4E+17	4.0E+17
^{133}Xe	6.7E+18	7.9E+18

Table 14. *Emissions isotope composition and amount during the 24-hour period of the release used for intercomparison.*

To summarise, 16 results (eight for each of the reactors) covered eight different NWP models and four dispersion models. The Danish Emergency Response Model of the Atmosphere (DERMA) and Severe Nuclear Accident Program (SNAP) are both long-range models, while RIMPUFF is a medium range model. The latter comes in two versions as discussed earlier; one used with ARGOS DSS (SSM and DEMA) and the other used in RODOS DSS (Vattenfall). Although both DSS use the same dispersion model, the specific version of RIMPUFF is different and therefore was treated as different model. Although four isotopes were modelled, this analysis only considered ground deposition of ^{137}Cs. This was done to simplify the analysis. Other isotopes, except those of noble gases, should give more or less the same results for deposition.

Participant	Reactor	Dispersion model	NWP model
DEMA	Brokdorf	RIMPUFF (ARGOS)	NOMAD
DEMA	Ringhals	RIMPUFF (ARGOS)	NOMAD
DEMA	Brokdorf	RIMPUFF (ARGOS)	DK-HIRLAM
DEMA	Ringhals	RIMPUFF (ARGOS)	DK-HIRLAM
DEMA	Brokdorf	DERMA	DK-HIRLAM-HIRES
DEMA	Ringhals	DERMA	DK-HIRLAM-HIRES
DEMA	Brokdorf	DERMA	DK-HIRLAM
DEMA	Ringhals	DERMA	DK-HIRLAM
DEMA	Brokdorf	DERMA	ECMWF
DEMA	Ringhals	DERMA	ECMWF
NRPA	Brokdorf	SNAP	NO-HIRLAM
NRPA	Ringhals	SNAP	NO-HIRLAM
SSM	Brokdorf	RIMPUFF (ARGOS)	SE-HIRLAM
SSM	Ringhals	RIMPUFF (ARGOS)	SE-HIRLAM
Vattenfall	Brokdorf	RIMPUFF (RODOS)	SE-HIRLAM
Vattenfall	Ringhals	RIMPUFF (RODOS)	SE-HIRLAM

Table 15. *Summaries of delivered data for intercomparison. DEMA delivered 12 different results on different combinations of dispersion models and NWP models. NRPA, SSM and Vattenfall delivered two each, one for each NPP, from operational dispersion modelling tool.*

Ground deposition was chosen because this matters most for long-term consequences. Air concentration is primarily of importance during plume passage when sky shine and inhalation is of concern. For each result, the deposition given in the last modelling time step was used as input to the analysis. The length and number of time steps varied between models – from 44 to 132 hours. The last step yields a result where the plume has passed and allowed all ^{137}Cs to deposit in the area.

The spatial extent within which each model operates varies. Figure 20 illustrates this for a selection of NWP-models hosted by the Danish Meteorological Institute. In practice this means one model may simulate the dispersion further afield than other models. No actions were taken to compensate for this effect. What could have been done was to normalise all results to a minimum extent covered by all models. Instead it was assumed that all models covered the area of interest used in this analyses. While this is not quite true because some results shows a sudden cut-off where one could expect a continuation the results were used as-is for the sake of practicability.

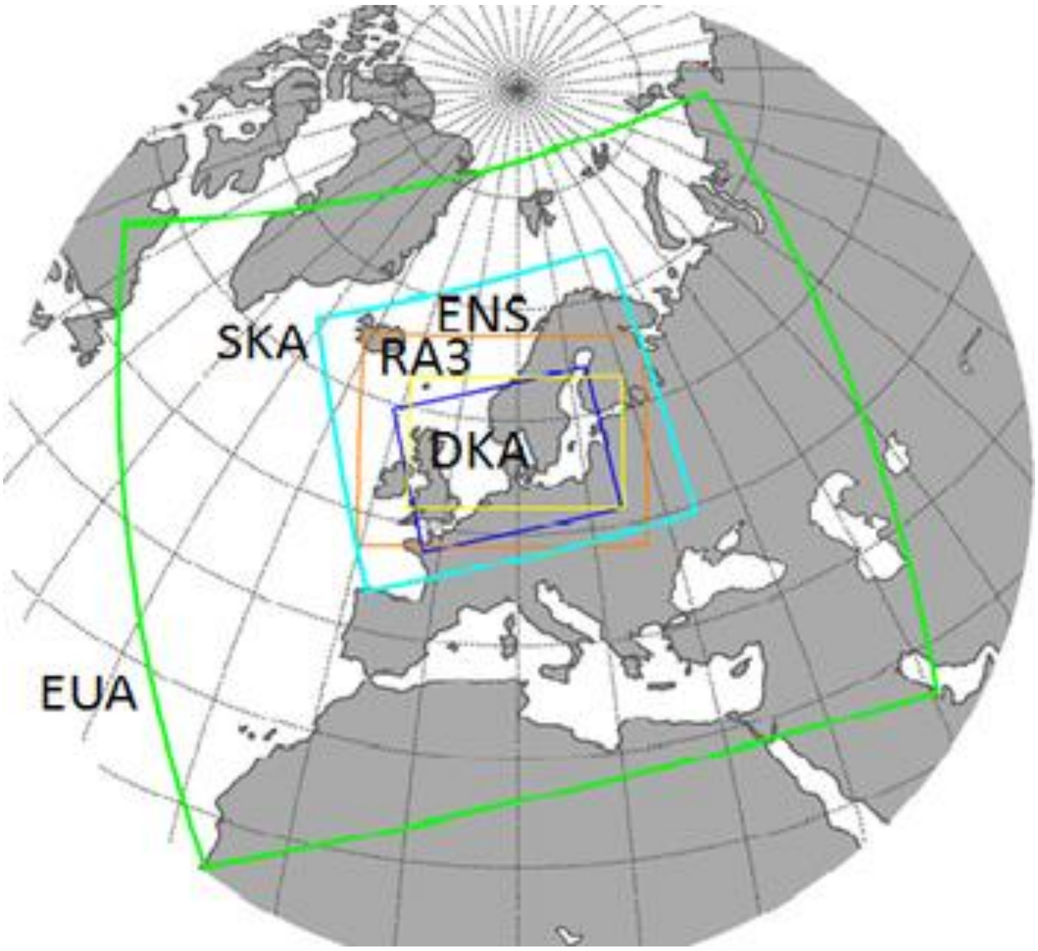

Figure 20. *The spatial extent of different NWP-models operated by Danish Meteorological Institute. In this report, EUA and SKA was used by DEMA.*

In order to compare the results, they had to be projected to one common projection, and converted to raster data with a common cell size. The latter was set to 2 km x 2 km, which should fit all models native resolution. Next, the deposition values were reclassified according to the following rules:

- Values < 3000 were removed
- Values > = 3000 and <10000 were set to 3000 (Bq/m^2)
- Values > = 10000 and <100000 were set to 10000 (Bq/m^2)
- Values > = 100000 were set to 100000 (Bq/m^2)

After reclassification, the results were of a form that facilitated comparison. They now showed where the deposition was equal to or larger than 3 kBq/m^2, 10 kBq/m^2 and 100 kBq/m^2. These results are presented later as individual results for each of the dispersion calculations that were made. A relative comparison of the results was achieved by counting the number of results that agree that a grid cell exceeds a certain value and applying this value to the cell. In this case, 10 kBq/m^2 and 100 kKBq/m^2 were used as values. For each of these values, all eight models were compared, yielding a cell value between zero and eight. In addition, the four results based on Rimpuff were compared separately. The same applies for the four long-range models. This was to see if there are differences between the two modelling concepts.

5.1.1 Brokdorf Case

Eight dispersion results were calculated for the Brokdorf case. Each of them are presented here and a comparison of levels is shown in the second part. Although the results match rather well, there seems to be a difference between long-range results and RIMPUFF results.

Individual results

The first shown in this section are the results from DEMAs dispersion run using the RIMPUFF-model with Danish HIRLAM-data in ARGOS (Figure 21). Next results (Figure 22) exhibit results from the Danish long-range model DERMA run with ECMWF-model. This is a global low resolution model which is also the basis for other models

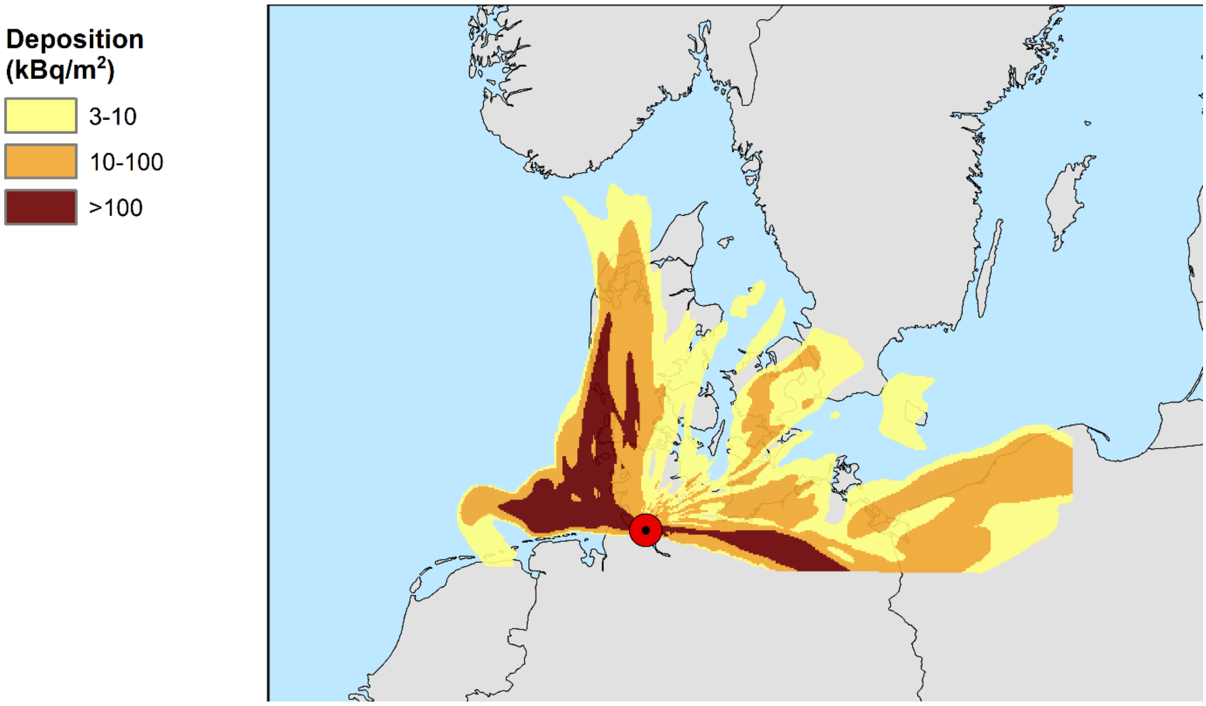

Figure 21. *RIMPUFF with Danish HIRLAM-model.*

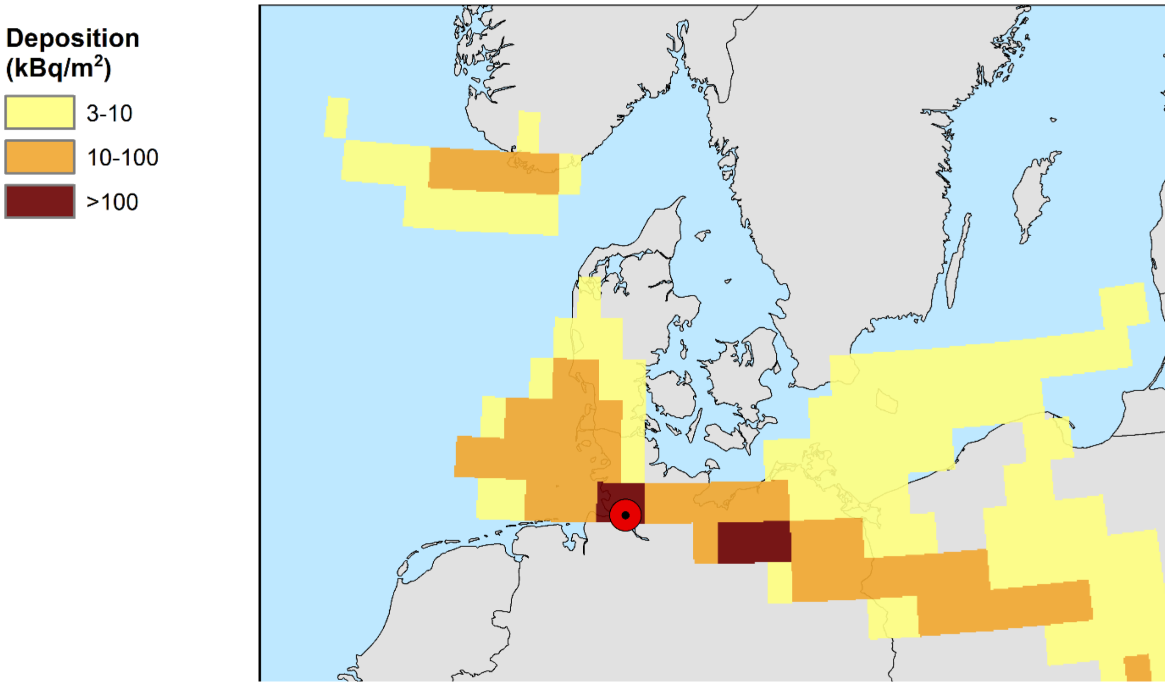

Figure 22. *DERMA with ECMWF-model.*

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Figure 23 displays results of the DERMA-model run with the Danish HIRLAM-model.

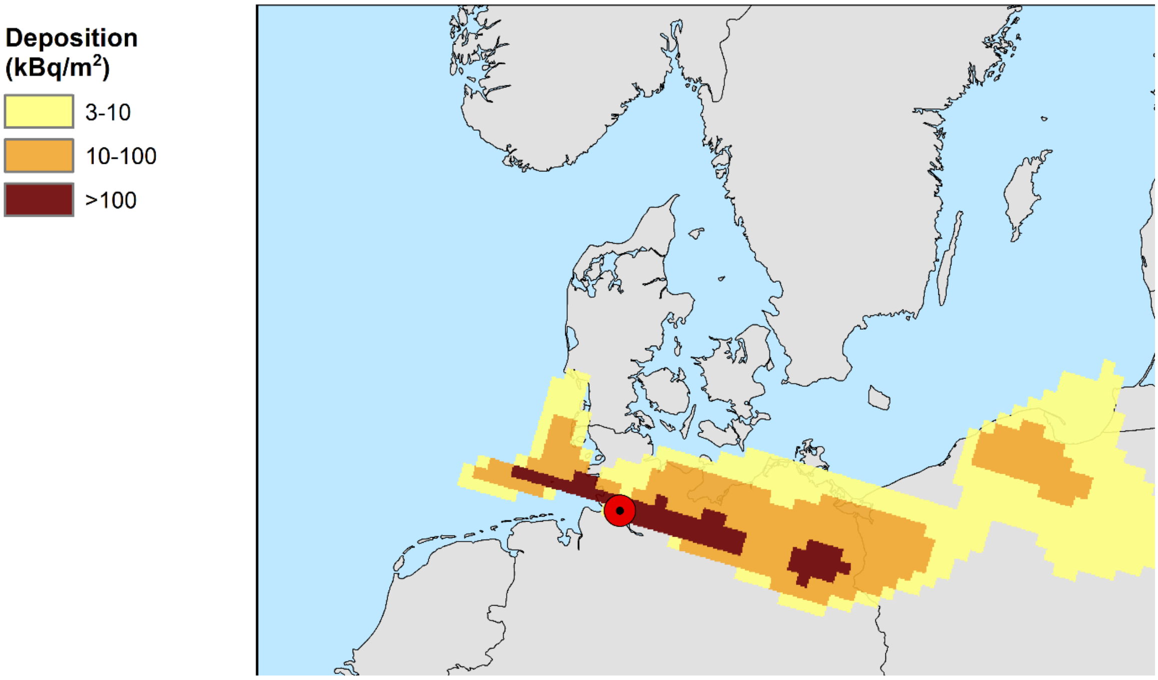

Figure 23. *DERMA with HIRLAM-model.*

Figure 24 displays DEMAs results from RIMPUFF using NOMADS-model. This is freely available NWP-data provided by NOAA. It is low-resolution and covers the whole globe.

