Nordic nuclear safety research

NKS-514
ISBN 978-87-7893-614-1

NKS-B REMSEM – Modelling and Monitoring of Fallout Impacts After a Nuclear Explosion: Enhancing Nordic Preparedness

Henrik Öberg[1], Eyjólfur Guðmundsson[1], Pernille Ahlmann Jensen[1]
Anders Axelsson[2], Anna Maria Blixt Buhr[2], Lars Ideström[2],
Catharina Söderström[2]
Justin Brown[3], Ali Hosseini[3]
Jenny Aasa[4], Daniel Edgar[4], Amelie Fondell[4]
Pia Keski-Jaskari [5], Päivi Roivainen[5], Mikko Voutilainen[5]
Fredrik Lidman[6], Annika Tovedal[6]
Elias Pagh Senstius[7], Joakim Hoff-Møller [7]
Ole Christian Lind[8]
Violeta Hansen[9], Mats Isaksson[9]

[1]Icelandic Radiation Safety Authority
[2]Swedish Radiation Safety Authority
[3]Norwegian Radiation and Nuclear Safety Authority
[4]Swedish Food Agency
[5]Finnish Radiation and Nuclear Safety Authority
[6]Swedish Defence Research Agency
[7]Danish Emergency Management Agency
[8]Norwegian University of Life Sciences
[9]University of Gothenburg

September 2026

Abstract

The NKS REMSEM 2026 seminar was held in Reykjavík on 19–20 August 2026, bringing together Nordic experts to discuss modelling, environmental measurements and emergency preparedness in relation to nuclear detonation scenarios relevant to the Nordic region. The seminar followed the first REMSEM seminar in 2025, which identified scientific and practical challenges related to modelling radionuclide transfer following nuclear explosions.

The 2026 seminar focused on strengthening the connection between scenario development, modelling, measurements, situational awareness and decision-making. Presentations addressed modelling approaches and development needs, food-chain impacts and countermeasures, measurement integration and data use, and urgent protective actions.

Breakout discussions focused on four themes: modelling under high uncertainty; integration of measurements and modelling; prioritisation and countermeasures; and Nordic preparedness and cooperation. Common challenges included uncertainties in modelling and source terms, limited measurement and analytical capacity, knowledge gaps concerning radionuclide behaviour and transfer to food and aquatic systems, and differences in national preparedness arrangements.

Several priorities for continued Nordic cooperation were identified, including model comparison and benchmarking, strengthened measurement capabilities and protocols, improved guidance for food and feed, competence development, and broader involvement of relevant authorities and organisations.

The seminar confirmed the value of continued REMSEM activities within the NKS framework. While practical exercises remain important for Nordic and national emergency preparedness, REMSEM provides a suitable Nordic forum for expert exchange, scientific discussion and development of common approaches. The seminar outcomes are consolidated into a forward-looking roadmap for strengthening Nordic decision support and preparedness for nuclear detonation scenarios.

Key words

Nuclear detonation, radioecological modelling, environmental monitoring, emergency preparedness, Nordic cooperation

NKS-514
ISBN 978-87-7893-614-1
Electronic report, September 2026
NKS Secretariat
P.O. Box 49
DK - 4000 Roskilde, Denmark
Phone +45 4677 4041
www.nks.org
e-mail nks@nks.org

NKS-B REMSEM – Modelling and Monitoring of Fallout Impacts After a Nuclear Explosion: Enhancing Nordic Preparedness

Final Report from the NKS-B REMSEM (Contract: AFT/B(26)6)

Henrik Öberg[1], Eyjólfur Guðmundsson[1], Pernille Ahlmann Jensen[1]
Anders Axelsson[2], Anna Maria Blixt Buhr[2], Lars Ideström[2], Catharina Söderström[2]
Justin Brown[3], Ali Hosseini[3]
Jenny Aasa[4], Daniel Edgar[4], Amelie Fondell[4]
Pia Keski-Jaskari [5], Päivi Roivainen[5], Mikko Voutilainen[5]
Fredrik Lidman[6], Annika Tovedal[6]
Elias Pagh Senstius[7], Joakim Hoff-Møller [7]
Ole Christian Lind[8]
Violeta Hansen[9], Mats Isaksson[9]

[1]Icelandic Radiation Safety Authority
[2]Swedish Radiation Safety Authority
[3]Norwegian Radiation and Nuclear Safety Authority
[4]Swedish Food Agency
[5]Finnish Radiation and Nuclear Safety Authority
[6]Swedish Defence Research Agency
[7]Danish Emergency Management Agency
[8]Norwegian University of Life Sciences
[9]University of Gothenburg

Table of contents

1. Introduction

The NKS REMSEM seminar 2026 was held in Reykjavík, Iceland, on 19–20 August 2026, bringing together experts from the Nordic countries to exchange knowledge and experience on radioecological modelling, environmental monitoring, countermeasures and emergency preparedness in relation to nuclear detonation scenarios.

The seminar followed the first NKS REMSEM seminar, held in 2025, which focused primarily on modelling the transfer of radionuclides through the environment following a nuclear explosion. The 2025 seminar identified several scientific, methodological and practical challenges requiring further work. These included uncertainties related to nuclear detonation source terms and fallout particle characteristics, limited knowledge of radionuclide transfer to food and feed, the need for improved measurement strategies, and the challenges associated with developing models that are sufficiently detailed to represent complex environmental processes while remaining suitable for operational use during an emergency.

The need for continued work in this area remains particularly relevant given the current geopolitical situation and the potential consequences of a nuclear detonation. Unlike many conventional radiological emergency scenarios, a nuclear detonation may result in very rapid and extensive contamination, while measurement capacity is likely to be limited during the initial phase. Rapid, evidence-based decisions may nevertheless be required regarding sheltering, evacuation, food and water restrictions, agricultural countermeasures and the protection of emergency responders.

Against this background, the 2026 REMSEM project sought to strengthen Nordic cooperation on modelling and monitoring of the environmental consequences of nuclear detonations, with particular emphasis on scenarios relevant to the Nordic region. A central objective was to improve the connection between scenario development, modelling, measurements and decision-making, and to identify where further research, methodological development or coordinated Nordic activities could provide added value.

The seminar was also intended to move beyond the identification of scientific challenges towards a more structured assessment of gaps and priorities. Through expert presentations and breakout discussions, participants were therefore invited to consider which capabilities and knowledge are most important for Nordic preparedness, which uncertainties are most critical, and which issues could realistically be addressed through Nordic collaboration.

The outcome of the seminar is intended to provide a basis for further REMSEM activities, or similar, and for the development of a forward-looking roadmap identifying priorities for research, modelling development, monitoring and cooperation.

2. Seminar – scope and program

The REMSEM 2026 seminar was designed to build on the scientific and methodological discussions initiated in 2025 while placing greater emphasis on practical preparedness and scenarios relevant to the Nordic countries.

The scope of the seminar covered the chain from the characteristics of a nuclear detonation and resulting fallout, through environmental transport and measurements, to modelling, dose assessment and the implementation of protective measures. Attention was given to the fact that the characteristics and consequences of a nuclear detonation may differ substantially from those associated with a nuclear power plant accident. Consequently, existing models, monitoring strategies and emergency preparedness arrangements may require adaptation to ensure that they are appropriate for nuclear detonation scenarios.

A key theme throughout the seminar was the management of uncertainty. The limited availability of measurements in the early phase of an event, combined with uncertainties in the source term, fallout characteristics, meteorological conditions and environmental transfer processes, means that decision-makers may need to act before a comprehensive picture of the situation is available. The seminar therefore considered how models and measurements can be combined to provide timely and sufficiently robust decision support.