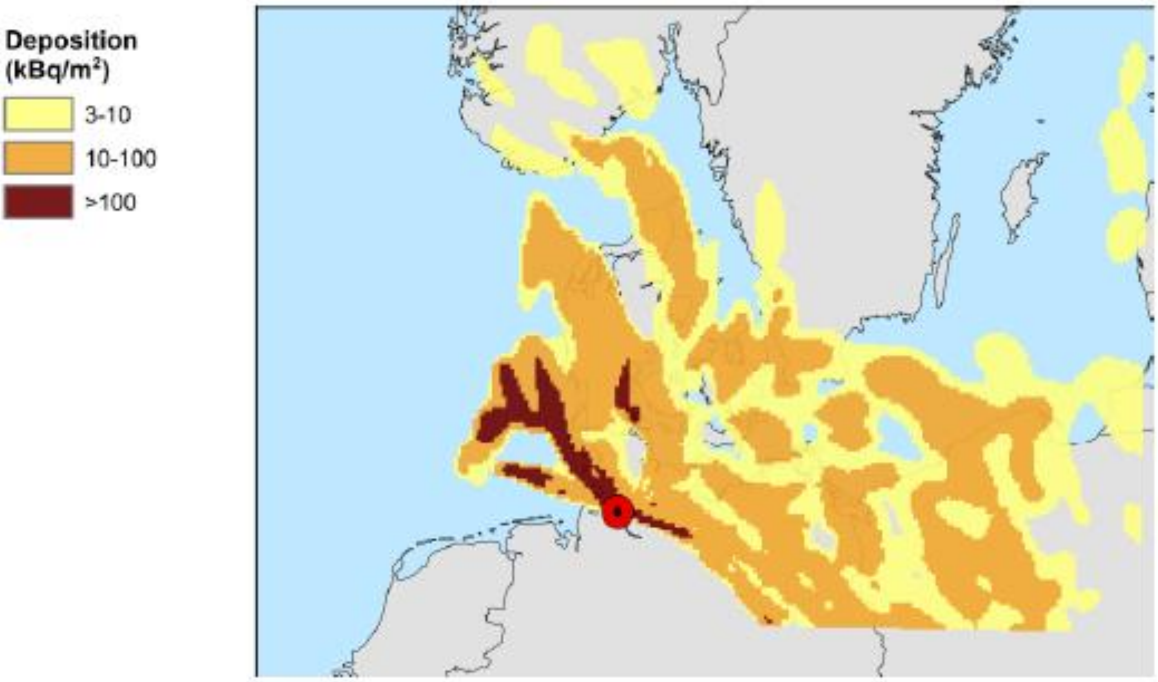

Figure 24. RIMPUFF with NOMADS-model.

The final result from DEMA on Brokdorf is again the DERMA model run with high resolution HIRLAM (SKA-model) (Figure 25).

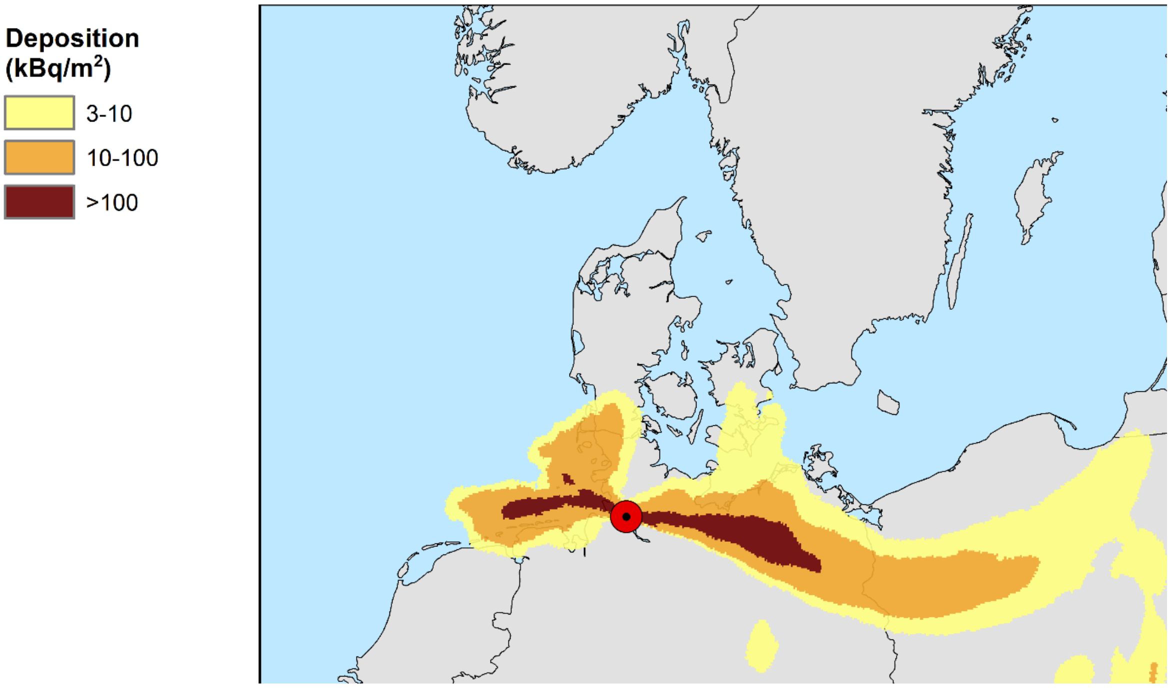

Figure 25. *DERMA with high resolution Danish HIRLAM-model*.

Figure 26 displays the long-range model SNAP. The model uses the Norwegian HIRLAM-model.

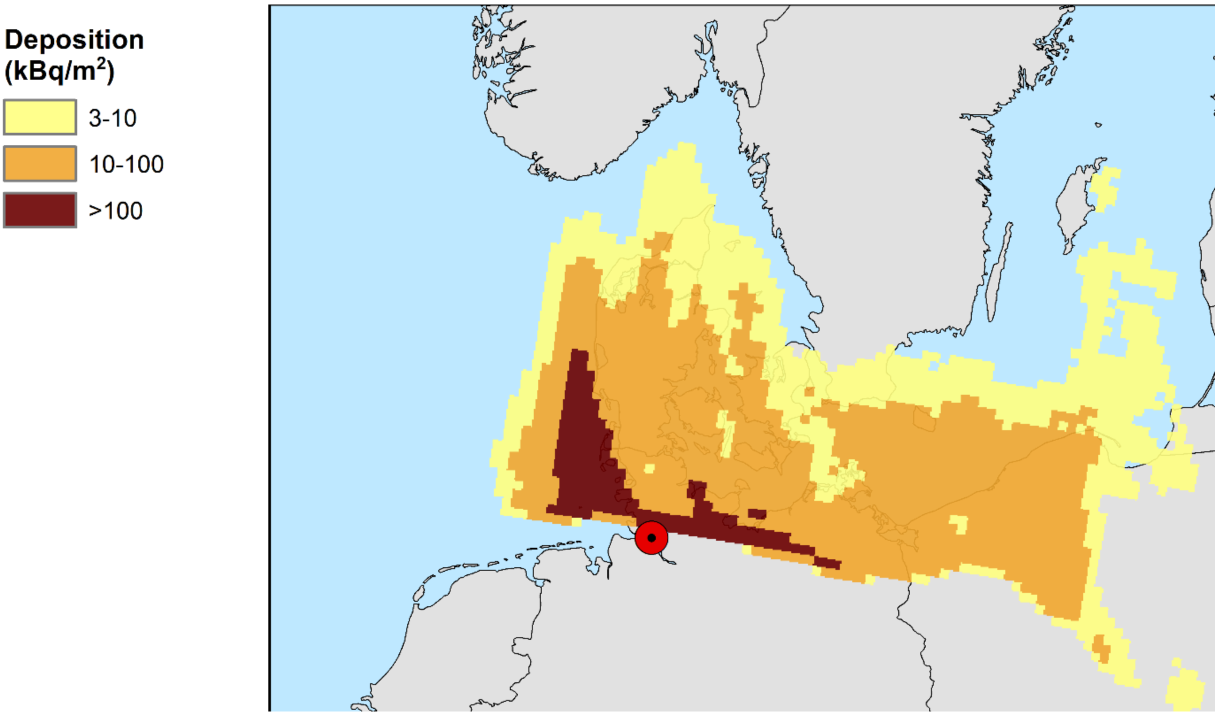

Figure 26. *SNAP with Norwegian HIRLAM-model*.

Figure 27 displays results from SSM, who used the ARGOS version of RIMPUFF with the Swedish HIRLAM-model.

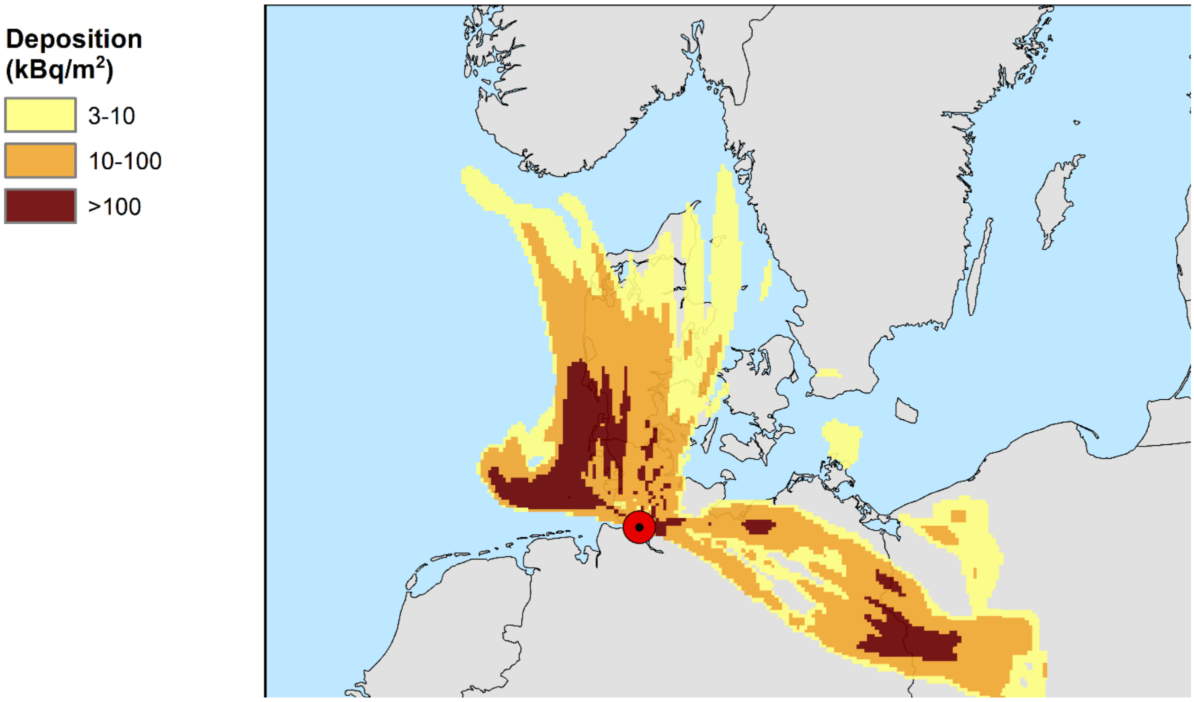

Figure 27. *ARGOS version of RIMPUFF with Swedish HIRLAM-model.*

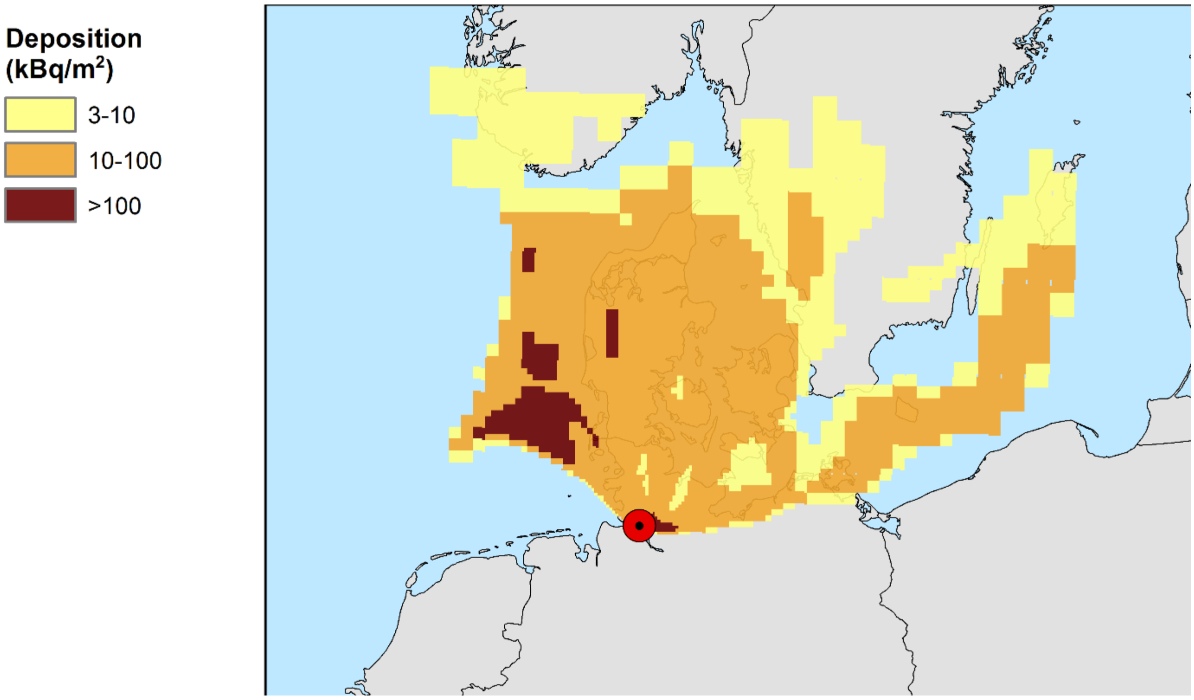

Figure 28. *RODOS version of RIMPUFF with Swedish HIRLAM-model.*

Finally, as displayed in Figure 28, Vattenfall used Rimpuff in RODOS, run with the Swedish HIRLAM-model. This is the same model as used by SSM. RODOS uses a telescopic grid, which means the output resolution is higher (smaller grid cells) close to the release point and decrease gradually away from the source.

Brokdorf Comparison

Figure 29 shows how all the modelling results for the Brokdorf scenario agree to which areas are contaminated with levels of 10 kBq/m^2 or more. Figure 30 and Figure 31 shows the agreement between long-range and RIMPUFF results respectively. In general, some models seems to disperse more than others do. Looking back at the individual results, all three results from the DERMA model agree quiet well. Results from RIMPUFF agree less. What is worth noticing is the difference between long-range and RIMPUFF as shown in Figure 30 and Figure 31. While long-range deposit more towards east and west, RIMPUFF results shows a tendency more to the north-west over Denmark.

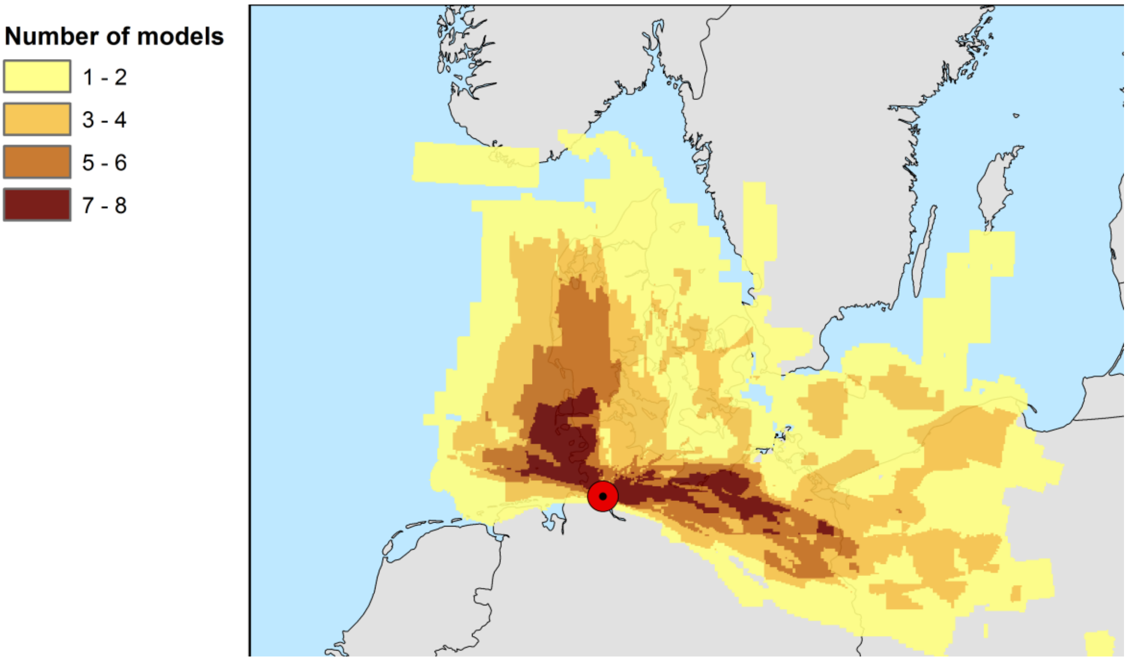

Figure 29. *A comparison of how all results agree to which areas are contaminated with 10 kBq/m^2 or more.*

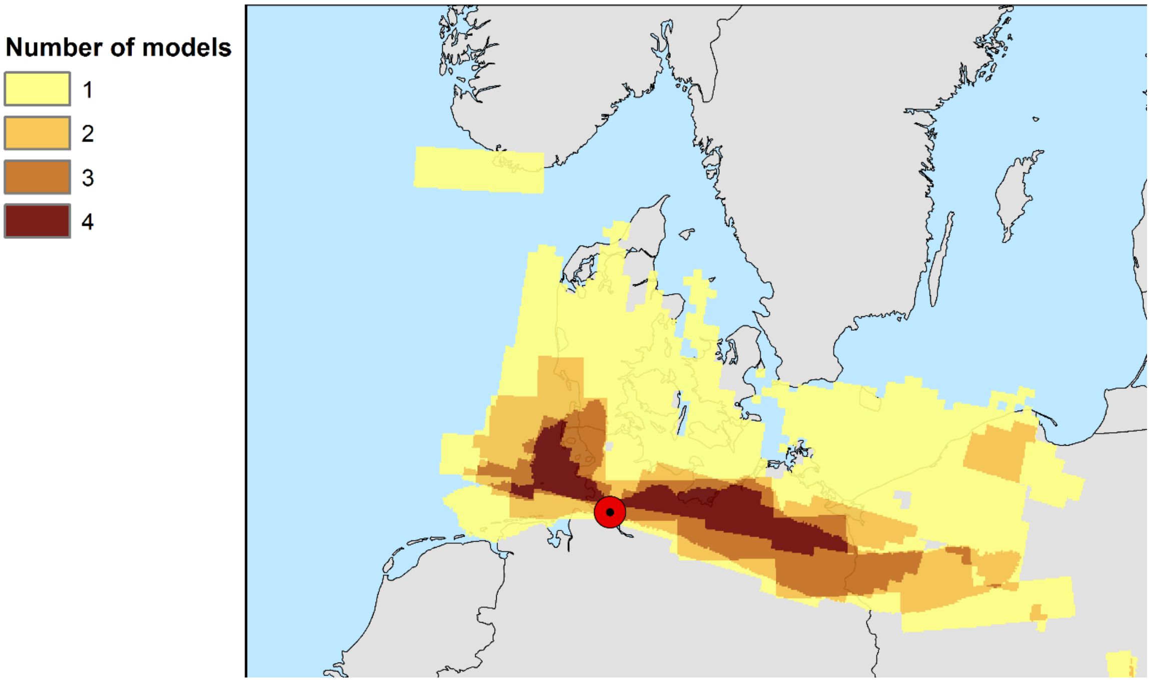

Figure 30. *A comparison of how results from long-range models agree to which areas are contaminated with 10 kBq/m*^{2} *or more*.