The programme was structured around four thematic areas:

1. **Current activities**, providing an overview of ongoing Nordic and international work relevant to nuclear detonation scenarios.
2. **Modelling approaches and development needs**, focusing on model development, validation, uncertainty and sensitivity, and the distinction between research and operational modelling.
3. **Countermeasures and food-chain impacts**, addressing radionuclide behaviour, food and environmental monitoring, and the implications for protective actions.
4. **Measurement integration and data use**, focusing on measurement strategies, data integration, preparedness arrangements and the potential use of new technologies, including artificial intelligence (AI).

The presentations were complemented by breakout group discussions, where participants were asked to move from the scientific and technical issues presented during the seminar towards identification of gaps, priorities and potential actions for Nordic cooperation.

2.1 Seminar program

The seminar consisted of expert presentations, plenary discussions and four breakout group sessions. The programme was deliberately structured to allow the presentations to inform the subsequent breakout discussions. The four breakout groups were assigned different but interconnected topics, covering modelling under high uncertainty; integration of measurements and modelling; prioritisation and countermeasures; and Nordic preparedness and cooperation.

The full seminar programme is provided below:

Day 1:

Time	Topic	Presenter (organisation)
8.45-9.00	Seminar opening: introduction and scope	Henrik Öberg (IRSA)
9.00-9.05	NSFS Young Generation Network	Andrea Reinhardsdóttir (IRSA)
9.05-9.15	NKS application information	Kasper Grann Andersson (DTU)
	Topic 1 – Current activities	**Chair: Henrik Öberg**
9.15-9.35	Model development and evaluation for ND, Results from PREDICT WP3.1 and WP3.3	Heiko Klein (Norwegian Met Office)
9.35-9.55	Nordic-US dispersion modelling project	Ali Hosseini (DSA)
9.55-10.15	Monitoring of radionuclides in food	Jenny Aasa (SLV)
10.15-10.45	***Coffee break***	
10.45-11.05	An academic perspective	Ari Ikonen (University of Eastern Finland)
11.05-11.20	Early protective Actions Following a Nuclear Detonation	Pia Keski-Jaskari (STUK)
11.20-11.40	Discussion on Topic 1	
	Topic 2 - Modelling Approaches and Development Needs	**Chair: Anna Maria Blixt Buhr**
11.40-12.00	Overview of PREDICT project with regards to radionuclide food-chain transfer	Justin Brown (DSA)
12.00-12.20	Modelling Scenario-Specific Nuclide Vectors for Nuclear Weapons Explosions - Progress and Challenges	Annika Tovedal (FOI)
12.20-13.20	***Lunch***	
13.20-13.40	Presenting LARCalc: a tool to estimate age and sex-specific Lifetime Attributable Risk after fallout from an RN-event	Mats Isaksson (University of Gothenburg)
13.40-14.00	Aquatic Modelling of Fallout Radionuclides in Catchments, Estuaries and Fjords: Implications for Nuclear Preparedness	Ole Christian Lind (NMBU)
14.00-14.20	Discussion on Topic 2	
	Topic 3 - Countermeasures and Food-chain Impacts	**Chair: Ali Hosseini**
14.20-14.50	The UK approach to modelling the transfer of radionuclides through terrestrial foodchains	Jonathan Sherwood (UKHSA) *(Invited speaker)*
14.50-15.20	***Coffee break***	
15.20-15.40	Recovery management options for inhabited areas contaminated by nuclear blast fallout	Kasper Grann Andersson (DTU)
15.40-16.00	Dominant radionuclides contributing to post detonation radiation dose	Mikko Voutilainen (STUK)
16.00-16.20	Radionuclide food-chain transfer modelling and derivation of maximum permitted levels	Justin Brown (DSA)
16.20-16.40	Food consequences and extent of fallout from nuclear explosions	Anders Axelsson (SSM)
16.40-17.00	Discussion on Topic 3	

17.00-17.10	***Practical information***
19:00-	***Joint dinner***

Day 2

Time	**Topic**	**Presenter (organisation)**
	Topic 4 - Measurement integration and Data Use	**Chair: Jenny Aasa**
9.00-9.20	Cosmogenic radionuclides as natural analogues for transport and retention processes following nuclear fallout in Nordic ecosystems	Fredrik Lidman (FOI)
9.20-9.40	Performance comparison of gamma detectors for drinking water monitoring following radiological emergencies	Mats Isaksson (University of Gothenburg)
9.40-10.00	Measuring strategy post detonation	Catarina Söderström/Lars Ideström (SSM)
10.00-10.20	Radionuclides from nuclear explosion in drinking water- measurements, capacity and responsibilities	Amelie Fondell (SLV)
10.20-10.50	***Coffee break***	
10.50-11.10	Discussion on Topic 4	
11.10-12.30	**Groupwise breakout discussions (see separate document on discussion themes)**	
12.30-13.30	***Lunch***	
13.30-14.15	Presentation of results from breakout group discussions	
14.15-15.00	**Joint discussion: Priorities and recommendations**	**Chairs: Henrik Öberg and Anna Maria Blixt Buhr**
15.00-15.30	***Coffee break***	
15.30-16.15	Summary, roadmap process	
16.15-16.30	Next steps and future collaboration	

3. Abstracts of seminar presentations

The seminar presentations provided a broad overview of current activities, scientific knowledge and development needs relevant to the modelling and assessment of the consequences of nuclear detonations.

The following sections provide abstracts of the presentations according to the four thematic areas of the seminar. The order of the abstracts follows the order of the presentations in the seminar program. In the end of each topical section, following the abstracts of the presentations included in the session, a summary of the plenary discussion of each topical session is given.

3.1 Topic 1 – Current activities

The presentations under Topic 1 provided an overview of ongoing Nordic and international activities relevant to nuclear detonation scenarios and the assessment of resulting consequences.

3.1.1 Model development and evaluation for ND, Results from PREDICT WP3.1 and WP3.3

Heiko Klein

Norwegian Meteorological Institute

Abstract

The PREDICT Work Package 3, part of the PIANOFORTE EJP project, focuses on advancing models to simulate fallout from nuclear detonations for improved consequence assessments. A key component of this effort is the validation of models against historical nuclear test events with available high-accuracy data, such as the mid-20th-century detonation tests conducted at the Nevada and New Mexico test sites.

Model validation was conducted in two phases following the methodology outlined by (Rolph et al., 2014). The initial phase, starting in early 2025, utilized unvalidated models, many of which employed stable cloud parameterizations from (Glasstone & Dolan, 1977), (Harvey et al., 1992), and (Rolph et al., 2014). Modelers were given until mid-2026 to refine their models before the second validation phase. Although the evaluation of the second phase is ongoing, preliminary results are presented.

The European partners employed stable-cloud dispersion models, which simulate atmospheric transport and dispersion starting approximately 15 minutes post-detonation, after the fallout cloud stabilizes. Historical events not only provided opportunities for model comparison but also enabled sensitivity analyses of critical nonlinear model parameters, including cloud geometry, particle density, particle size, and particle height distribution. These sensitivity studies proved instrumental in refining models for the second validation phase.

Validated models were subsequently applied to diverse weather scenarios at two European sites: Bergen, Norway, representing mountainous terrain, and Emden, Germany, representing flat terrain. Weather conditions ranged from inversion scenarios to precipitation fronts, resulting in significant variability in fallout patterns, both in terms of distance from ground zero and the uncertainties associated with different models. The analysis also highlights the limitations of current models in accurately representing the complexity of real-world events.