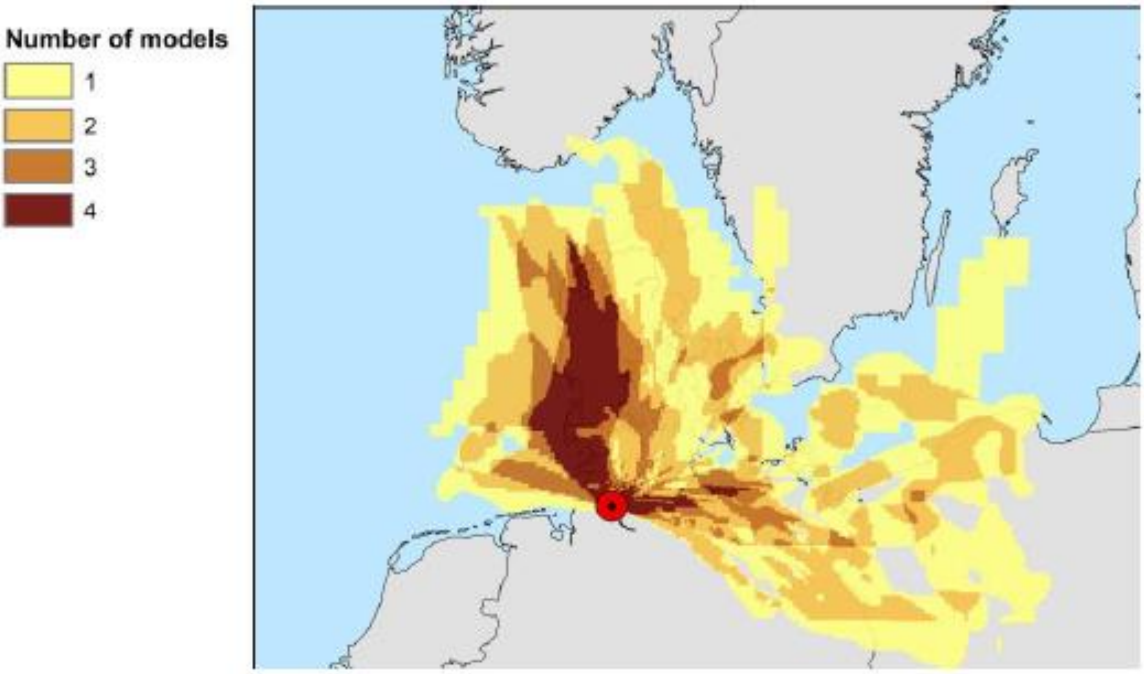

Figure 31. *A comparison of how results from RIMPUFF agree to which areas are contaminated with 10 kBq/m*^{2} *or more*.

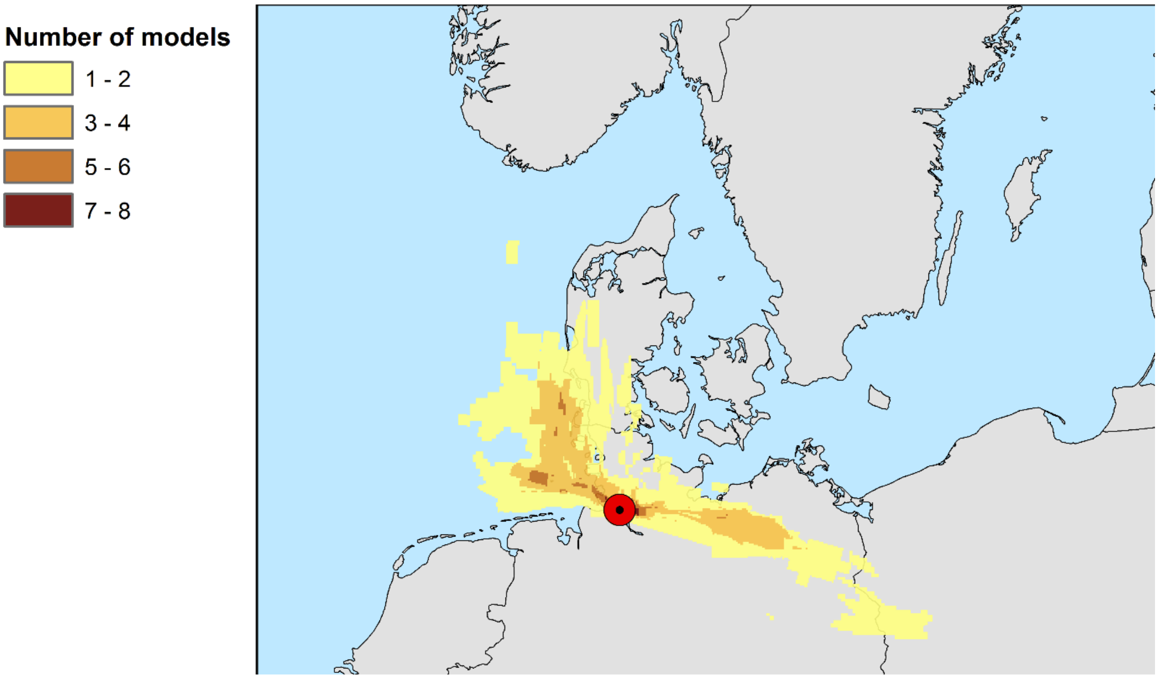

Figure 32. *A comparison of how all results agree to which areas are contaminated with 100 kBq/m*^{2} *or more.*

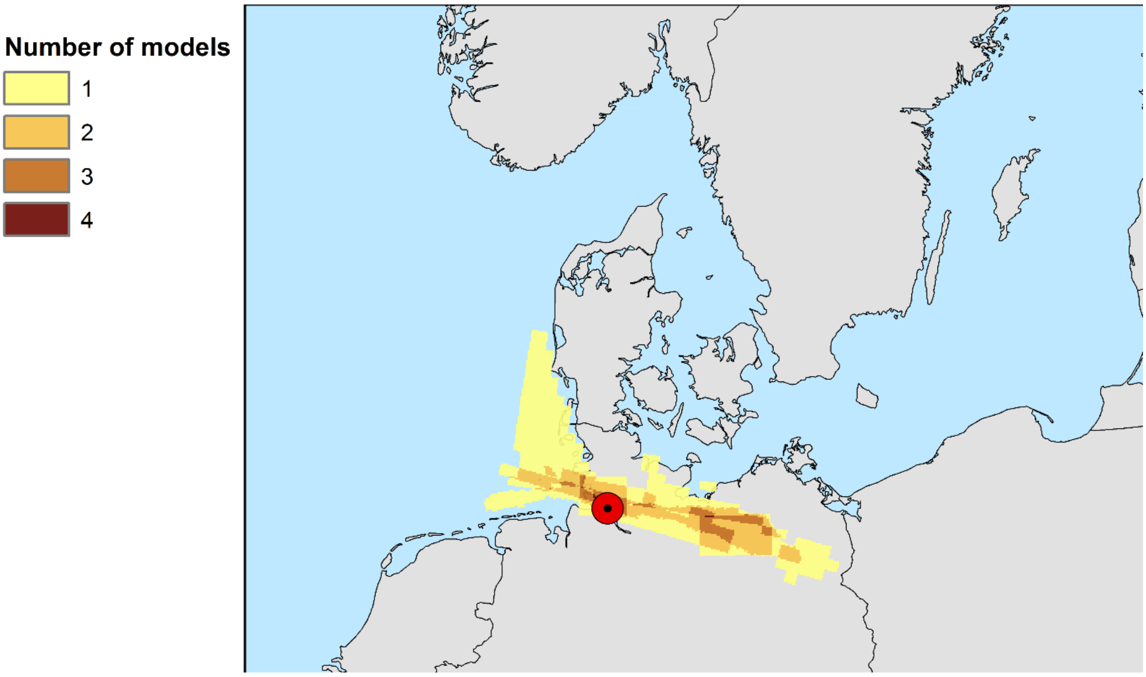

Figure 33. *A comparison of how results from long-range models agree to which areas are contaminated with 100 kBq/m*^{2} *or more.*

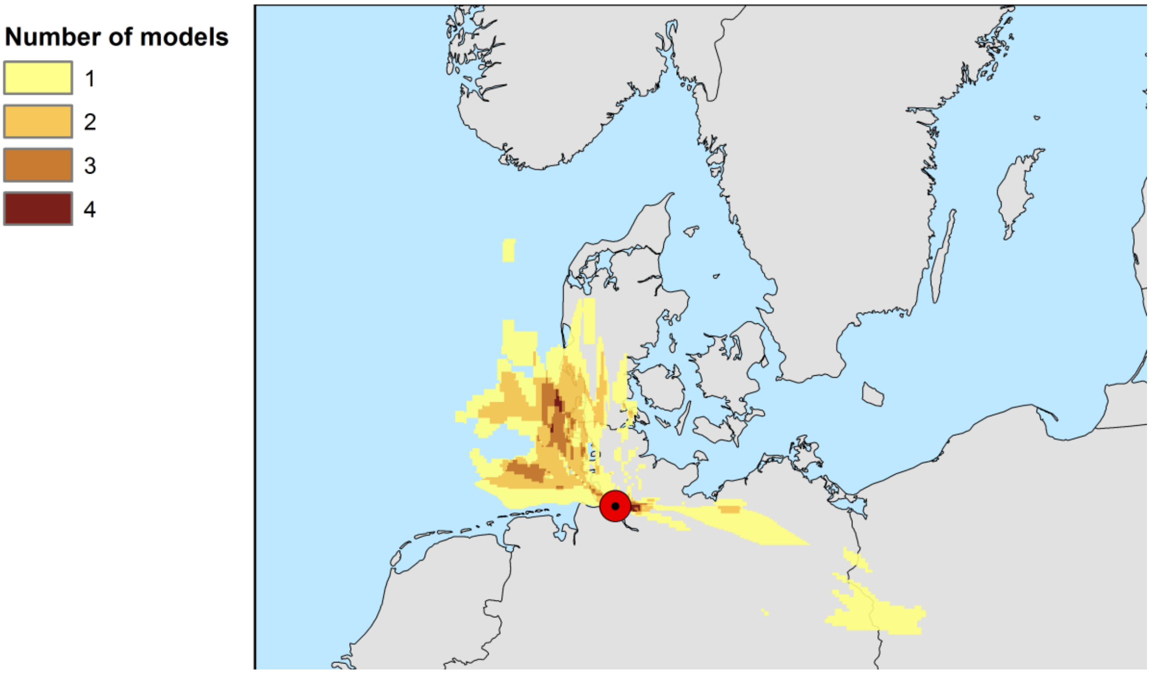

Figure 34. *A comparison of how results from RIMPUFF agree to which areas are contaminated with 100 kBq/m^2 or more.*

Figure 32, Figure 33 and Figure 34 show the same comparisons for areas exceeding 100 kBq/m^2. For this level, the difference between long-range and RIMPUFF results are even clearer.

5.1.2 Ringhals Case

As for the Brokdorf scenario, eight dispersions were calculated for the Ringhals case. Each of them is presented here, and relative comparison of levels is shown in the second part. Compared to calculations made for Brokdorf, these results match rather well.

Individual results

First are shown the results from DEMAs dispersion run using the RIMPUFF-model with Danish HIRLAM-data in ARGOS in Figure 35.

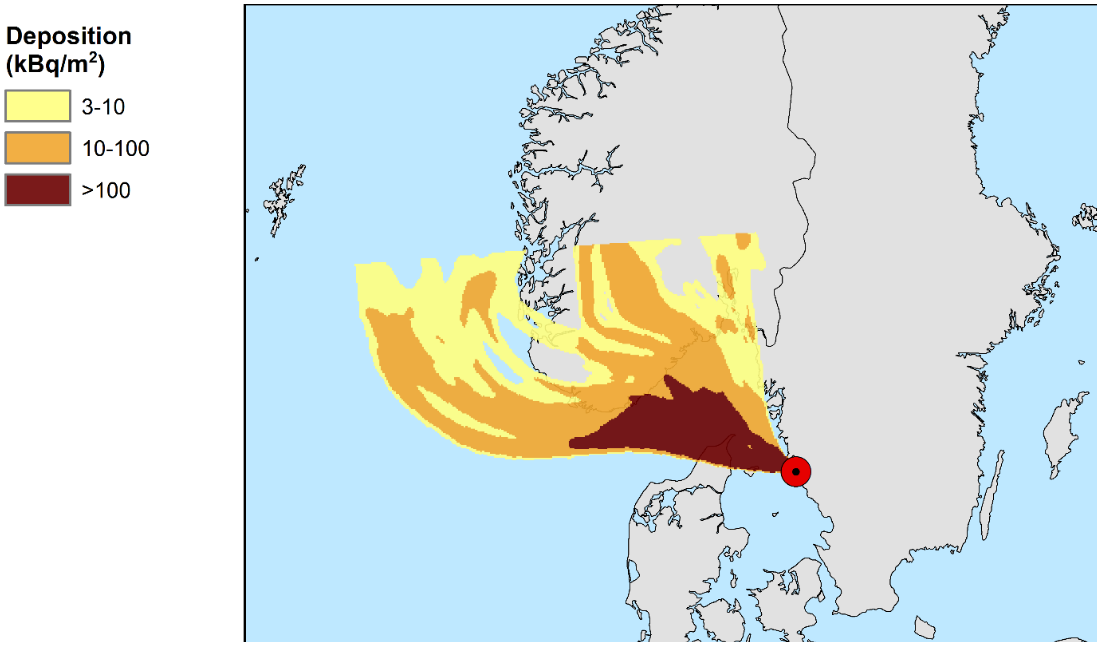

Figure 35. *RIMPUFF with Danish HIRLAM-model.*

Next, Figure 36 shows results from the Danish long-range model DERMA run with ECMWF-model. This is a global low resolution model which is also the basis for other models. Figure 37 shows the DERMA-model run with the Danish HIRLAM-model.

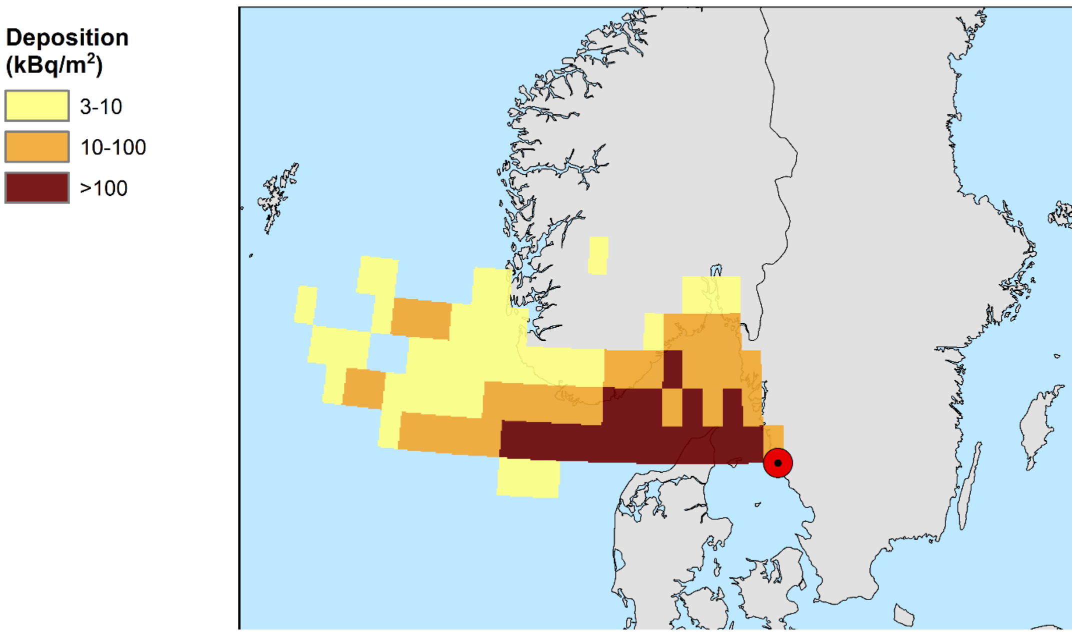

Figure 36. *DERMA with ECMWF-model.*

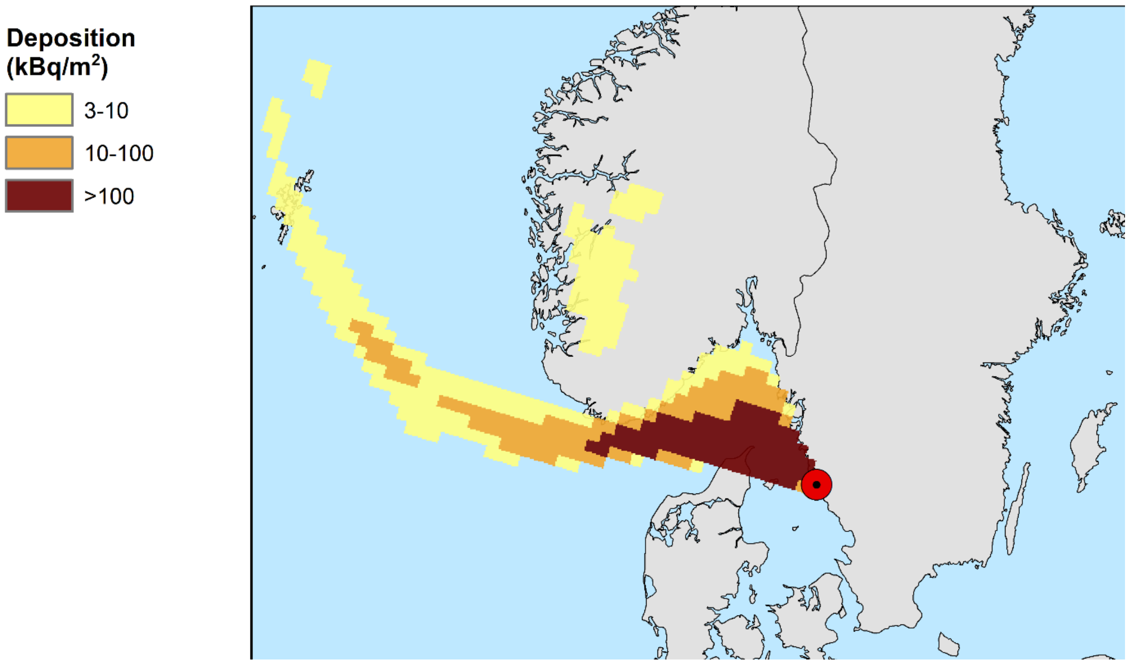

Figure 37. *DERMA with Danish HIRLAM-model.*

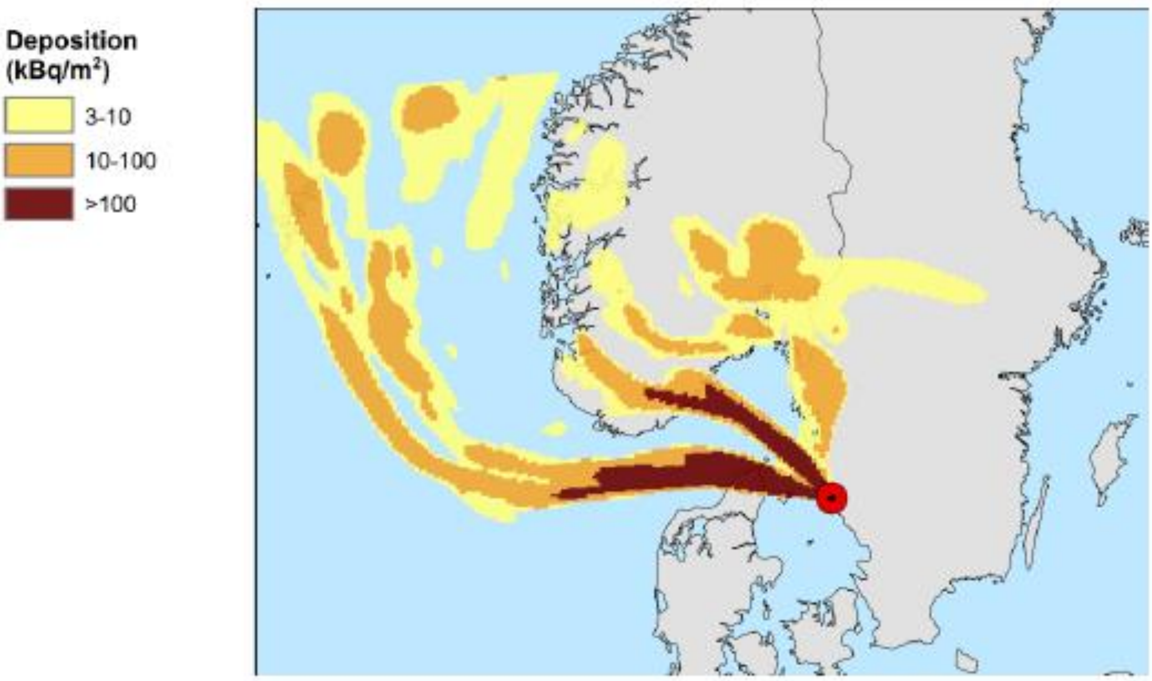

Figure 38. RIMPUFF with NOMAD-model.

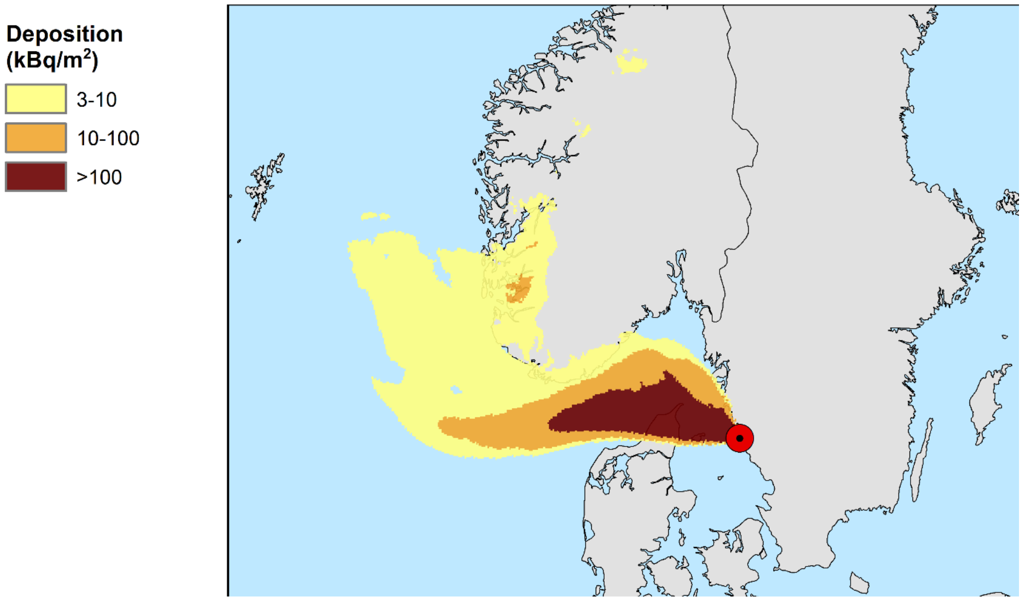

Figure 39. *DERMA with high resolution Danish HIRLAM-model.*

Figure 36 shows DEMAs results from RIMPUFF using NOMADS-model and the final result from DEMA on Ringhals is again the DERMA model run with high resolution HIRLAM (SKA-model) and displayed in Figure 37. Figure 38 displays the ong-range model SNAP which uses the Norwegian HIRLAM-model.

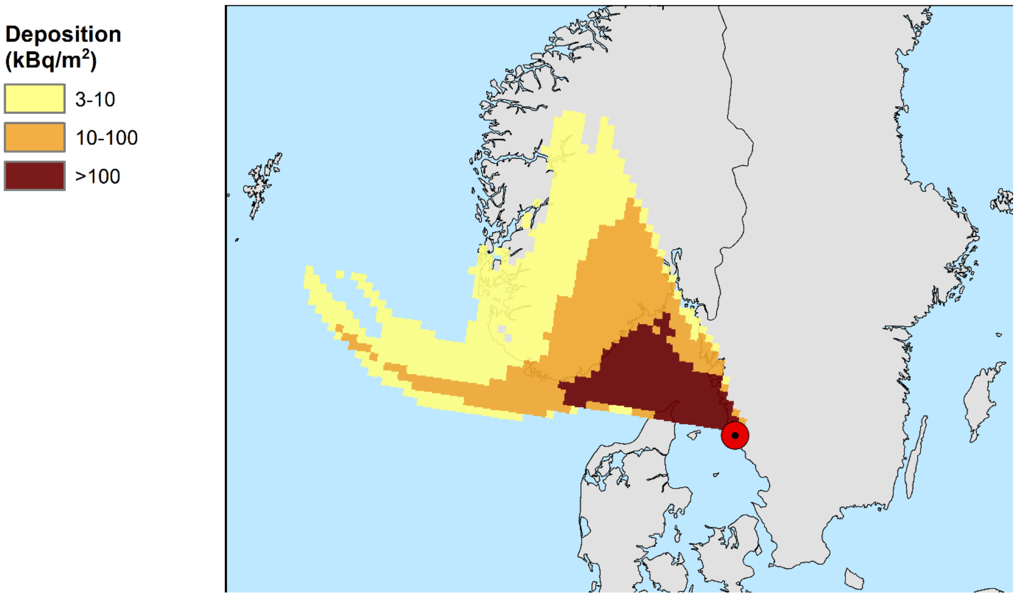

Figure 40. *SNAP with Norwegian HIRLAM-model.*

Figure 41 exhibits results from SSM, who used the ARGOS version of RIMPUFF with the Swedish HIRLAM-model

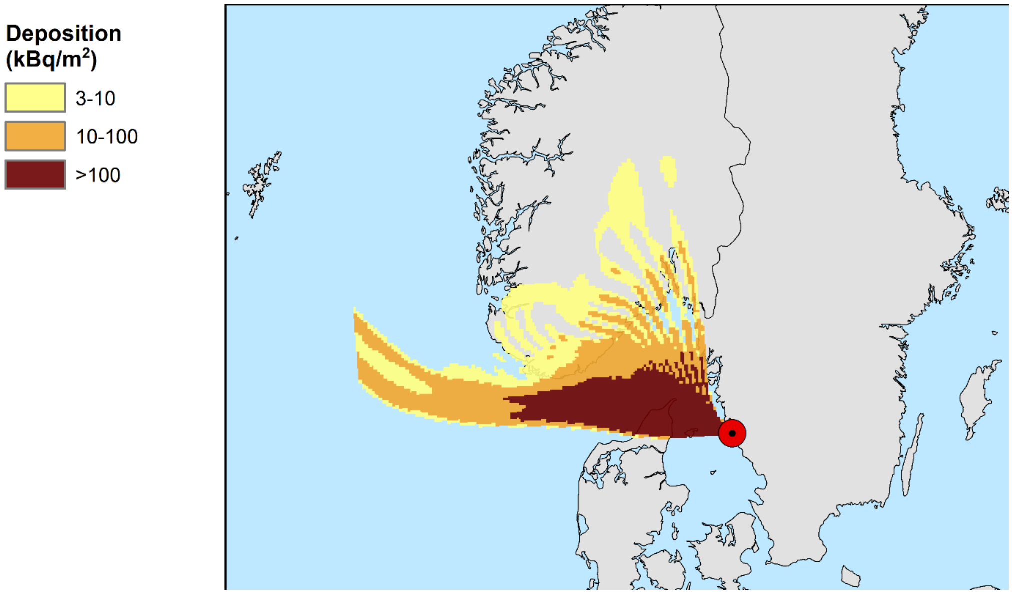

Figure 41. *RIMPUFF with Swedish HIRLAM-model.*

Finally, Vattenfall employed Ripuff in RODOS run with the Swedish HIRLAM-model. This is the same NWP model used by SSM. RODOS uses a telescopic grid, which means the output resolution is higher (smaller grid cells) close to the release point and decrease gradually away from the source (Figure 42).

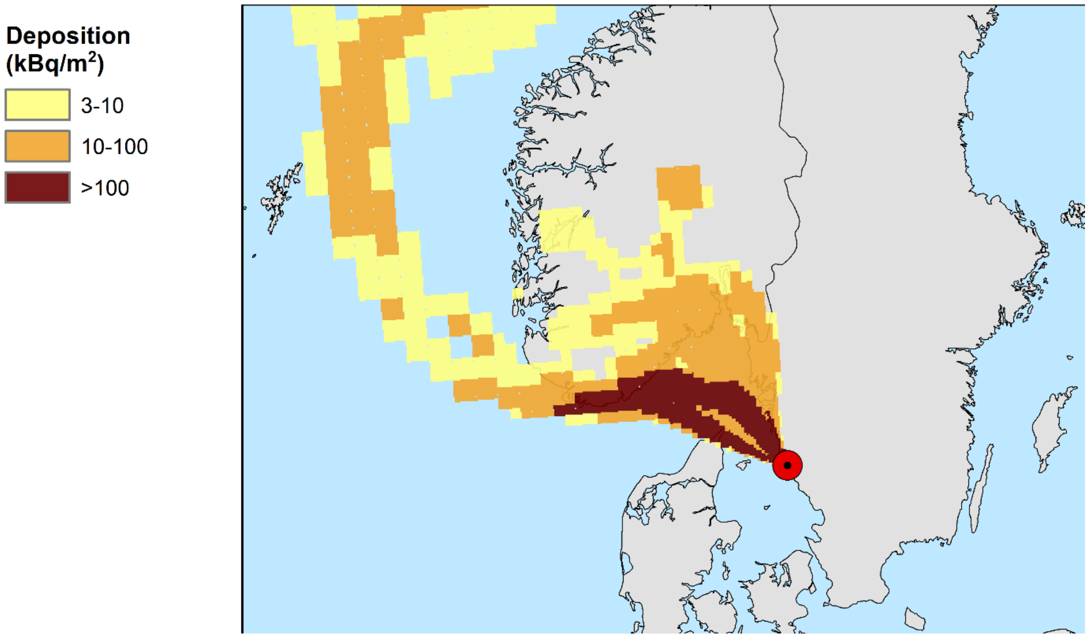

Figure 42. *RODOS version of RIMPUFF with Swedish HIRLAM-model.*

Comparison of levels

Figure 43 shows how all modelling results from Ringhals agree to which areas are contaminated with levels of 10 kBq/m^2 or more. For this case models agree quiet well to which areas receives this level. Figure 44 and Figure 45 shows the agreement between long-range and RIMPUFF results. Especially the long-range models agree well, while results from RIMPUFF to some less degree. Vattenfalls calculations deposits more ^{137}Cs further away from the source compared to the others. This creates the tail over the North Sea.

Figure 46, 47 and 48 show the same comparisons for areas exceeding 100 kBq/m^2. At this level the models more or less deposit ^{137}Cs in the same area.