References

Rolph, G.D., Ngan, F., Draxler, R. R. 2014, Modeling the fallout from stabilized nuclear clouds using the HYSPLIT atmospheric dispersion model, JER Volume 136, https://www.sciencedirect.com/science/article/pii/S0265931X14001453#bib45

Glasstone, S. and Dolan, P. J. 1977, The Effects of Nuclear Weapons, https://atomicarchive.com/resources/documents/effects/glasstone-dolan

Harvey, T., Serduke, F., Edwards, L., Peters, L. 1992, KDFOC3: A Nuclear Fallout Assessment Capability, LLNL, UCRL-TM-222788

3.1.2 Nordic-US Dispersion Modelling Project

Ali Hosseini

Norwegian Radiation and Nuclear Safety Authority

Abstract

The Nordic–US dispersion modelling project is a multilateral technical collaboration involving Nordic emergency preparedness authorities and United States partners, including the National Nuclear Security Administration (NNSA) and the National Atmospheric Release Advisory Center (NARAC). The project aims to strengthen preparedness for nuclear detonation scenarios through systematic comparison of national atmospheric dispersion and consequence assessment capabilities.

The collaboration applies a scenario-based intercomparison methodology in which all participants model a common nuclear detonation scenario using their standard operational tools, meteorological inputs, and workflows. The approach intentionally avoids full harmonization of model inputs in order to represent realistic emergency response conditions. The primary objective is to quantify variability in model outputs and assess the implications for decision-support products and protective action strategies.

A central activity was a technical exchange workshop at Lawrence Livermore National Laboratory (LLNL), bringing together experts from Denmark, Finland, Iceland, Norway, Sweden, and the United States to discuss and compare results from national simulations. These discussions highlighted the high sensitivity of model outputs to differences in numerical weather prediction data, model parameterizations, spatial resolution, and the implementation of source-term information and dispersion processes. Variability in predicted fallout patterns and dose metrics between models highlights the inherent uncertainty associated with nuclear detonation modelling under operational conditions.

The project emphasizes the translation of model outputs into actionable decision-support products, particularly for early-phase response where timely guidance is critical. The collaboration has improved understanding of model variability, highlighted methodological and operational gaps, and strengthened international cooperation. Ongoing work focuses on model benchmarking, communication of uncertainty, and integration of modelling results into protective action planning.

3.1.3 Monitoring of Radionuclides in Food

Jenny Aasa, Daniel Edgar

Swedish Food Agency

Abstract

The Swedish Food Agency regularly conducts market basket studies with the aim to get an overall picture of the amount of, and exposure to, e.g. potentially harmful substances in food representative for the average Swedish consumption.

For the first time, the Swedish Food Agency has analysed both anthropogenic and naturally occurring radionuclides in a market basket study. Also, food items not regularly consumed by the general population were analyzed. Those foods mainly consisted of meat from game, reindeer and lamb, different species of fish and shellfish, wild berries and mushrooms. In total, ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb, ^{210}Po, ^{232}Th, ^{228}Ra, ^{212}Pb, ^{235}U, ^{40}K, ^{137}Cs and ^{90}Sr were analyzed in food groups (pooled samples of specific food categories) from the market basket and in samples from not regularly consumed foods.

The levels of radionuclides in the market basket samples, combined with data on general consumption, were used to estimate the mean annual radiological dose for the average Swedish consumer. The dose was estimated to 0.4 mSv/year. Naturally occurring radionuclides contributed almost entirely (99.5%) to the dose, with the largest contribution coming from ^{228}Ra (51%), ^{210}Po (22%), and ^{210}Pb (14%). The food groups beverages, vegetables, potatoes and cereal products contributed most to the dose.

The levels of the radionuclides in the additional foods were used for calculations where the mean radiological dose for each specific food type at 95th percentile portion sizes was estimated at the assumption that it would not exceed 0.1 mSv per year. ^{137}Cs and ^{210}Po were the most frequently detected radionuclides, where ^{210}Po was the main contributor to the dose in most of the analyzed foods. Overall, the results indicated that it is possible to consume a lot of each food type, except for reindeer and mussels, without exceeding 0.1 mSv per year.

In conclusion, it is a complex work to get an overview of the total radiological exposure, as different techniques and many analyses are needed along with careful sample handling. Also, high standards of all analytical steps and low detection limits are required for reliable data. However, data from this type of studies are valuable input for e.g. modelling, and the Swedish Food Agency could contribute with data on occurrence and on food consumption.

References

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

Livsmedelsverket. 2024a. L 2024 nr 08: The Swedish Market Basket Study 2022. Per capita-based analyses of nutrients and toxic compounds in market baskets and assessment of benefit or risk. Livsmedelsverkets rapportserie. Uppsala.

3.1.4 An academic perspective

Ari Ikonen

Department of Environmental and Biological Sciences, University of Eastern Finland and EnviroCase, Ltd.

Abstract

As outlined previously (Appelblad et al., 2025), there are needs to compile and synthesise existing information, to acquire new empirical data particularly for less studied radionuclides and for fractionation and bioavailability of the fallout, and to improve and better utilise modelling resources. Ideally, one would pour in all empirical and theoretical understanding to develop a comprehensive research model, use it for sensitivity and uncertainty analyses to find most effective avenues for further development of both the empirical basis and the modelling, and eventually simplify into an operational-level model — this would allow simultaneously benefiting of both bottom-up and top-down approaches. Clearly, such endeavours would require multiple iterations and much dialogue, which would be best served by usefully sharing the efforts.

Whilst the specific resources in the Nordic countries are relatively thin and experiencing a continued generational shift, there are a few academic laboratories capable of dealing with radioactive materials but a large and wide community able to contribute to the general science and modelling. With academia, engagement with other disciplines (e.g. in atmospheric physics or ecotoxicology) is natural, often less convenient across various authorities or other establishments. Synthesising literature would also be very fitting to the resource structure of universities. Coordinated distribution of work across various research groups could also be purposefully used to alleviate security concerns. However, students and researchers of today need clear career prospects and sufficient funding.

Reference

Appelblad, P, Tovedal, A, Östman, M, Andersson, P, Axelsson, A, Blixt Buhr, AM, Brown, J, Hosseini, A, Lind, OC, Öberg, H, Roivainen, P, Virtanen, S, Aasa, J, Edgar, D, Ehrs, S, Fondell, A, Gunnare, S, Neil Persson, K, Roed, H & Senstius, EP. 2025. Report from NKS-B REMSEM: the 1st Nordic seminar regarding modelling of radionuclide transfer from fallout after a nuclear explosion. NKS-507. Nordic Nuclear Safety Research. 38 pp.

3.1.5 Urgent Protective Actions Following Nuclear Detonation

Antero Kuusi, Mikko Voutilainen and Pia Keski-Jaskari

STUK, Radiation and Nuclear Safety Authority

Abstract
The radiation situation caused by nuclear detonation and the resulting dose accumulation in the population differ significantly from those of a nuclear power plant accident. After nuclear detonation, the population may be exposed to extremely high radiation doses within a short period of time. The main source of dose accumulation is external exposure from fallout generated by the explosion, which requires different protective measures, decision-making criteria, and operational models compared with nuclear power plant accidents.

Finland's national guidance has been updated to include urgent protective actions for nuclear detonation scenarios. First-response instructions have also been revised to account for the radiation protection of first responders operating in fallout conditions. Immediate sheltering indoors is recommended within a radius of up to 100 km in all directions from the detonation point, and up to 200 km in the direction of the prevailing wind due to the expected spread of radioactive fallout. The recommended shelter indoors duration ranges from 2–3 hours up to 6–12 hours, with 6–12 hours being the most likely duration. Necessary evacuations must be carried out methodically in the appropriate direction. For first responders, the maximum dose rate permitted in the operational area has been set at 100 mSv/h.

This presentation outlines the main principles of immediate protective actions, the effects of sheltering indoors and evacuation, the required distances, and the radiation doses received by first responders.

References
ICRP, https://www.icrp.org/page.asp?id=611

3.1.6 Summary of Topic 1 plenary discussion

The discussion highlighted the need to consider whether the radionuclides currently included in food monitoring programmes are sufficiently representative of those that may be important following a nuclear detonation. The standard set of radionuclides commonly investigated in monitoring programmes may not necessarily capture the radionuclides that dominate dose or are most relevant for the specific characteristics of nuclear-detonation fallout in the first months. The Swedish Radiation Safety Authority (SSM) and the Swedish Food Agency (SLV) discussed the possibility of expanding existing food-basket studies to include additional radionuclides, such as Ba-140, and whether controlled experiments using spiked food could be used to develop or validate analytical methodologies. It was also noted that an ongoing SLV project on drinking water takes radionuclide vectors from nuclear weapons into account, providing another example of how monitoring and analytical preparedness can be adapted to nuclear detonation scenarios. Collaboration with laboratories possessing the necessary analytical capabilities was identified as a potential way forward.

A research-level modelling approach could also contribute by developing a nuclide-vector model and estimating which radionuclides are likely to be most important under different scenarios. Such an approach could help assess the resources and analytical capacity required for emergency measurements. It was noted that several countries have historically focused on a relatively limited set of standard radionuclides. FOI described an approach in which gamma spectrometry could be used intensively during the first approximately two months following an event to identify the radionuclides dominating the dose.

The discussion also highlighted that studies of radionuclide behavior do not necessarily require radioactive materials in all cases. For elements such as barium, relevant processes can potentially be investigated using stable isotopes, providing opportunities for experimental work while avoiding the need to work with radioactive isotopes. Furthermore, it was pointed out that greater use should also be made of proxy elements, historical data, and existing literature.

3.2 Topic 2 – Modelling Approaches and Development Needs

Topic 2 focused on the development and application of models for nuclear detonation scenarios, including the challenges associated with uncertainty, model complexity and the availability of relevant data.

3.2.1 Overview of PREDICT project with regards to radionuclide food-chain transfer

Justin Brown

Norwegian Radiation and Nuclear Safety Authority

Abstract

The aim of the EU PREDICT project is to improve radiological assessment and decision-support capabilities for nuclear detonations, with particular emphasis on the fallout zone where protective actions can substantially reduce public health impacts. As part of the work in Task 2.3, the applicability of existing terrestrial food-chain transfer models, including FDMT and FARMLAND, to post-detonation scenarios is evaluated and potential directions for model developments are identified.

The extent to which radionuclide transfer following a nuclear detonation (ND) differs from that following a nuclear power plant accident was examined. Particular attention was given to the influence of particle size, physicochemical form, radionuclide solubility, interception by vegetation, weathering, transfer to livestock, and the importance of short-lived radionuclides.

Simplified methodologies were developed to rank radionuclides according to their potential contribution to ingestion dose by combining amounts of ND-produced radionuclides, ingestion dose coefficients and food-chain transfer parameters. The approach developed by Norwegian partners was subsequently compared with simulations undertaken using the FDMT model implemented within the AFRY Intelligent Scenario Modelling Platform. The results demonstrate that consideration of food-chain transfer substantially alters radionuclide rankings compared with rankings based solely on activity inventories or dose coefficients. In particular, radiocaesium and radiostrontium isotopes become significantly more important contributors to ingestion dose at intermediate and longer times following deposition. Preliminary model comparisons indicate that the simplified ranking methodology provides a practical means of identifying the radionuclides most relevant for emergency response, while highlighting the value of more comprehensive dynamic modelling.

Important knowledge gaps are also identified, particularly concerning the behaviour and bioavailability of radioactive particles produced by ND, and a recommendation is made for further experimental work together with continued development of food-chain transfer models and associated uncertainty analyses to strengthen decision support for nuclear emergency preparedness.

3.2.2 Modelling Scenario-Specific Nuclide Vectors for Nuclear Weapons Explosions - Progress and Challenges

Annika Tovedal

Swedish Defence Research Agency (FOI)

Abstract

Accurate characterization of source terms is essential for assessing the radiological consequences of nuclear weapon explosions and for planning effective response and recovery actions. The Swedish Defence Research Agency (FOI) is developing a model that generates data on radionuclide vectors, radionuclide fractionation among different particle types, and the environmental dispersion of released radionuclides.

The model accounts for a range of key parameters including the weapons yield (fission products); height of burst; neutron activation of surrounding environment, weapon material and fissile material; particle size distributions and composition; the chemical attributes of the radionuclide vector; and meteorological conditions.

This presentation will highlight the following selected aspect of the ongoing work at FOI:

- application of height of burst to distribute radionuclides among different particle distributions.

References

Andersson, P, Goliath M, Produktion av nuklider vid kärnvapenexplosioner, FOI-D-1111—SE, 2021

Spriggs, G, D & Egbert S, D. 2017. Total Residual Radiation Source Term Produced by the Hiroshima Detonation. LLNL-TR-814785, Lawrence Livermore National Laboratory.

Spriggs, G, D, Neuscamman, S, J, Nasstrom, J, S, Knight, K, B. Fallout Cloud Regimes. United States: N. p., 2020. Web.

von Schoenberg, P, Elfverson D, Persson L, Å, Vågberg D. NWSWAMP Manual, Version 1.4, FOI-R-5769--SE, 2026

3.2.3 Presenting LARCalc: a tool to estimate age and sex-specific Lifetime Attributable Risk after fallout from an RN-event

Jonathan Sundström[1], Mats Isaksson[1] and Christopher Rääf[2]

[1] *Department of Medical Radiation Sciences, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden.*

[2] *Medical Radiation Physics, Department of Translational Medicine, Lund University, Malmö, Sweden*

Abstract

In the event of an RN-event that leads to the emission of radionuclides into the environment, planning for the extent of the radiological impact in advance is crucial. We present LARCalc, a simple decision support tool to estimate the radiological consequences of various releases of radionuclides to the environment. LARCalc utilizes ^{137}Cs ground deposition in combination with fallout-specific nuclide vectors to estimate cumulative effective dose, organ-specific absorbed dose, and lifetime attributable cancer risk. Additionally, it can estimate the residual dose and the averted cumulative lifetime attributable risk from various protective measures, such as evacuation, food restrictions, and decontamination. The LARCalc tool can also estimate collective dose and the potential increased incidence in the number of cancers in various populations. It thus provides a visualization of the radiological impact of releases and the effects of different countermeasures. The dose models used by LARCalc are based on previously published works and methods for dose calculation based on ground deposition. These include the pathways groundshine, cloudshine, inhalation, and ingestion of caesium, iodine, and strontium through foodstuffs. LARCalc is intended to be a rapid alternative for planning of protective measures in case of an emergency and can visualize how the dose or risk varies with time, age, gender and countermeasures.