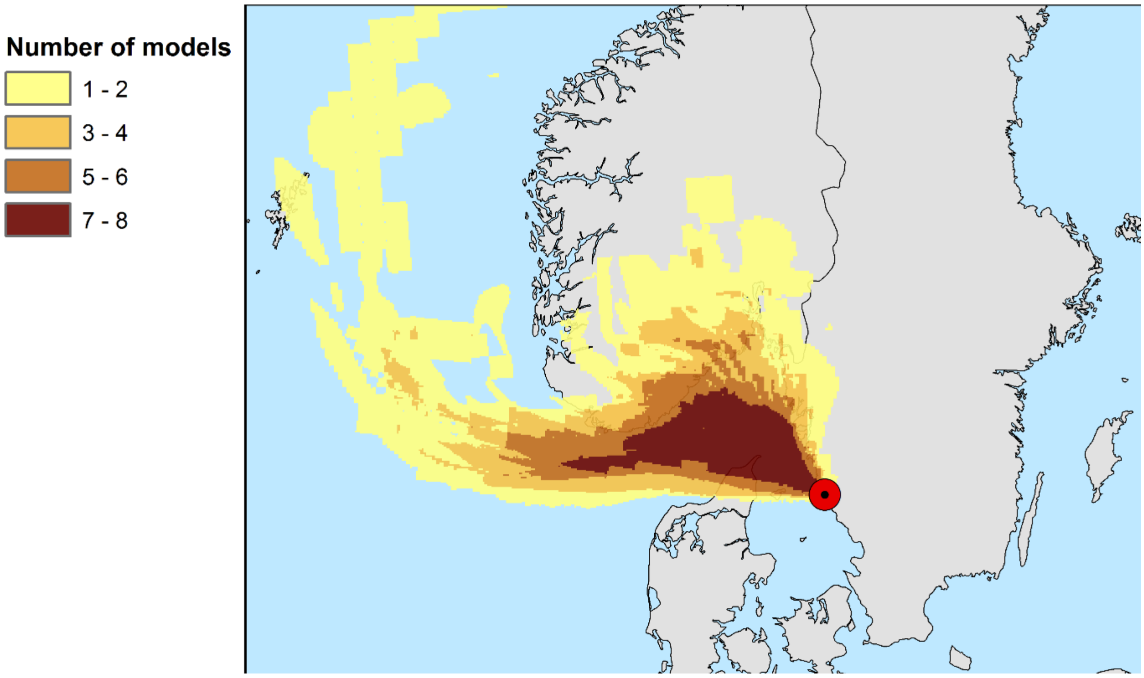

Figure 43. *A comparison of how all results agree to which areas are contaminated with 10 kBq/m^2 or more.*

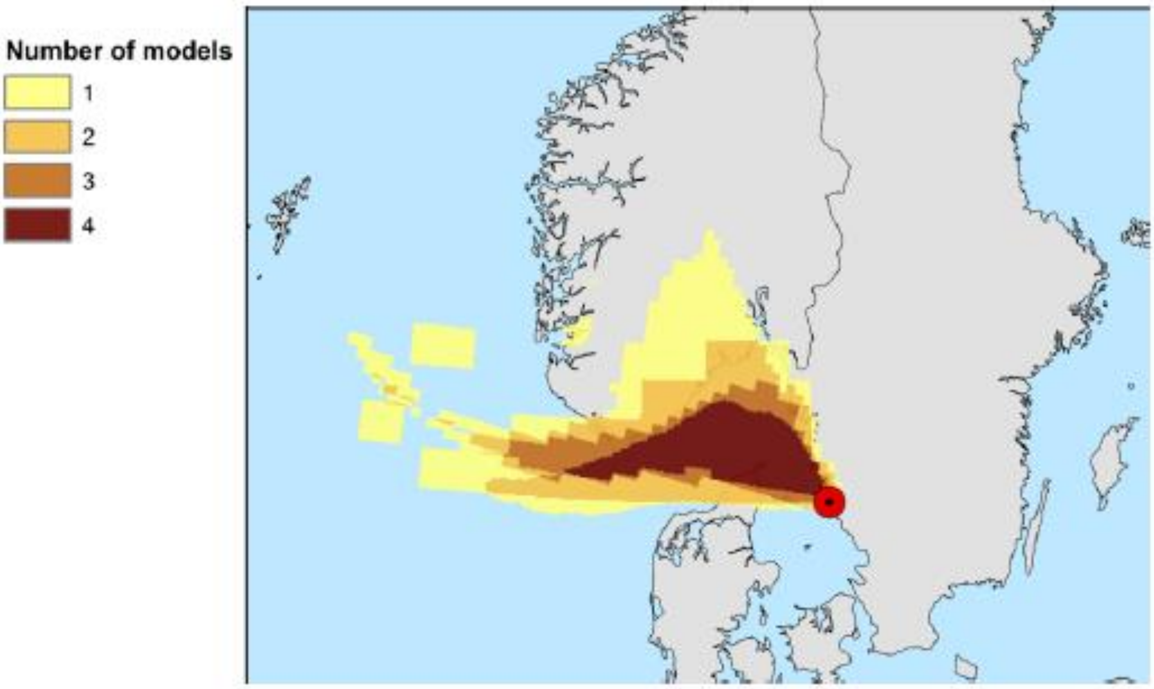

Figure 44. *A comparison of how results from long-range models agree to which areas are contaminated with 10 kBq/m² or more.*

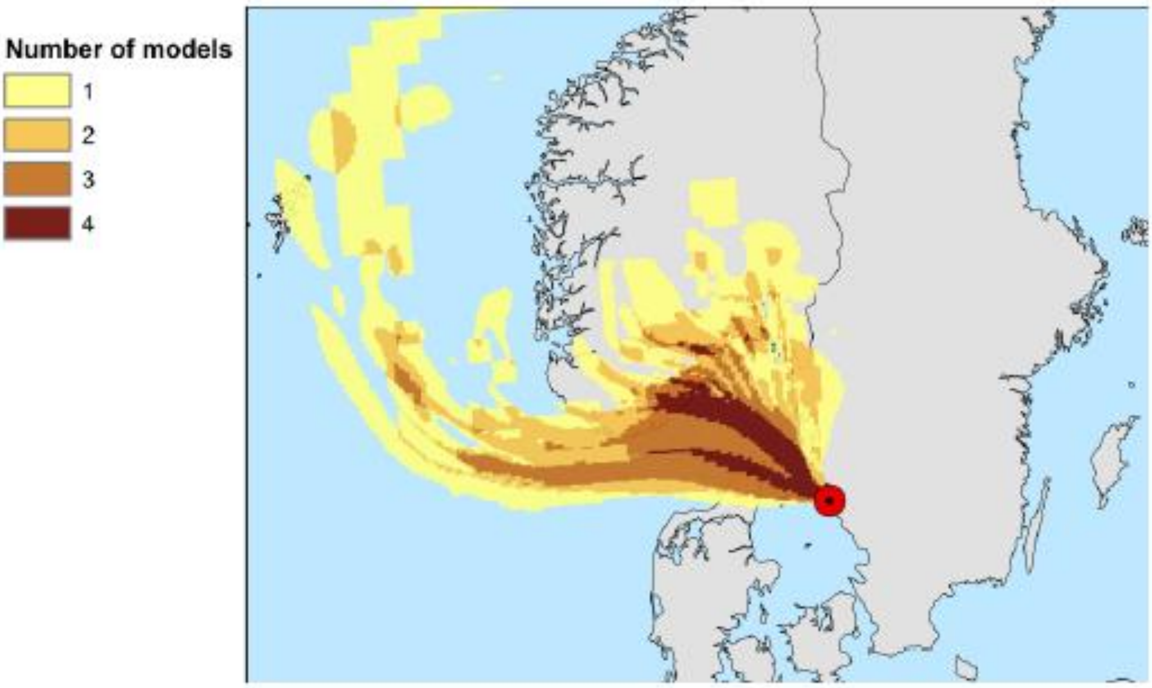

Figure 45. *A comparison of how results from RIMPUFF agree to which areas are contaminated with 10 kBq/m² or more.*

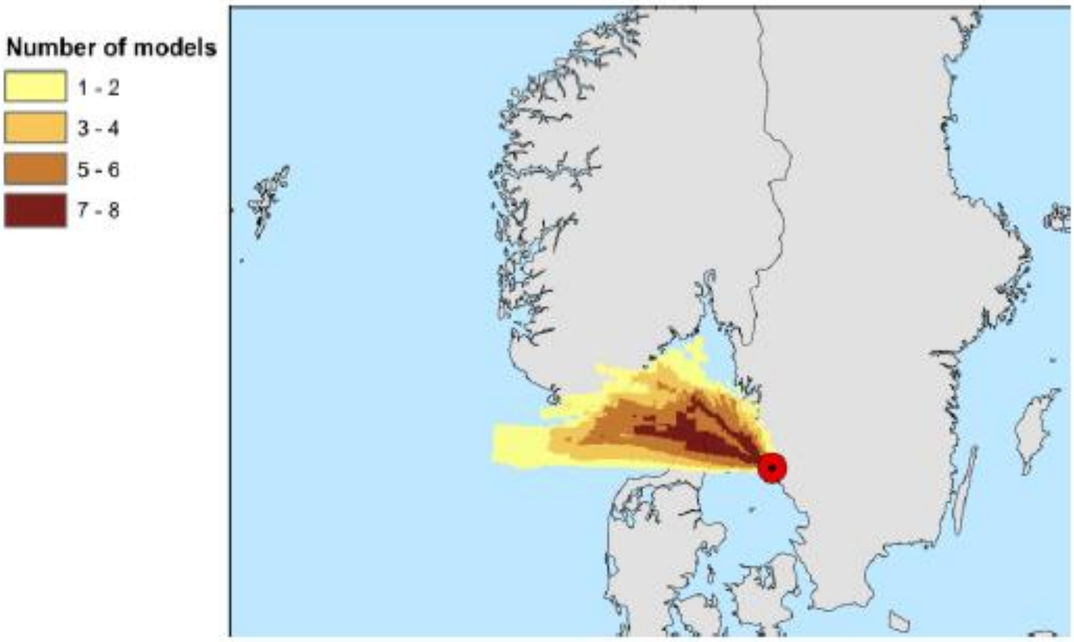

Figure 46. *A comparison of how all results agree to which areas are contaminated with 100 kBq/m^2 or more.*

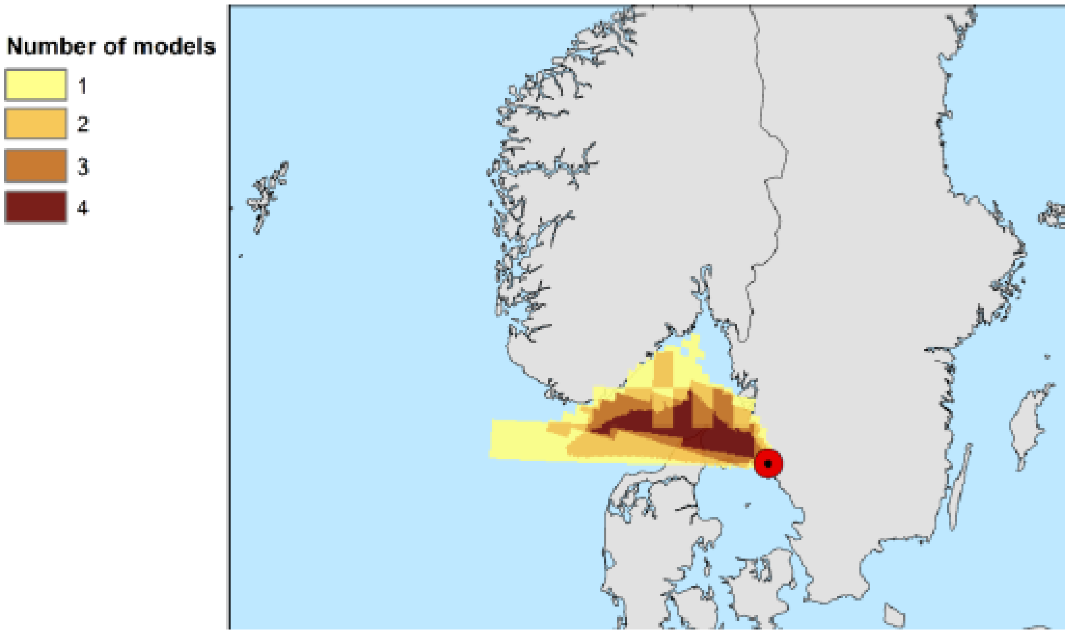

Figure 47. *A comparison of how results from long-range models agree to which areas are contaminated with 100 kBq/m^2 or more.*

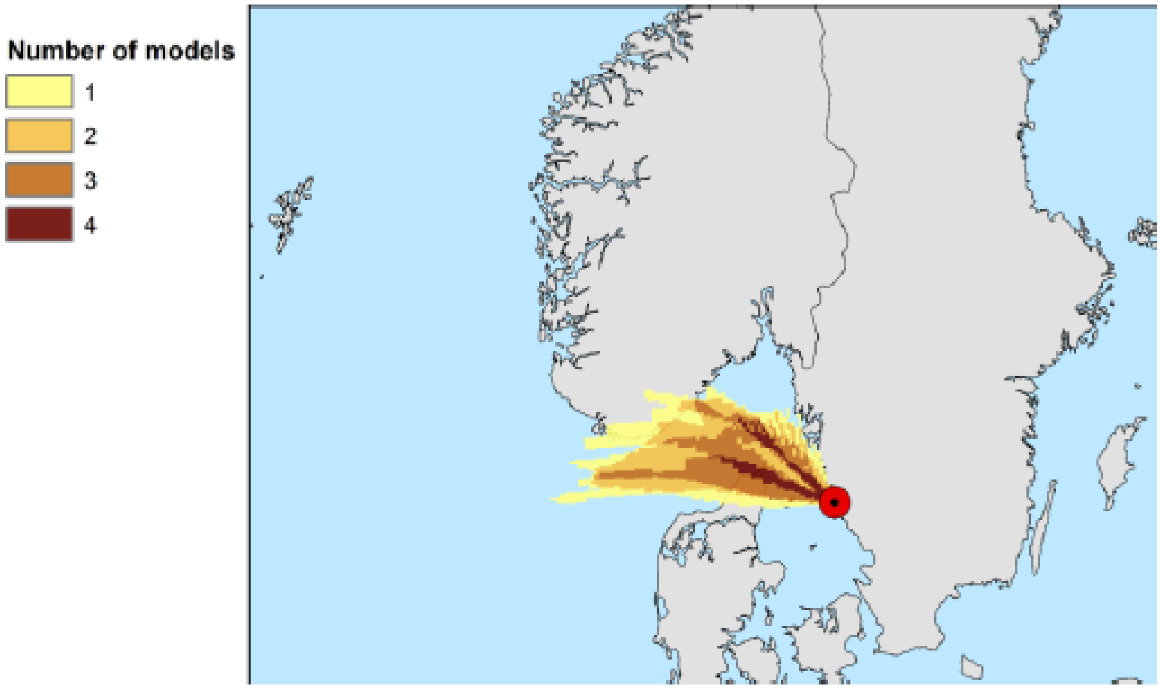

Figure 48. *A comparison of how results from RIMPUFF agree to which areas are contaminated with 100 kBq/m^2 or more.*

With respect to the results for deposition, thyroid dose and total effective dose from the dispersion modelling which were performed with the source terms defined in chapter 2.0. These results are based on the calculations done by the descision support system and the dispersion model. For deposition, the results are taken from the final time step. Areas with contamination over 100 kBq/m^2 and 1000 kBq/m^2 are shown. This corresponds to areas that are considered as contaminated according to Nordic Guidlines. Thyroid dose was as calculated by the decision support system. It only considers dose from inhalation and not disgestion. Levels above 10 mGy and 50 mGy are displayed. Nordic Guidelines recommend iodine prophylaxis for children when doses are estimated to be 10 mGy, and 50 mGy for adults. Total effective dose is integrated over two days. Levels above 1 mSv and 10 mSv are displayed. This corresponds to when Nordic Guidlines recommend partial sheltering indoor (1-10 mSv) and full sheltering indoor (> 10 mSv).

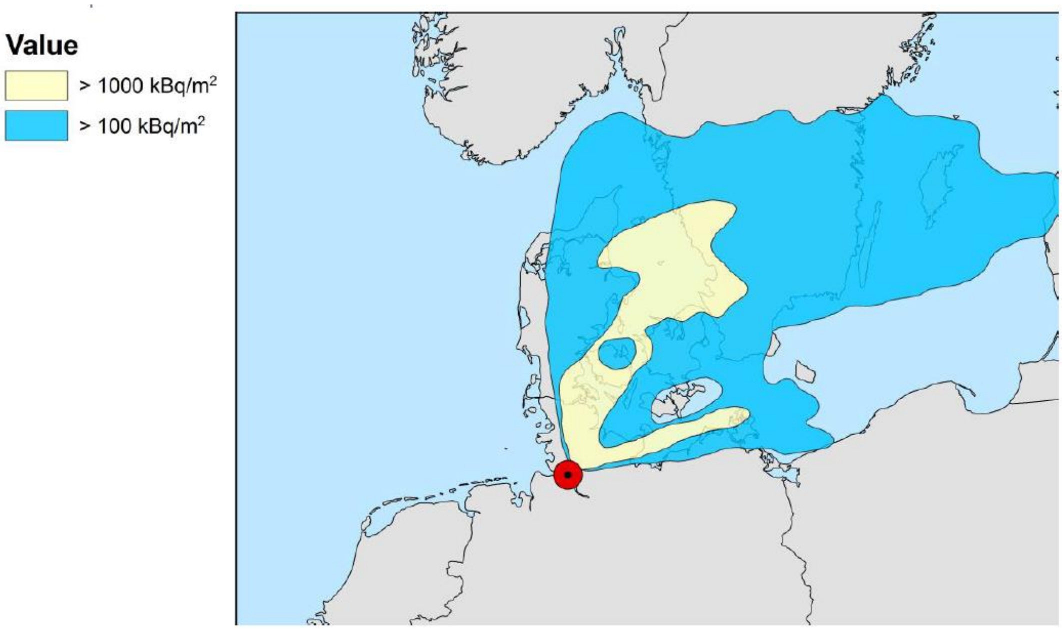

Figure 49. *NRPAs calculation of ^{131}I deposition following a release from Brokdorf.*

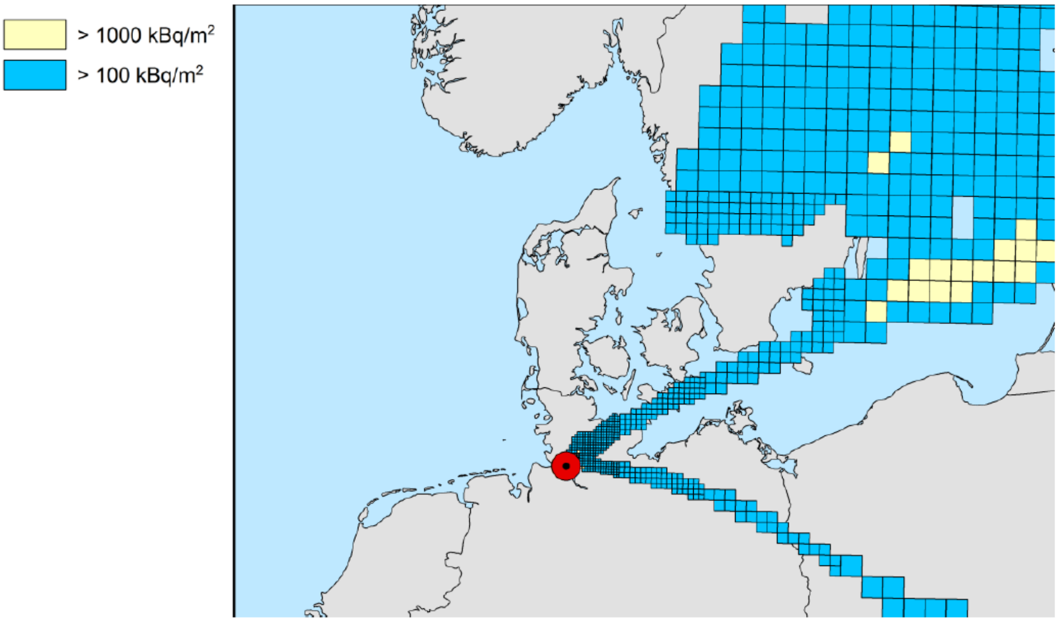

Figure 50. *Vattenfalls calculation of ^{131}I deposition following a release from Brokdorf.*