3.2.4 Aquatic Modelling of Fallout Radionuclides in Catchments, Estuaries and Fjords: Implications for Nuclear Preparedness

Ole Christian Lind

Norwegian University of Life Sciences

Abstract

Following a nuclear event with atmospheric transport of radioactivity and subsequent deposition onto the earth's surface, radionuclides may subsequentially be subject to substantial redistribution due to runoff processes. Radionuclides might migrate from terrestrial surfaces into aquatic systems via rainwater, snowmelt, and stormwater. Catchment processes may transport radionuclides to downstream aquatic environments, including estuaries and fjords that received little or no direct atmospheric deposition. In addition, water reservoirs may be affected by direct deposition. Thus, the simulation of radionuclides in aquatic systems is important and arguably should form part of decision support systems (DSS) used for nuclear emergency preparedness. While Java-based Real-time On-line DecisiOn Support System (JRODOS) includes aquatic modelling capabilities, comparable functionality is currently lacking within Accident Reporting and Guidance Operational System (ARGOS), highlighting an opportunity for further development. Thus, there is scope to explore integrating aquatic models in the ARGOS environment. The present work introduces aquatic modelling tools that potentially could be used with ARGOS. They include INtegrated CAtchment model for RADionuclides (INCA-RAD) for catchment transport of radionuclides (Liland et al., 2020; Lin et al., 2019) and OpenDrift for estuary, coastal and ocean modelling. The latter allows dynamic speciation codes (including colloids and particle properties) to be implemented (Simonsen et al., 2025).

References

Liland, A., Lind, O.C., Bartnicki, J., Brown, J.E., Dyve, J.E., Iosjpe, M., Klein, H., Lin, Y., Simonsen, M., Strand, P., Thørring, H., Ytre-Eide, M.A., Salbu, B., 2020. Using a chain of models to predict health and environmental impacts in Norway from a hypothetical nuclear accident at the Sellafield site. J. Environ. Radioact. 214-215, 106159

Lin, Y., Couture, R.M., Klein, H., Ytre-Eide, M.A., Dyve, J.E., Lind, O.C., Bartnicki, J., Nizzetto, L., Butterfield, D., Larssen, T., Salbu, B., 2019. Modelling Environmental Impacts of Cesium-137 Under a Hypothetical Release of Radioactive Waste. Bull Environ Contam Toxicol 103, 69–74.

Simonsen, M., Berge, E., Klein, H., Brown, J., Ulimoen, M., Saetra, O., Hosseini, A., Lind, O.C., 2025. Marine and atmospheric transport modeling supporting nuclear preparedness in Norway: Recent achievements and remaining challenges. The Science of the total environment 961, 178161–178161.

3.2.5 Summary of Topic 2 plenary discussion

The discussion focused on the balance between research-level understanding and practical requirements for emergency preparedness. A key point was that a sufficiently detailed understanding of the complexity of the system is needed before it can be simplified into an operational model. Simplification without understanding the underlying processes and assumptions may result in important factors being overlooked. This was considered particularly relevant when performing a gap analysis of existing models and identifying where additional research is needed.

The discussion also considered the behaviour of fallout particles in aquatic environments. Following the presentation on aquatic modelling of fallout radionuclides, it was discussed whether plutonium and potentially other fallout particles could preferentially accumulate in bottom sediments in rivers, potentially reducing their subsequent transfer to fish and, consequently, human exposure. However, this was identified as an area where further research may be needed to establish whether and how such processes are represented in existing applied models.

The potential use of AI in model development was also discussed. AI-based approaches may enable very rapid calculations and potentially make ensemble calculations more feasible. The European CIThARA project was mentioned as an example of work in this area. AI could potentially be used to emulate physical models and substantially reduce computational times, including for dispersion calculations. However, concerns were raised regarding the accuracy, uncertainty and transparency of AI-based approaches. In particular, emulation of physical models may introduce additional uncertainties that need to be properly understood and quantified. The use of weather-model outputs as training data for AI models was considered a potentially promising avenue for further development.

3.3 Topic 3 - Countermeasures and Food-chain Impacts

Topic 3 addressed the environmental and radiological consequences of fallout, with particular emphasis on radionuclide behaviour, food-chain transfer and the implications for protective measures.

3.3.1 The UK approach to modelling the transfer of radionuclides through terrestrial foodchains

Jonathan Sherwood

UK Health Security Agency (UKHSA)

<u>Abstract</u>

In the UK, foodchain models are used to support assessments and advice in a variety of situations, including both routine and accidental (or acute) release scenarios. In this presentation, the two models used by the UK Health Security Agency (UKHSA) and the Food Standards Agency (FSA) will be described along with the various applications for which they are used.

The FARMLAND model (Brown & Simmonds, 1995) has been developed by UKHSA and its predecessor organisations over several decades and incorporates submodels representing the major crop types and animals farmed in the UK. Each submodel consists of multiple compartments, and the movement of radionuclides due to physical and biological processes is simulated using first-order kinetics between interconnected compartments.

The PRISM model (Quintessa (n.d.)) was developed by Quintessa, built on their AMBER compartment modelling platform. PRISM is the FSA's principal tool for evaluating radionuclide dynamics in agricultural systems, incorporating a wide range of crop and animal categories. Like FARMLAND, PRISM employs kinetic compartment models for soil, plant, and animal systems.

While the two models share a number of similarities including the range of environmental processes they seek to describe, there are important differences in terms of model complexity, data sources, process parameterisation, the radionuclides included and the treatment of ingrowth of radioactive progeny.

As part of Task 2.3 of the Pianoforte PREDICT project, results were compared from three models for a hypothetical nuclear detonation scenario: FARMLAND (run by UKHSA), PRISM (run by FSA) and a third terrestrial foodchain model, FDMT (Müller et al., 2004) (run by DSA). It is possible to explain some of the differences in the limited number of results compared so far but significant opportunities remain for more detailed intercomparison studies. Such work would improve understanding of the models and inform future model development.

<u>References</u>

Brown, J & Simmonds, J. 1995. FARMLAND: A Dynamic Model for the Transfer of Radionuclides through Terrestrial Foodchains. NRPB, Chilton (UK). NRPB-R273.

3.3.2 Recovery management options for inhabited areas contaminated by nuclear blast fallout

Kasper Grann Andersson

Technical University of Denmark

Abstract

A few decades ago, workgroups under the European EURANOS project created the 'European recovery handbooks' for use in European countries to prepare for and facilitate recovery of radioactively contaminated inhabited, food-producing, and natural areas as well as drinking water. Certain cost-effectiveness elements of inhabited area recovery methods were also fed into the consequence model ERMIN, which is an integral part of the ARGOS and RODOS decision support systems. To accommodate the considerable differences in features between fallout scenarios involving fallout from a large NPP accident (for which the handbook series was originally created) and those involving fallout from a nuclear burst, the European inhabited areas recovery handbook is being revised in the European PREDICT project.

Volatile radionuclides would in a NPP scenario to a great extent be released to the environment in the form of small (typically slightly submicroneous particles). However, after a nuclear ground level burst, where huge amounts of soil and debris are lifted into the air by the fireball, the volatiles would form a surface coating on large particles. Calculations made in the PREDICT project by both the Norwegian Met-Office and RIVM (Netherlands) in cooperation with UKHSA suggest that at more than 100 km distance from a ground burst location, the contaminant deposition is dominated by particles greater than 20 µm carrying volatile surface contaminants. Large particles are known to be comparatively easier to remove (e.g., by water hosing techniques) after airborne deposition on an impermeable surface. However, it is likely that a particle surface coating of volatile radionuclides, like Cs-137, would quite rapidly dissolve in the environment. Contaminant particles from a high air burst are expected to generally be substantially smaller. Also text sections describing other management specific features of a nuclear bomb scenario are being written for the revised handbook.

3.3.3 Dominant radionuclides contributing to post detonation radiation dose

Mikko Voutilainen[1], Tuomas Peltonen[1], Andreas Uppstu[2], Rostislav Kouznetsov[2]

[1] *STUK, Radiation and Nuclear Safety Authority of Finland, Finland*

[2] *FMI, Finnish Meteorological Institute, Finland*

Abstract
This work investigates the dominant radionuclides contributing to post-detonation radiation dose following a nuclear surface burst. The assessment considers 69 radionuclides identified as most relevant for dose formation, covering key fission products and activation products affecting external and internal exposure pathways (Kraus & Foster, 2014). The initial conditions resulting from the nuclear detonation were determined using publicly available Cold War-era information, providing a historically grounded basis for estimating the subsequent dispersion, deposition, and time-dependent radiological impacts. Atmospheric dispersion and deposition were modelled with the SILAM model developed by the Finnish Meteorological Institute (Sofiev et al., 2015).