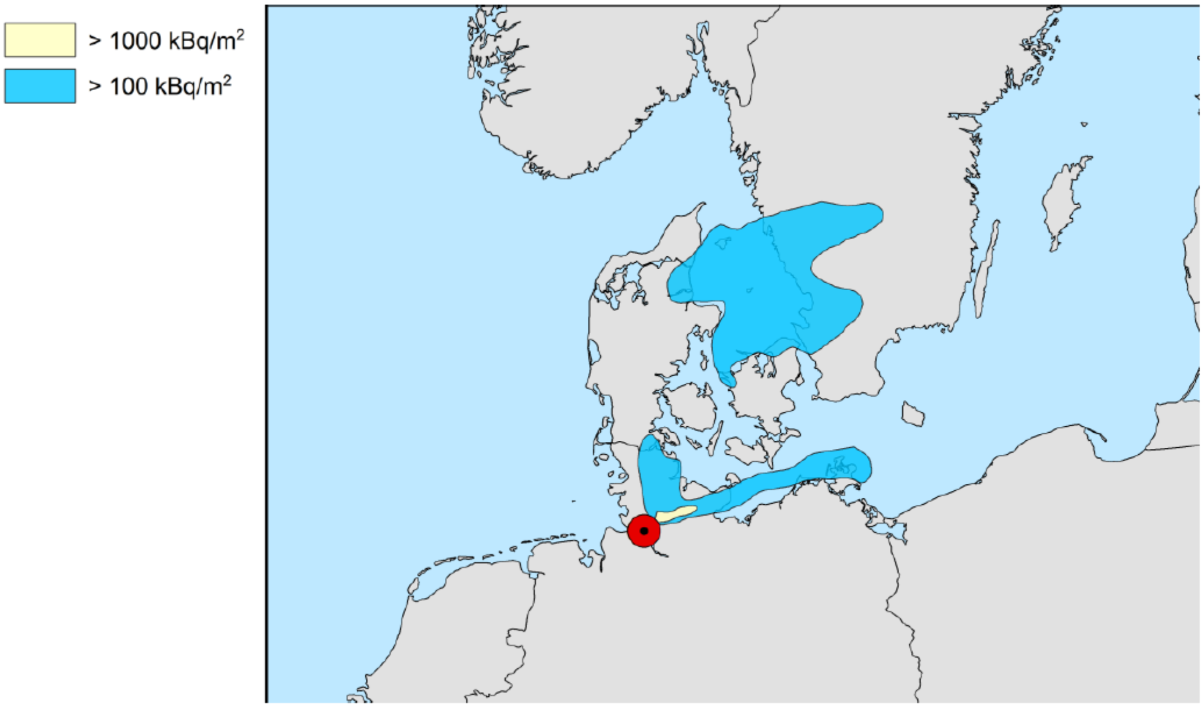

Figure 51. *NRPAs calculation of ^{137}Cs deposition following a release from Brokdorf.*

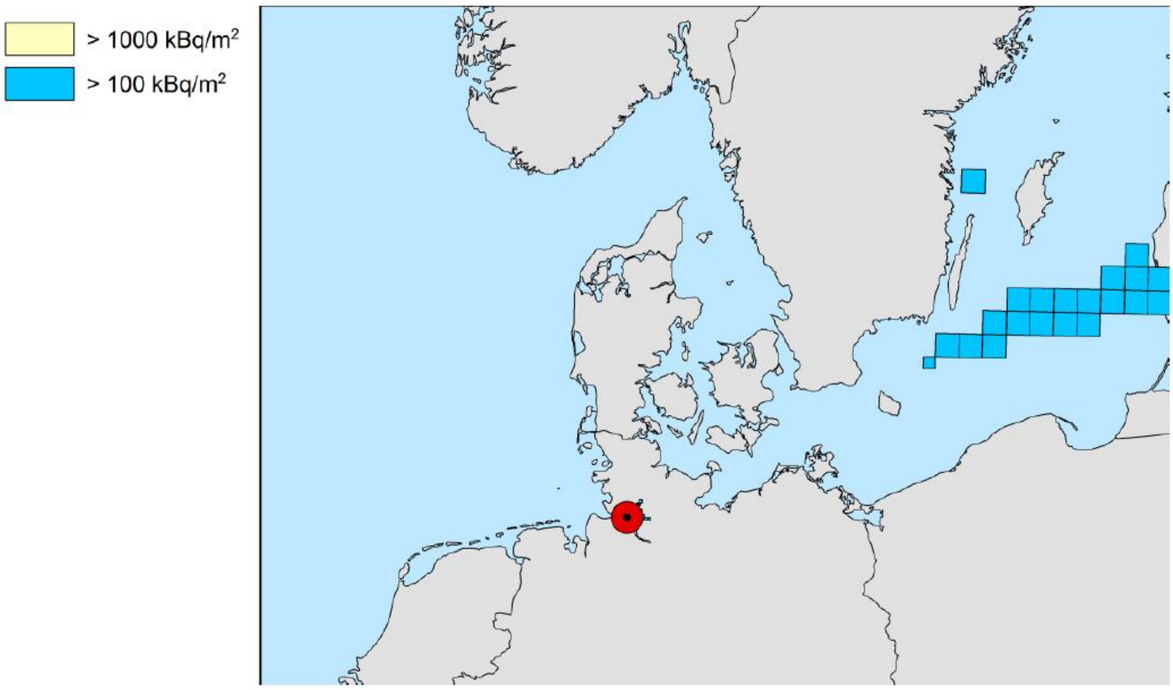

Figure 52. *Vattenfalls calculation of ^{137}Cs deposition following a release from Brokdorf.*

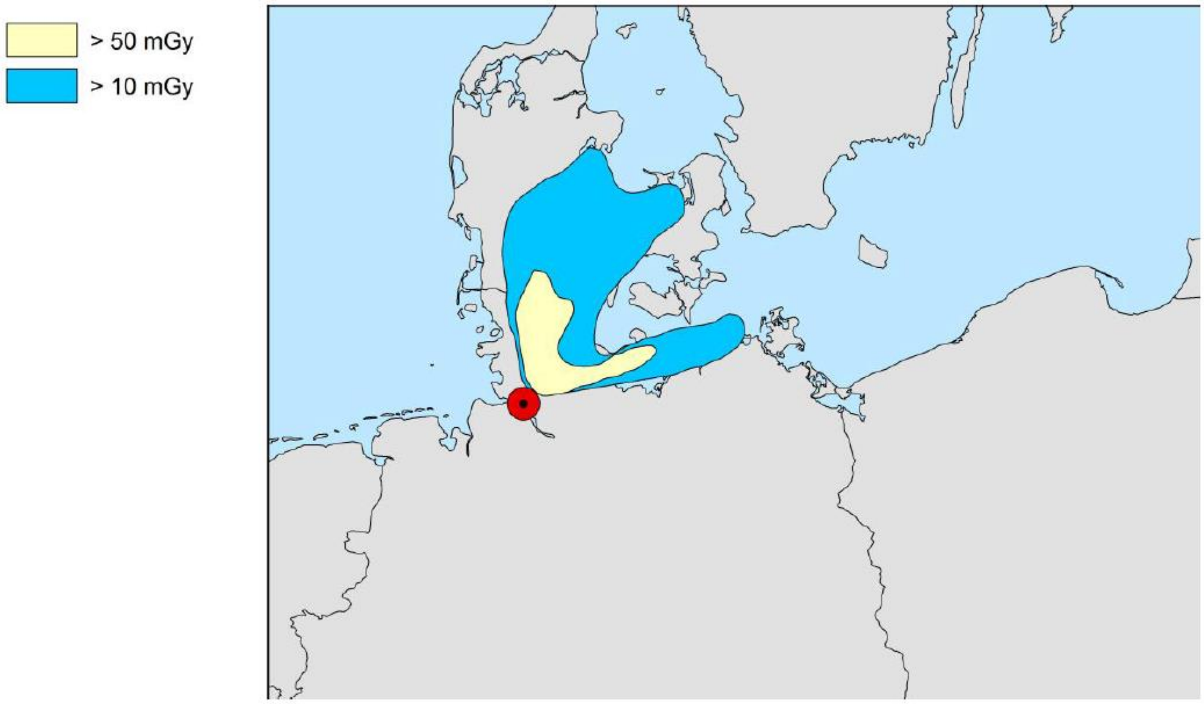

Figure 53. *NRPAs calculation of thyroid dose following a release from Brokdorf.*

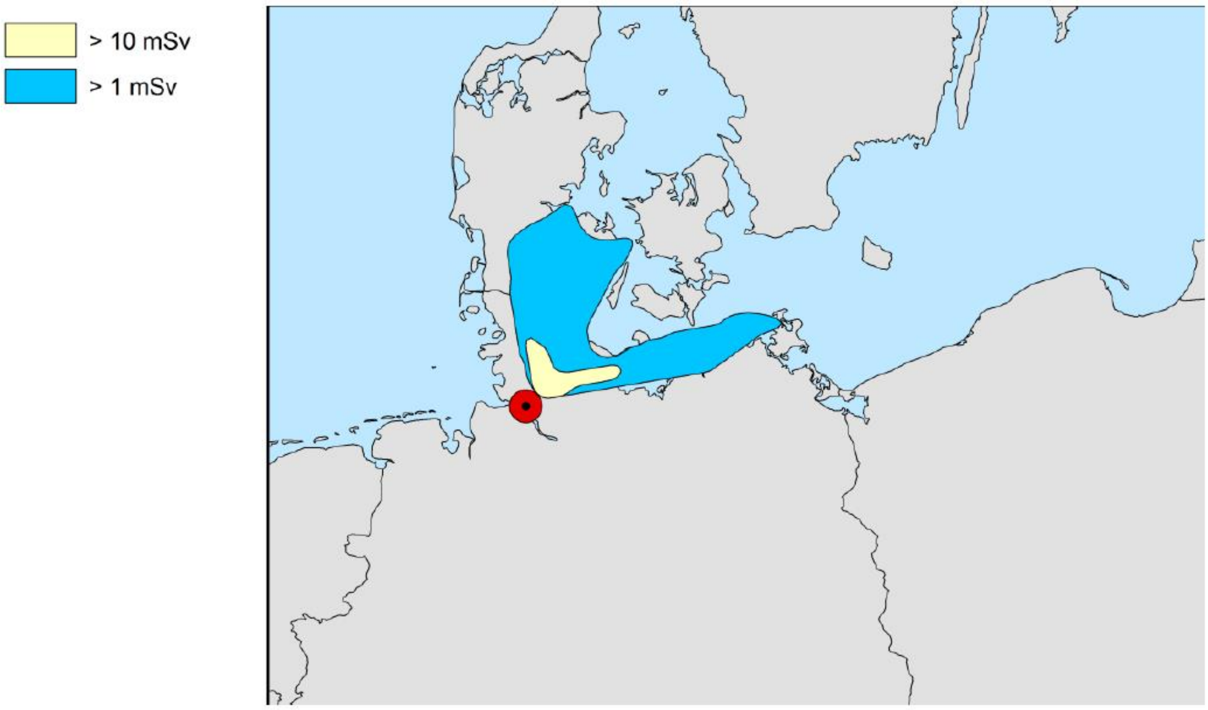

Figure 54. *NRPAs calculation of total effective dose following a release from Brokdorf.*

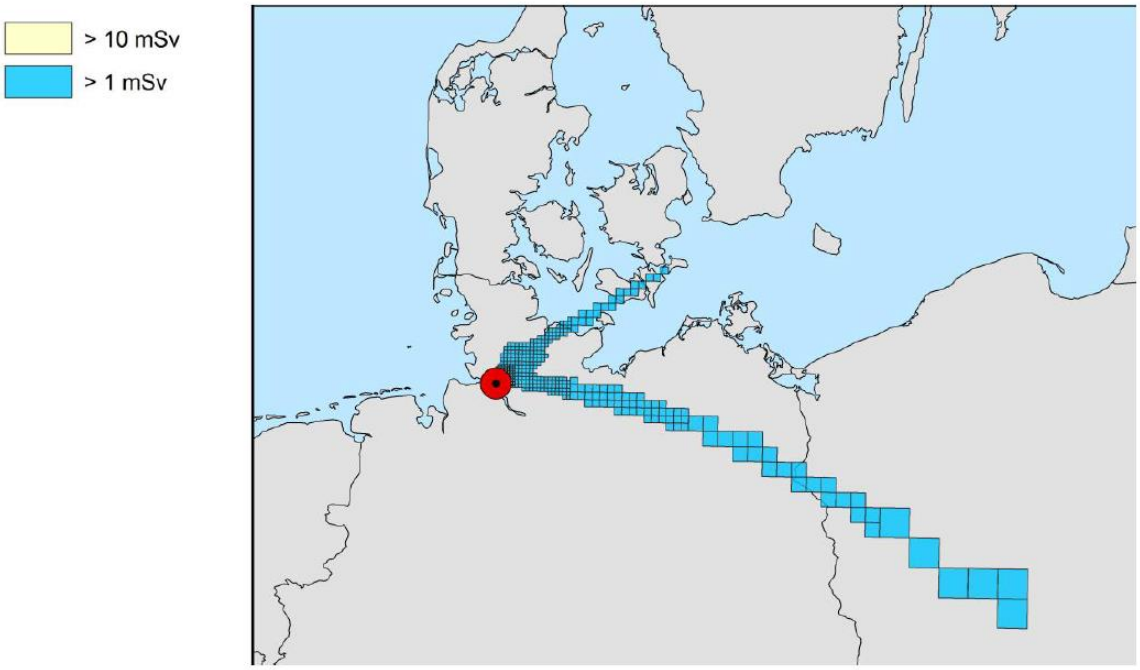

Figure 55. *Vattenfalls calculation of total effective dose following a release from Brokdorf.*

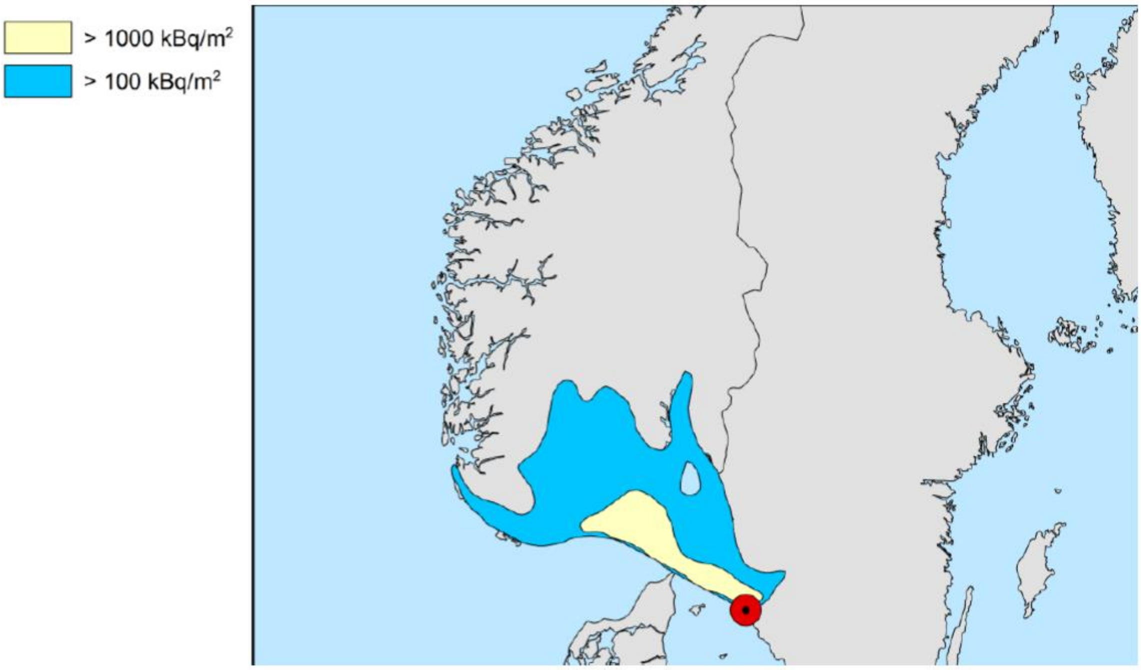

Figure 56. *NRPAs calculation of ^{131}I deposition following a release from Ringhals.*

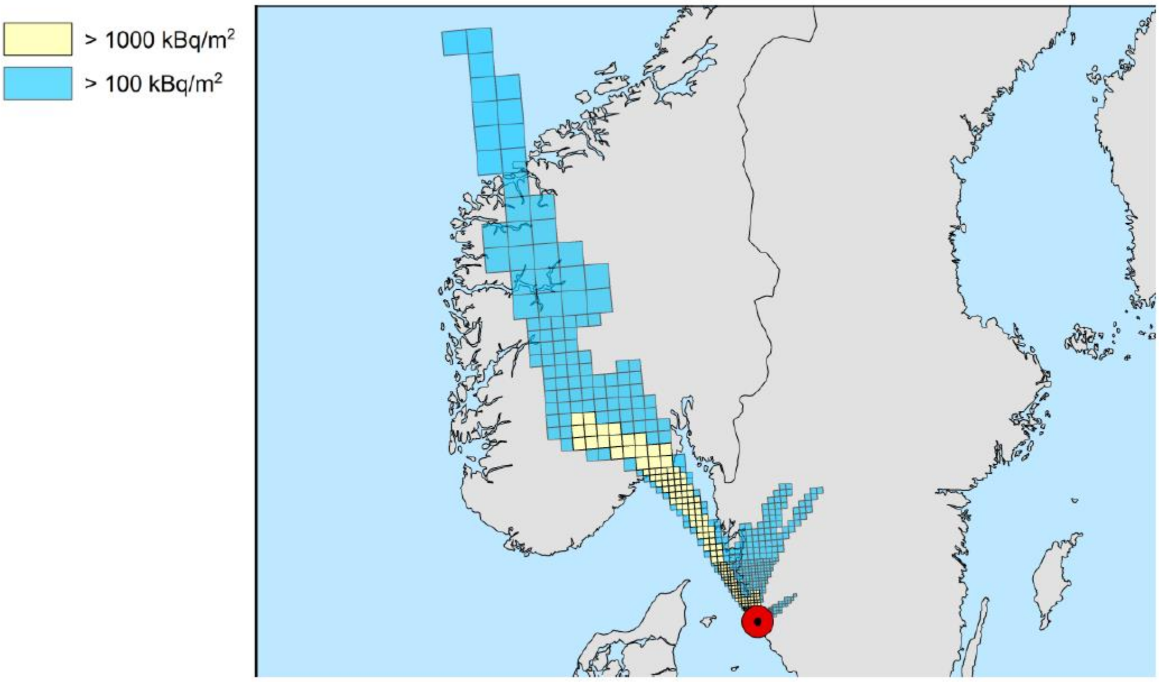

Figure 57. *Vattenfalls calculation of ^{131}I deposition following a release from Ringhals.*

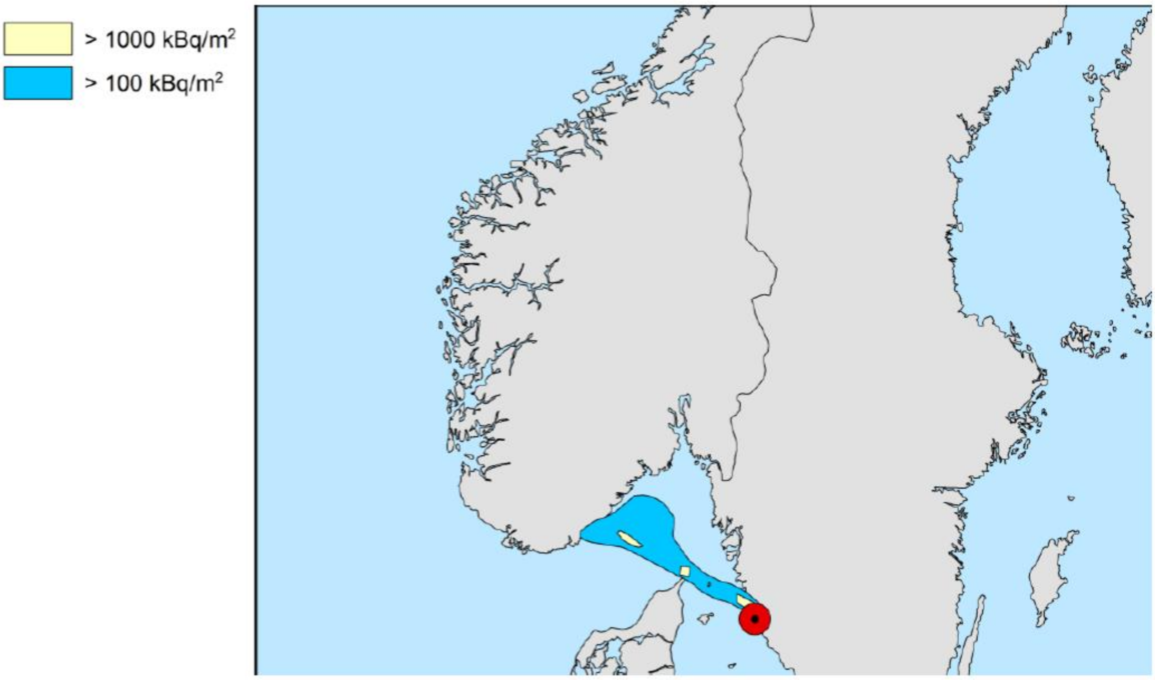

Figure 58. *NRPAs calculation of ^{137}Cs deposition following a release from Ringhals.*

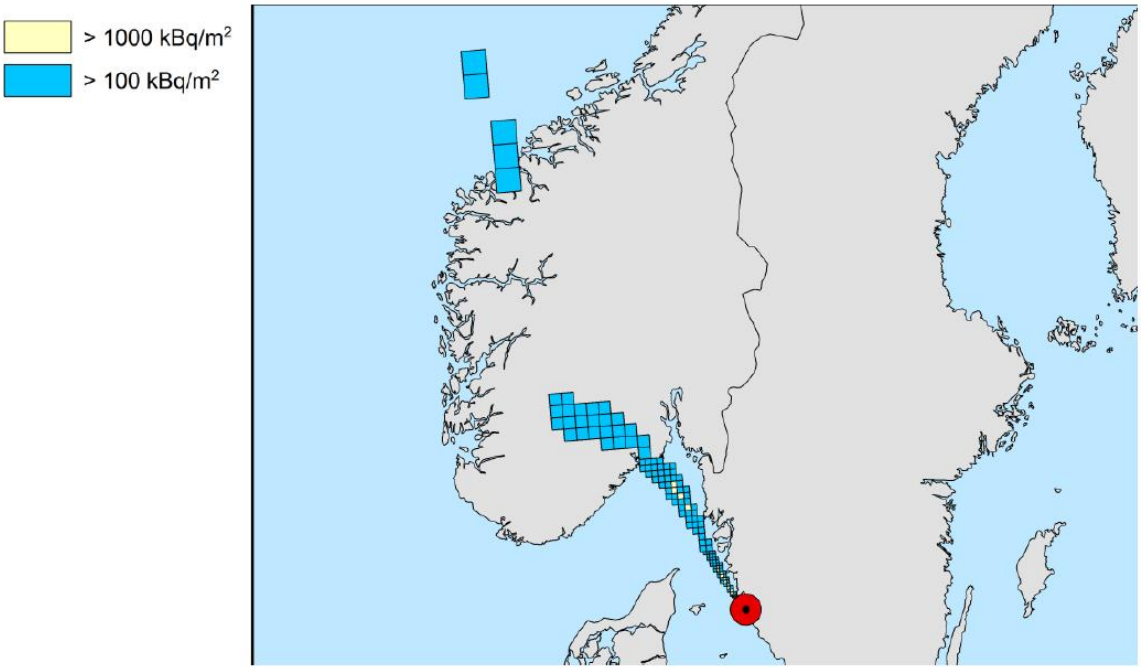

Figure 59. *Vattenfalls calculation of ^{137}Cs deposition following a release from Ringhals.*

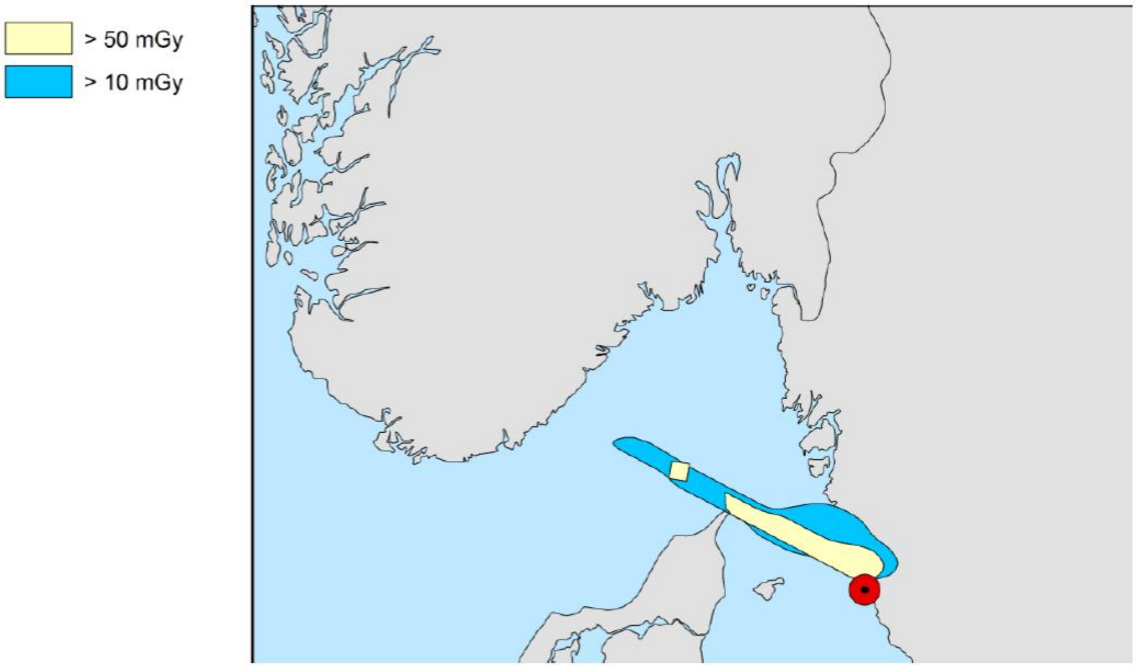

Figure 60. *NRPAs calculation of thyroid dose following a release from Ringhals.*

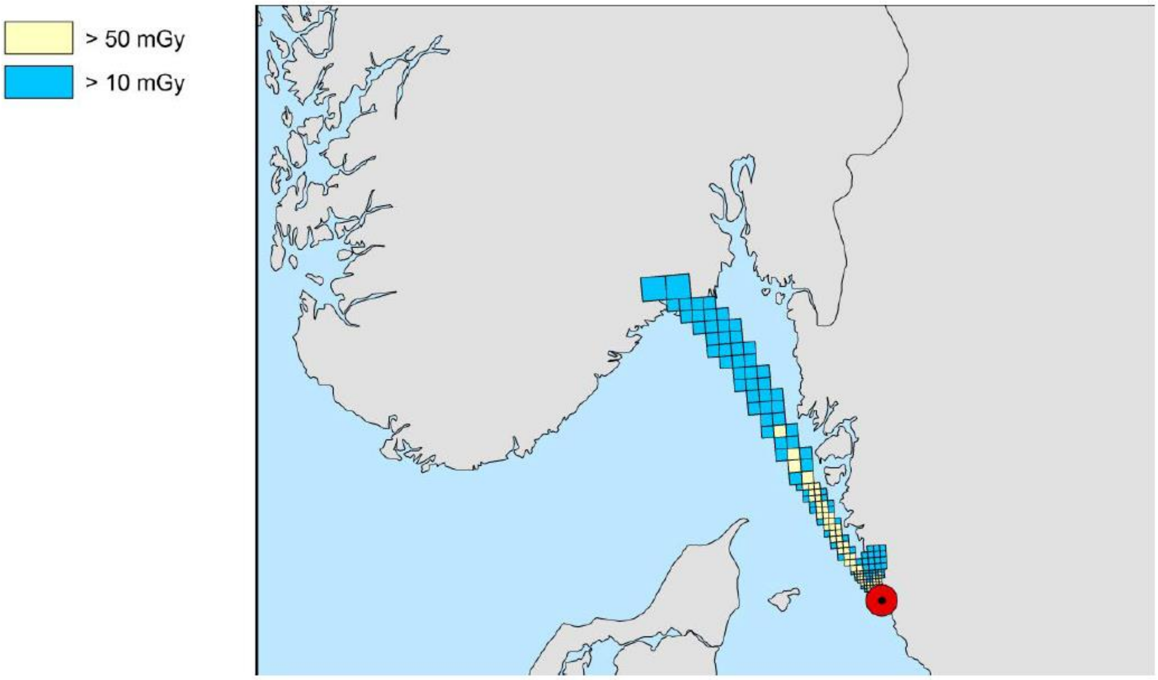

Figure 61. *Vattenfalls calculation of thyroid dose following a release from Ringhals.*

Figure 62. *NRPAs calculation of total effective dose following a release from Ringhals.*

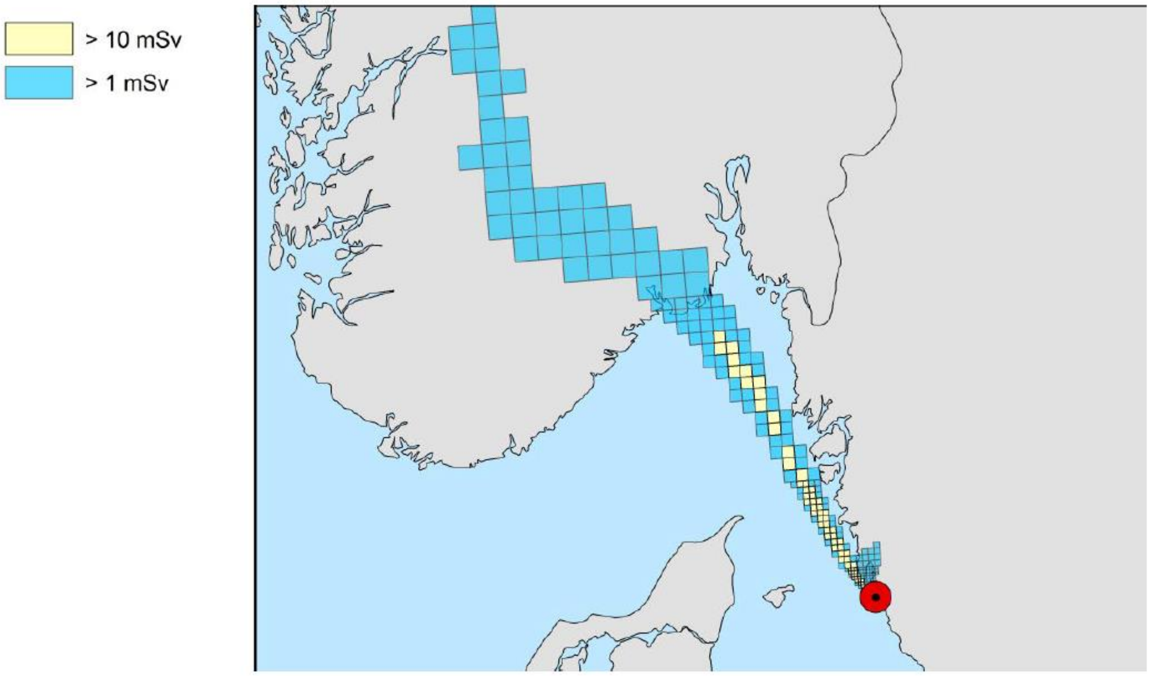

Figure 63. *Vattenfalls calculation of total effective dose following a release from Ringhals.*

5.2 Ecosystem Transfer

The results from the model runs performed by the NRPA using the model described previously and implemented in ECOLEGO are provided below (Tables 16, 17, 18).

	May ^{134}**Cs (1000 Bq/m^2)**				**October** ^{134}**Cs (1000 Bq/m^2)**			
Bq/kg Bq/l	7 days	90 days	1 year	2 year	7 days	90 days[a]	1 year	2 year
Beef	4.43E+01	3.13E+01	2.50E-02	1.81E-02	2.82E+01	*4.81E+01*	2.53E-02	1.81E-02
Milk	2.21E+01	1.55E+01	1.21E-02	8.66E-03	1.41E+01	*2.40E+01*	1.21E-02	8.66E-03
Grass	1.58E+02	3.50E-01	5.50E-01	3.90E-01	2.00E+02	*2.96E+00*	5.50E-01	3.90E-01
Blueberry	*7.50E+02*[a]	1.17E+01	2.53E+01	1.80E+01	7.50E+02	*1.17E+01*	2.53E+01	1.80E+01
Leafy veg.	*9.38E+02*[a]	1.73E+00	7.90E-02	5.70E-02	2.02E+02	*2.98E+00*	7.90E-02	5.70E-02
Root veg.	*4.69E+01*[a]	9.00E-02	9.70E-02	6.90E-02	1.10E+01	*1.49E-01*	9.70E-02	6.90E-02
Mushroom	*3.00E+02*[a]	3.00E+02	2.15E+02	1.54E+02	3.00E+02	*3.00E+02*	2.15E+02	1.54E+02

[a] Values in italics are considered invalid as they occur at a time when of the specified food products would not be available under the given scenario conditions.