The results show that radiation exposure following the detonation is dominated by external irradiation from deposited fallout, while external exposure from the passing radioactive cloud and inhalation account for only minor fractions of the total dose. Short-lived radionuclides dominate the early external dose rate and therefore drive the initial radiological hazard. Most of the cumulative dose is delivered during the first days and weeks, with I-134, I-132, I-135, Mn-56, La-140, and La-142 among the principal contributors. As the fallout ages, the radionuclides dominating the external dose rate change markedly. The contribution from short-lived iodine isotopes decreases, while the Zr-95 to Nb-95 and Ru-103 to Rh-103m decay chains become increasingly important. After approximately one to two years, the remaining activity is largely associated with the Ru-106 to Rh-106 and Ce-144 to Pr-144 decay chains. Over longer timescales, contamination is increasingly controlled by the Sr-90 to Y-90 and Cs-137 to Ba-137m decay chains, which become dominant after several years. These findings demonstrate the strongly time-dependent nature of post-detonation radiological consequences and highlight the importance of radionuclide-specific assessments for emergency response, environmental monitoring, and long-term consequence management.

References

Kraus, T, & Foster, K. 2014. Analysis of fission and activation radionuclides produced by a uranium fueled nuclear detonation and identification of the top dose-producing radionuclides. Health Phys., 107:150–163.

Sofiev, M, Vira, J, Kouznetsov, R, Prank, M, Soares, J & Genikhovich, E. 2015. Construction of the silam eulerian atmospheric dispersion model based on the advection algorithm of Michael Galperin. Geoscientific Model Development, 8(11):3497–3522.

3.3.4 Radionuclide food-chain transfer modelling and application of Maximum Permitted Levels (MPLs)

Justin Brown, Ali Hosseini, Håvard Thørring

Norwegian Radiation and Nuclear Safety Authority

Abstract

Following a nuclear detonation or other radiological emergency, decisions on restrictions affecting food production and consumption require reliable predictions of radionuclide transfer through agricultural systems. Within the PREDICT project, a methodology has been developed to link atmospheric dispersion modelling outputs with dynamic food-chain transfer modelling to identify areas where foodstuffs may exceed the Maximum Permitted Levels (MPLs) specified in Council Regulation (Euratom) 2016/52. The approach provides a practical connection between source-term and dispersion modelling and the evaluation of protective actions.

The Food Chain and Dose Module for Terrestrial Pathways (FDMT), implemented within the AFRY Intelligent Scenario Modelling platform, was extended to support additional radionuclides relevant to nuclear detonation scenarios. Results were then coupled with dispersion model outputs from ARGOS. Food-chain transfer values (T_{ag}) were derived for selected radionuclides and agricultural products at 7-day, 30-day and 1-year time points following deposition. These were combined with spatial datasets of wet deposition and integrated air concentrations within a GIS environment to estimate radionuclide concentrations in foodstuffs and evaluate compliance with Euratom MPLs.

Application of the methodology demonstrates that the radionuclides and food categories driving potential intervention requirements evolve markedly with time. Iodine-131 dominates exceedances during the early phase, whereas longer-lived radionuclides, including isotopes of strontium and caesium, become increasingly important at later times. The resulting maps illustrate both the spatial extent and temporal evolution of potential food restrictions, providing a useful basis for considering protective action strategies. Although the large number of radionuclide and food-category combinations limits direct application during the urgent response phase, the methodology offers significant value for emergency planning, scenario evaluation and decision support during the transition and later phases of a radiological emergency.

3.3.5 Food consequences and extent of fallout from nuclear explosions

Anders Axelsson

Swedish Radiation Safety Authority (SSM)

Abstract

Intervention levels for selected foodstuffs were combined with the results of atmospheric dispersion modelling to produce estimates of the geographical scale of impact on food production following fallout from a nuclear explosion.

Fallout exceeding the intervention levels indicates that the limit values for concentration of radionuclides in foodstuffs set out in Council Regulation (Euratom) 2016/52 may be exceeded in food produced in an area. The intervention level for drinking water was adopted from work by the Swedish Defence Research Agency (Tovedal *et. al.*, 2021). The other intervention levels used were recently derived by SSM (Axelsson *et. al.*, 2026). They are based on nuclide composition of fallout derived by SSM (Axelsson *et. al.*, 2023), and on fallout-to-foodstuffs transfer factors from modelling by Andersson (2023, 2024) using ECOSYS (Müller & Proehl, 1993).

The dispersion modelling was done by J. Lindgren (SSM) using the MATCH model (Persson *et. al.*, 2000). The "batch" calculation mode of the ARGOS decision support system (Hoe *et. al.*, 2009) was utilized to take into consideration weather conditions occurring over several months.

Assuming a 100-kiloton nuclear explosion at ground level, the results indicate that fallout could result in exceedance of Council Regulation (Euratom) 2016/52 limit values in some foodstuffs (including drinking water from surface recipients) produced several thousand kilometres from the explosion. The distance of possible impact on food production is expected to be greatest at an early stage (first months after the explosion). Longer-term impact on food production can also be significant but would be expected to extend to somewhat smaller distances from the explosion.

Food production could be affected in areas where other radiological effects of the fallout would be insignificant. In particular, it is demonstrated that food production in the Nordic countries could be affected by a nuclear explosion in Ukraine.

References

Andersson, K. G. 2023. Investigation of early radionuclide concentrations in various food items produced in an area affected by fresh nuclear bomb fallout. Unpublished (SSM document number SSM2023-3858-7)

Andersson, K. G. 2024. Investigation of radionuclide concentrations in various food items one year after airborne areal contamination from NPP accident or nuclear bomb fallout. Unpublished (SSM document number SSM2024-1038-7)

Axelsson, A, Kock, P, Johansson, J, Lindgren, J, Blixt Buhr, A M, Boson, J, Bäverstam, U & Karlsson, S. 2023. Radiological Consequences of Fallout from Nuclear Explosions (Report 2023:05e). SSM

Axelsson, A, Blixt Buhr, A M, Johansson, J, Kock, P, Lindgren, J & Söderström, C. 2026. Food contamination from fallout following a nuclear explosion (Report 2026:08e). SSM

Hoe, S, McGinnity, P, Charnock, T, Gering, F, Schou Jacobsen, L. H, Havskov Sørensen, J, Andersson, K. G & Astrup, P. 2009. ARGOS Decision Support System for Emergency Management. In: Proceedings (online). Argentine Radiation Protection Society

Müller, H & Pröhl, G. 1993. ECOSYS-87: a dynamic model for assessing radiological consequences of nuclear accidents. Health Physics 64(3). 232-252.

Persson, C, Robertson, L, & Thaning, L. 2000. Model for Simulation of Air and Ground Contamination Associated with Nuclear Weapons. An Emergency Preparedness Model (Meteorologi 95). SMHI and FOA

Tovedal, A, Nylén, T, Björnham, O & Grahn, H. 2021. Dricksvatten från ytvattentäkt efter ett radioaktivt nedfall (Report FOI-R--4930--SE). FOI

3.3.6 Summary of Topic 3 plenary discussion

The discussion addressed the practical implications of a nuclear detonation, including the potentially very large geographical areas affected and the resulting need to prioritise decontamination and other countermeasures. The scale of the affected area, combined with the potentially extensive destruction caused by the explosion itself, means that prioritisation will be essential.