Table 16. *NRPA model prognosis of ^{134}Cs activity concentrations in foodproducts and pasture with time for a 1 kBq/m^2 initial deposition.*

	May ^{137}**Cs (1000 Bq/m^2)**				**October** ^{137}**Cs (1000 Bq/m^2)**			
Bq/kg Bq/l	7 days	90 days	1 year	2 year	7 days	90 days[a]	1 year	2 year
Beef	4.45E+01	3.38E+01	3.46E-02	3.38E-02	2.84E+01	*5.19E+01*	3.46E-02	3.38E-02
Milk	2.22E+01	1.69E+01	1.65E-02	1.62E-02	1.42E+01	*2.59E+01*	1.65E-02	1.62E-02
Grass	1.59E+02	3.70E-01	7.50E-01	7.30E-01	2.01E+02	*3.18E+00*	7.50E-01	7.30E-01
Blueberry	*7.55E+02*[a]	1.20E+01	3.46E+01	3.38E+01	7.55E+02	*1.20E+01*	3.46E+01	3.38E+01
Leafy veg.	*9.44E+02*[a]	1.87E+00	1.10E-01	1.10E-01	2.04E+02	*3.22E+00*	1.10E-01	1.10E-01
Root veg.	*4.72E+01*[a]	9.00E-02	1.30E-01	1.30E-01	1.02E+01	*1.60E-01*	1.30E-01	1.30E-01
Mushroom	*3.00E+02*[a]	3.00E+02	2.93E+02	2.87E+02	3.00E+02	*3.00E+02*	2.93E+02	2.87E+02

[a] Values in italics are considered invalid as they occur at a time when of the specified food products would not be available under the given scenario conditions.

Table 17. *NRPA model prognosis of ^{137}Cs activity concentrations in foodproducts and pasture with time for a 1 kBq/m^2 initial deposition.*

	May ^{90}Sr (1000 Bq/m^2)				October ^{90}Sr (1000 Bq/m^2)			
Bq/kg Bq/l	7 days	90 days	1 year	2 year	7 days	90 days[a]	1 year	2 year
Beef	9.20E-01	1.37E+00	1.80E-02	1.75E-02	5.60E-01	1.80E+00	1.80E-02	1.75E-02
Milk	9.20E-01	1.37E+00	1.80E-02	1.75E-02	5.60E-01	1.80E+00	1.80E-02	1.75E-02
Grass	2.54E+02	5.90E-01	3.90E+00	3.81E+00	3.09E+02	4.88E+00	3.90E+00	3.81E+00
Blueberry	1.16E+03[a]	1.83E+01	7.21E+00	7.04E+00	1.16E+03	1.83E+01	7.21E+00	7.04E+00
Leafy veg.	9.44E+02[a]	1.87E+00	1.40E+00	1.30E+00	2.04E+02	3.22E+00	1.40E+00	1.30E+00
Root veg.	4.72E+00[a]	9.37E-03	2.30E+00	2.20E+00	1.02E+00	1.60E-02	2.30E+00	2.20E+00
Mushroom	6.00E+00[a]	6.00E+00	5.86E+00	5.72E+00	6.00E+00	6.00E+00	5.86E+00	5.72E+00

[a] Values in italics are considered invalid as they occur at a time when of the specified food products would not be available under the given scenario conditions.

Table 18. *NRPA model prognosis of ^{90}Sr activity concentrations in foodproducts and pasture with time for a 1 kBq/m^2 initial deposition.*

Maximum activity concentrations of all radionuclides are observed in edible and non edible vegetation during the initial period (i.e. at 7 days) but have a tendency to decline rapidly reflecting high weathering rates from vegetation. The maximum activity concentration of radionuclides with levels in the order of 1 kBq/kg f.w. for ^{134}Cs, ^{137}Cs and ^{90}Sr were observed in Blueberry shrubs and leafy vegetables at 7 days for the May deposition scenario but this would not have corresponded to a time when the food product would be available for human consumption; both of these food prdocuts would be harvested later in the year. The case for the October scenario is somewhat different in the sense that the initial deposition could coincide with a time when some of these types of foods are still be collected or produced. For example, cranberries (*Vaccinium vitis-idaea*) are still often available at this late point in the season.

A better resolved picture of the time dynamics of radionuclides in beef are provide in Figures 64 and 65.

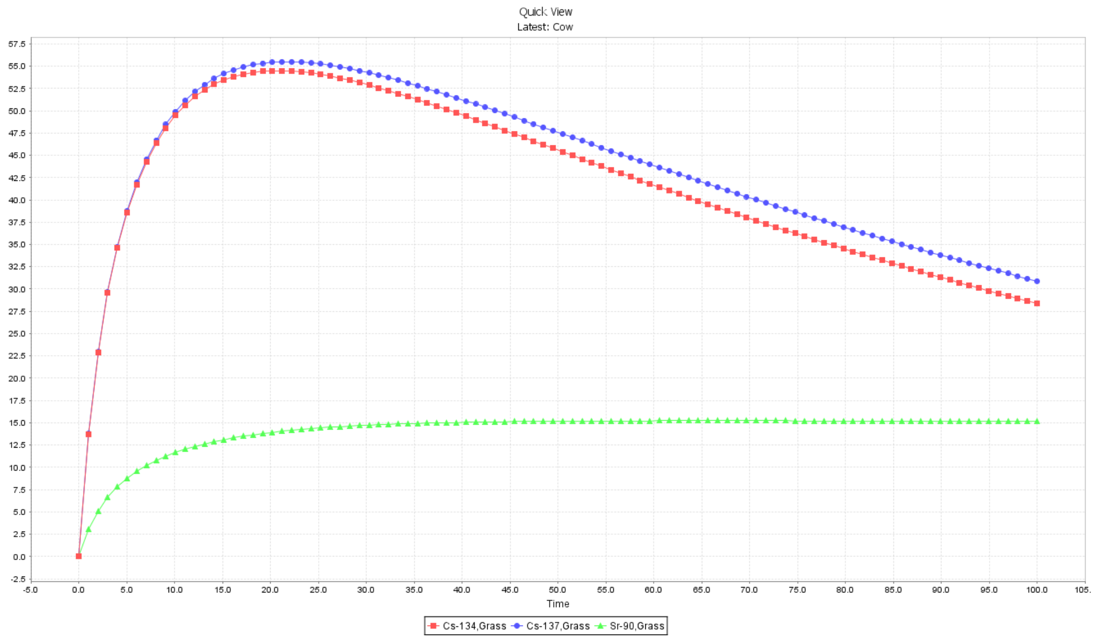

Figure 64. *Activity concentrations of* ^{134}Cs*,* ^{137}Cs *and* ^{90}Sr *in beef, May scenario*.

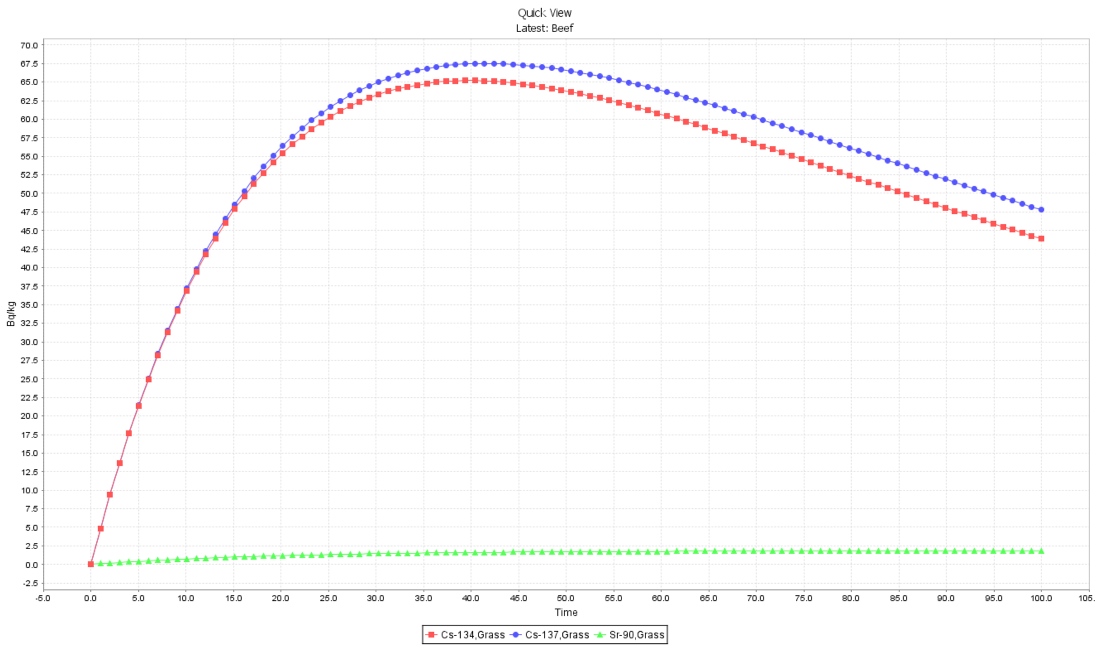

Figure 65. *Activity concentrations of* ^{134}Cs*,* ^{137}Cs *and* ^{90}Sr *in beef, October scenario*.

The simulations show that the peak in activity concentrations of ^{137}Cs (and other radionuclides not shown) in beef cattle occurs with a delay of several weeks following the initial deposition event. This assumes that cattle are left to graze on contaminated pasture following an accident (in reality this would be highly unlikely) but demonstrates that considerable time would be required for cattle to accumulate radionuclides in their body even were they to continue feeding on contaminated forage. Maximum levels of ^{137}Cs in beef attain levels in the range 50 – 70 Bq/kg f.w. with slightly higher levels observed in the October deposition scenario. This may reflect the consideration that the initial interception of ^{137}Cs by grass is greater at the end of the growing season compared to a period at the start of the growing season and that effect of "biomass dilution" in grass is removed for the October scenario.

Tables 19 and 20 indicate results generated by Vattenfall.

	October **^{137}Cs (100000 Bq/m^2)**			
Bq/kg Bq/l	7 days	90 days	1 year	2 year
Beef	19.6	4.05	0.63	0.37
Milk	2063.06	97.26	6.51	1.98
Grass	19537	3010	17.8	13.1
Berries	0	0	1.67	1.26
Leafy veg.	6804	878	3.1	2.3
Root veg.	234.8	245.7	3.11	2.35

Table 19. *Selection of transfer results from Vattenfall for ^{137}Cs for the 100000 Bq/m^2 ^{137}Cs band for the Ringhals scenario.*

		October		
Bq/kg	7 days	90 days	1 year	2 year
Beef	30.3	5.9	0.52	0.21
Milk	3186	141.7	5.4	1.19
Grass	30178	4386	14.8	7.9
Berries	0	0	1.39	0.76
Leafy veg.	10510	1282	2.58	1.42
Root veg.	362.7	357.9	2.58	1.42

Table 20. *Selection of transfer results from Vattenfall for ^{1347}Cs for the 100000 Bq/m^2 ^{137}Cs band for the Ringhals scenario.*

A preliminary analysis to identify and explain the similarities and differences between the 2 sets of model prognosis (from NRPA and Vattenfall) has been conducted. The comparison is presented in Table 21.

		Vattenfall/NRPA		
Beef	7 days	90 days	1 yr	2 yrs
^{134}Cs	*0.008*	*0.0009*	0.16	*0.09*
^{137}Cs	*0.005*	*0.0006*	0.14	*0.08*
Berries				
^{134}Cs	*0.000*	*0.000*	*0.0004*	*0.0003*
^{137}Cs	*0.000*	*0.000*	*0.0004*	*0,0003*
Milk				
^{134}Cs	1.7	*0.04*	3.3	1.03
^{137}Cs	1.1	*0.03*	2.9	0.91
Leafy Veg.				
^{134}Cs	0.40	3.23	0.24	0.18
^{137}Cs	0.25	2.02	0.21	0.16
Root veg.				
^{134}Cs	0.24	*17.9*	0.2	0.15
^{137}Cs	0.17	*11.6*	0.18	0.14
Grass, int.				
^{134}Cs	1.1	11.0	0.2	0.15
^{137}Cs	0.74	7.0	0.18	0.13

Table 21. *A preliminary comparison of radiocaesium data from Vattenfall and NRPA model runs (expressed as a ratio between corresponding results). The prognoses are for the October scenario and have been normalised to the same deposition level (in Bq/m^2) . All cases where the results differ by more than one order of magnitude are highlighted in italics.*

Generally speaking the correspondence between the modelling results is reasonable. Prognoses for milk, for example, with the exception of data from 90 days, fall within a factor of 3 of one another.Some of the differences are straightforward to explain. For berries, no values were provided by Vattenfall for the period 7 days and 90 days presumably reflecting the reasonable assumption that, since the deposition event did not occur until October, the main harvesting period for berries would have passed. Of more concern is the very large discrepancy (the greatest of all differences in fact for the inter-comparison) between the values for berries at 1 year and 2 years because both model prognoses are based on the same approach at these times employing the use of Concentration concentration ratios. On further inspection it becomes clear that the transfer data for the Vattenfall predictions have a provenance in IAEA (2010) which provide a relatively low value based on 6 data points whereas the NRPA prediction have been based on IAEA (2014) with a much greater transfer value but where n = 354. Nonetheless, the apparent improvement in using an updated value underpinned by more data is a moot point because the data from IAEA (2010) are specific to berry shrubs whereas IAEA (2014) reports data for shrubs generally. As discussed in the methodology section for the NRPA model, the assumption that using generic transfer data for group-specific transfer data is a valid approach has not been substantiated. The huge difference in model output for this case also clearly demonstrates that model complexity has little relation to the magnitude of the discrepancy. Even when applying the simplest approach imaginable (i.e. basing prognoses on concentration ratios) large difference can appear because different datasets and assumptions have been applied.

The reason for discrepancies in relation to beef cattle have been more difficult to resolve, more so in view of the similarity in prognoses for milk. For the initial period (7 and 90 days) activity concentration levels predicted in cattle feed, i.e. grass, by the 2 models are not greatly dissimilar. It is intriguing therefore that the output from the modelling performed by Vatenfall are so very much lower than corresponding values provided by the NRPA. The Vatenfall values are notably also 2 orders of magnitude lower than corresponding values for milk provide by Vattenfall which is incompatible with the information that transfer coefficients applied in the model tend to be higher for beef than for milk (cf. TF for Beef = 0.022 d kg-1 with TF for Milk = 0.0046 d l-1). There may be some hidden explanation regarding the post accident management regime, i.e. what the beef cattle are assumed to be eating. At 2 years, the prognoses for beef from Vattenfall and the NRPA might be expected to be congruent because both approaches apply similar transfer factors sourced in the same publication.

However, they are not. A small subtlety exists in that, whereas the model used by Vatenfall used transfer coefficients, the approach used by the NRPA uses feed to animal concentration ratios which are considered to reduce some of the variability introduced by the animals size and how much it is eating when deriving transfer coefficients. Nonetheless, this slight difference in approach could not account for the differences seen, and the main cause may be more attributable to differences in model outputs for transfer to grass and in relation to how much contaminated grass the animal is eating.

6.0 Conclusions

As mentioned in the start of this chapter, one of the aims of this exercise was to compare what the results of dispersion calculations made by national competent authorities would look like if they were in possession of the same release point, time and source term. What differs between them in this case is the combination of dispersion model and NWP-data used, and how the operators configured the dispersion models to reproduce the accident scenario. It is not a comparison of which model is the best. This is not possible since there is no true result against which to compare them. Second, this only represents cases done on the same day from two different NPPs. To give a general view of how the different models compare to each other, more cases should be identified and calculated with different meteorological conditions.

The two cases used in the project show different results. For the Ringhals case, the models agree quiet well on direction and levels of deposition. For the Brokdorf case there is a difference when comparing long-range results with RIMPUFF results. Post analysis of the weather situation showed a case of vertical wind shear in the atmosphere over Brokdorf. This is a difference in wind speed and direction over a relatively short distance in the atmosphere. A plume can go different directions if or not this effect is taken into account. NWP-models with many vertical levels are better at modelling under these conditions. In this case, the RIMPUFF-model seem to model this situation better.

From the results of the project, it would appear that the different countries are unlikely to generate information based on the use of dispersion models that would result in a significant deviation between countires with respect to actions initiated based on the information generated. The NORCON analyses indicate reasonably robust prognoses when viewed against one another and any major deviations observed were most likely caused by conditions that would be apparent to the operators. It should also be considered that such information is usually handled with a degree of conservatism and caution which should be sufficient to remove any subtle differences in outputs when being used to support decision making processes.

In relation to the means and systems employed in assessing transfer of deposited radioactivity between environmental compartments or along food-chains the situation is somewhat more complex and the opportunities for variance between countries greater than can said to be the situation for dispersion modelling. It was apparent within NORCON that the extent to which national authorities, or other entities with a role to play in response provision, consider or conduct assessments of how radioactivity may be transferred and over what compartments or time periods such transfer is estimated, vary to some extent. In relation to the potential for disparities in the responses of various authorities to similar levels of contamination or likely contamination, it is the considered opinion of the NORCON project that likely spurces of such disparities lie in the later stages of impact assessments rather than in the procedures or routines implemented during the early phase. Given the potential impacts on coherent regional level response in the aftermath of a significant nuclear accident in the Nordic region, a focus of further work should probably be in the direction of establishing a more complete understanding of late phase assessments and how they are conducted within the Nordic/Scandinavian countries.

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Abstract max. 2000 characters	The NORCON project involved a comparative partial consequence analysis conducted within the Nordic region for a release of radioactivity from a nuclear power reactor(s) located within the region or in a nearby region of potential significance for the purpose of identifying methodological or procedural disparities between the participating countries with respect to the generation of the information used to direct post-accident responses over the short to long term. The project ranged from source term evaluation, to detailed dispersion/transport modelling and long term consequence assessment. The aims of the project included assessment of the potential for disparities and fractures in the assessment of impacts from a nuclear accident due to the implementation of

systems for the estimation of dispersion of contamination and the behaviour of contaminants in the environment in years following an accident. The results of the project indicate that the main potential source of divergence in assessing the potential impacts of a nuclear accident between the countries of the Nordic region lies within the routines and procedures implemented during assessment of late phase impacts.

Key words Nuclear accident, consequence, impact assessment, dispersion, transfer

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