It was noted that the primary purpose of a nuclear detonation may be the destruction of infrastructure rather than the production of radioactive fallout. Consequently, the assumption that a detonation would necessarily occur over a major city may not always be appropriate. Military targets could instead be prioritised, resulting in very different patterns of destruction and fallout. Nevertheless, from a civilian radiation-protection perspective, fallout becomes particularly important following the explosion, as it constitutes the principal radiological hazard outside the immediate destruction zone.

The potential for surface-water detonations was also raised as a scenario requiring further consideration. Different detonation environments could result in substantially different fallout characteristics and therefore different exposure pathways and countermeasure requirements.

The solubility and environmental behaviour of fallout particles along with their size distribution were highlighted as important factors when assessing consequences.

Finally, the possibility of using AI to support the synthesis of information during an emergency was discussed. Rather than necessarily replacing established models or expert judgement, AI could potentially assist in combining and structuring partial information from multiple sources to produce a more useful overall picture for decision-makers. This was identified as an area with potential, but also one requiring careful consideration of reliability and uncertainty.

3.4 Topic 4 – Measurement Integration and Data Use

Topic 4 focused on the role of measurements and data in supporting modelling and emergency decision-making.

3.4.1 Cosmogenic radionuclides as natural analogues for transport and retention processes following nuclear fallout in Nordic ecosystems

Fredrik Lidman

Swedish Defence Research Agency (FOI)

Abstract

Radioactive fallout from nuclear accidents or detonations creates complex patterns of deposition, retention, transport and uptake that are difficult to study in real-time. To address this, naturally occurring cosmogenic radionuclides offer a unique opportunity to serve as natural proxies for radioactive fallout, as their atmospheric deposition onto the landscape mimics the source term of atmospheric releases under realistic environmental conditions.

This study utilizes cosmogenic radionuclides – primarily ^{7}Be ($t_{½}$=53 d), with exploratory work on more analytically challenging nuclides like ^{22}Na ($t_{½}$=2.6 a) and ^{35}S ($t_{½}$=87 d) – to investigate the early-stage processes of fallout behavior in Nordic ecosystems. Geochemically, beryllium is a reactive and relatively insoluble element, making it a relevant analogue for several important radionuclides in a nuclear fallout vector. The inclusion of ^{22}Na (a relatively mobile and conservative tracer) and ^{35}S (a biologically active macronutrient) allows for a multi-faceted characterization of behavior of radionuclides with contrasting biogeochemical properties. Ultimately, the ambition is to move beyond initial feasibility measurements in vegetation, soil and water toward establishing integrated mass balances across diverse landscape types, including agricultural land, forests, peatlands, and urban environments.

Through a combination of field studies, method development for sampling challenging radionuclides in soil, biota, and water (e.g., through passive *in situ* sampling), and advanced laboratory analyses, the project aims to quantify key processes such as interception, vertical redistribution in soil profiles and transfer to surface waters. By coupling these measurements with existing hydrological and biogeochemical time series, we hope to generate high-quality process data that can be used to parameterize and validate radioecological models, ultimately improving the ability to predict radionuclide mobility and assess radiological risks in Nordic landscapes.

3.4.2 Performance comparison of gamma detectors for drinking water monitoring following radiological emergencies

Mats Isaksson[1], Jonathan Sundström[1], Charlotta Nilsson[2], & Christopher Rääf[3]

[1]Department of Medical Radiation Sciences, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

[2]Department of Physics, Lund University, Lund, Sweden

[3]Medical Radiation Physics, Department of Translational Medicine, Lund University, Malmö, Sweden

Abstract

Radioactive fallout following a nuclear or radiological event may contaminate surface waters and subsequently affect drinking water supplies. During the early phase of such incidents, monitoring of radioactivity in outgoing drinking water is essential to verify compliance with regulations. However, access to nuclide-specific measurements may be constrained due to high demand on gamma spectrometry facilities.

This study presents a Monte Carlo-based evaluation of 10 gamma detectors for continuous, on-site monitoring of drinking water at water treatment plants after radioactive fallout. Two representative release scenarios were considered: a nuclear power plant accident and a nuclear weapon detonation. For each scenario, radionuclide inventories were modelled at 48 h and 7 d post-release. Detector performance was assessed for two measurement configurations: a 4 L Marinelli beaker and a geometry where the detector is mounted directly against a large outlet pipe. All simulations assume a conservative worst-case scenario in which all radionuclides were assumed to be transferred to the water proportionally in accordance to the source term.

For each combination of detector, geometry and source term, simulated gamma spectra were analysed to determine both the minimum detectable activity and the minimum quantifiable activity for the key nuclides ^{131}I and ^{137}Cs. Background conditions were measured gamma spectra acquired at an operational Swedish water treatment plant using different detector systems, providing a realistic representation of in-situ monitoring conditions.

The results demonstrate that detector performance is strongly influenced by detector type, measurement geometry, and time after release. These findings underline the limitations of certain detector systems for emergency drinking water monitoring and provide practical guidance for selecting suitable instrumentation for radiological preparedness and response.

3.4.3 Measuring strategy post detonation

Catharina Söderström

Swedish Radiation Safety Authority, SSM

Abstract

Sweden's radiation emergency preparedness has, over the past decades, primarily focused on managing accidents at nuclear power plants (NPPs) and their consequences. In contrast, the consequences of a nuclear detonation in the vicinity of, or within, Swedish territory are considerably more difficult to predict. This is due to several factors. For example, information available both before and immediately after such an event is likely to be limited, while the consequences are expected to be severe, potentially affecting large geographical areas within a very short period of time. Furthermore, the location of a detonation cannot be anticipated in advance, making it difficult to pre-plan and deploy measurement activities.

These challenges must be considered when developing post-detonation measurement strategies. Although the strategies and measurement capabilities established for NPP accident scenarios provide a valuable foundation, they are insufficient to meet the full range of requirements following a nuclear detonation. During the initial response phase, measurement efforts will primarily focus on mapping ambient dose rates and delineating affected and unaffected areas to support decisions on protective actions, such as evacuation. In the subsequent recovery phase, measurement activities will increasingly be directed towards assessing contamination of agricultural land and food products, thereby providing the information required to support agriculture, food production, and public health protection.

3.4.4 Radionuclides from nuclear explosion in drinking water-measurements, capacity and responsibilities

Amelie Fondell *et al.*

Swedish Food Agency

<u>Abstract</u>

A brief overview of ongoing projects aiming to strengthen the capacity to manage radioactive fallout affecting drinking water and food.

”*Decision support and enhanced measurement capacity for drinking water producers and municipalities in the event of a radiological emergency”.* A large and long-running project involving many stakeholders including water producers, universities and authorities. The project is subdivided in five subprojects. A pilot study of an online instrument at a water treatment plant is one of the subprojects. The online instrument allows continuous measurements and automatic alarms when pre-defined threshold levels are exceeded. The challenges have been identifying appropriate alarm levels and the fact that expertsupport is required for interpreting the results. At present, no authority has clear responsibility for this.

The Swedish Food Agency does not intend to apply the Euratom 2016/52 limit values for liquid foodstuffs to drinking water but instead to retain the national regulation (LIVSFS 2022:12). Nevertheless, the values for liquid foodstuffs in Euratom 2016/52 will be used as reference values for laboratory method development and as guidance thresholds at which interventions such as restricting the public consumption of drinking water, could be needed.

An evaluation of the gross alpha-total beta screening method is also included in the project.

”Allocation of responsibilities and tasks in the event of a radiological incident affecting the food and drinking water supply chain”
The Swedish Food Agency, the Swedish Radiation Safety Authority and the Swedish Board of Agriculture are carrying out this project in cooperation. This project has a more administrative focus but aims to support practical action. Responsibilities during a radiological incident, particularly regarding sampling and analysis of food and water, are being examined.
Producers are responsible for product safety and therefore also for conducting measurements on their own products. These measurements are typically performed by commercial laboratories. However, authorities may need to step in before commercial laboratories can scale up their capacity.
Another key question is how to minimise impacts on trade and exports. This includes understanding what data are needed and what requirements are imposed by consumers and international partners, especially during the long recovery phase.
The project will also address responsibility for compiling and publishing results to support a national situational overview after an incident.

<u>References</u>

Council regulation Euratom 2016/52

Livsmedelsverket. 2022. Livsmedelsverkets föreskrifter om dricksvatten. LIVSFS 2022:12

Norlin K., Ramebäck H., Tovedal A. 2023. Measurements of gross alpha and gross beta at low alpha-to-beta activity ratios using LSC- a method for emergency preparedness. Applied Radiation and Isotopes. 201: 110983

Ramebäck H., Tovedal A., Norlin K. 2024. On the significance of the measurement evaluation method in decision making: a synthesis of JCGM 101 and JCGM 106 applied to gross alpha and gross beta measurements using LSC. Applied Radiation and Isotopes. 208: 111282

More publications from subprojects in "Decision support and enhanced measurement capacity for drinking water producers and municipalities in the event of a radiological emergency" to be announced later.

3.4.5 Summary of Topic 4 plenary discussion

The discussion focused on Nordic preparedness arrangements, with particular focus on inputs from countries other than Sweden, since all presenters under Topic 4 were affiliated with Swedish organisations. Participants noted that roles and responsibilities differ between countries and that, in several cases, frameworks and measurement protocols are still under development. Denmark is currently updating its nuclear emergency plan, including work on measurement protocols, while experiences from the UK illustrate differences in responsibilities between authorities for food and drinking water restrictions. In Finland, Sweden and Iceland, participants highlighted different challenges related to clearly defining responsibilities and ensuring that preparedness for radiological emergencies is recognised as a shared responsibility rather than resting primarily with the radiation safety authority. The discussion also highlighted differences in intervention or reference levels for food and drinking water between countries, which may have implications for detection capabilities and the practical implementation of monitoring strategies.

The importance of exercises and practical preparedness was also highlighted. As radiological emergencies are rare events, maintaining competence and ensuring that roles, responsibilities and measurement procedures are understood across relevant authorities can be challenging. Regular exercises may therefore be important for identifying gaps and strengthening cooperation between authorities within a country.

Participants considered whether AI could assist in bringing together and interpreting information from multiple sources, potentially supporting a more comprehensive situational picture. However, the public-sector context and the rarity of such events mean that the practical applications and benefits of AI are not yet clear. Concerns were also raised regarding the use of "black box" approaches, particularly where decisions with significant consequences remain the responsibility of humans. Any future use of AI would therefore need to address issues of transparency, reliability and clearly defined human responsibility.

4. Groupwise Breakout Discussions

The second major component of the seminar was a series of breakout group discussions intended to complement the expert presentations and provide an opportunity for participants to collectively identify challenges, priorities and potential areas for Nordic cooperation.

Participants were divided into four groups, with each group assigned a specific theme:

- **Group 1: Modelling under high uncertainty**
- **Group 2: Measurements and modelling – integration, capabilities and possibilities**
- **Group 3: Prioritization – decision process and countermeasures**
- **Group 4: Nordic preparedness and cooperation**

The topics were deliberately interconnected. While Group 1 focused primarily on modelling and uncertainty, Group 2 considered the relationship between modelling and measurements, Group 3 addressed the translation of technical and scientific information into practical decisions and countermeasures, and Group 4 considered the broader organisational and collaborative framework required to support Nordic preparedness.

Each group was provided with suggested discussion questions and focus areas to facilitate the discussions. These were intended as guidance rather than as fixed questions, allowing participants to raise additional issues relevant to their assigned topic.
To support a consistent synthesis of the discussions, all groups were asked to consider four overarching questions:

1. **What are the most important gaps identified?**
2. **Which issues are most urgent for Nordic preparedness, and which could realistically be addressed through Nordic collaboration?**
3. **What should be prioritised in future research and development?**
4. **What concrete next steps should REMSEM recommend?**

The groups subsequently presented their main conclusions in plenary, using a .ppt template that collected the groups' findings under each of the four questions listed above. The following sections consolidate the presentations and subsequent discussions and identify the main issues and potential areas for further work emerging from each group. The .ppt presentations from each group have been transformed into sections under chapter 9, Appendix.

4.1 Group 1: Modelling under high uncertainty

The discussion focused on the balance between simple and complex models and on how modelling can provide useful decision support under the high levels of uncertainty expected following a nuclear detonation. Participants emphasised that there is no single model that is optimal for all purposes. Complex models can represent relevant processes in greater detail but require more parameters and input data, while simpler models may be more suitable for rapid operational use but can produce different results depending on their assumptions.

A key issue was therefore the need to better understand structural and conceptual uncertainties, in addition to uncertainties in individual input parameters. Regular comparison and benchmarking of different models were considered important for identifying these uncertainties and understanding the influence of different assumptions. Sensitivity analysis

was also considered essential for determining which parameters and processes are most important and for establishing how models can appropriately be used operationally.
The group further discussed the transition from complex research models to simpler operational models. Simple models could potentially be developed from more complex models and used for rapid decision support in the early phase of an event, with more detailed models applied as additional information becomes available. Model outputs should, however, be appropriately validated and quality-controlled before being used for decision-making. Participants also noted that errors can arise from input data and from coupling models with post-processing tools such as GIS.

The applicability of models to different geographical regions was identified as another gap. Models developed using data from specific environments may not adequately represent Nordic conditions, highlighting the need for regionalisation and adaptation.

The potential use of AI was also discussed. AI could potentially facilitate rapid updating of models as new measurements become available, while Bayesian approaches could provide a non-AI alternative. However, participants stressed the need to understand the assumptions, uncertainties and limitations of new algorithms.

Preserving modelling competence was identified as an important long-term priority. Participants highlighted the need for continued training, exercises and knowledge exchange, particularly given the rarity of relevant emergency situations.

Potential areas for Nordic cooperation included:

- regular model comparison, benchmarking and validation exercises;
- exchange of models and modelling experience;
- common approaches to presenting and communicating model outputs and uncertainties;
- improved understanding of the modelling-to-decision-making process; and
- development of a Nordic platform for model exchange and comparison.

Nordic exercises were considered particularly valuable for maintaining competence and testing modelling capabilities under realistic conditions. These could initially be relatively small and gradually expanded to cover different scenarios and phases of an emergency.

Priorities and recommended next steps
The group identified opportunities to strengthen cooperation between regulatory authorities, emergency preparedness organisations, universities and other research environments, including through synergies with related disciplines such as climate and marine modelling.

The group recommended:

- Continue REMSEM-like activities to maintain Nordic cooperation and knowledge exchange.
- Develop training activities and Nordic exercises to maintain modelling competence.
- Establish regular model comparison and benchmarking activities.
- Strengthen cooperation between regulators and research organisations.
- Involve young scientists to support long-term competence and continuity.
- Explore a Nordic model-exchange and comparison platform.

A central message from the discussion was that the objective should not necessarily be to identify a single "best" model, but rather to understand the range of plausible results from different approaches and establish when different models are fit for purpose.

4.2 Group 2: Measurements and modelling – integration, capabilities and possibilities
The discussion focused on the practical challenges of obtaining and using measurements during the difficult conditions that may follow a nuclear detonation. Participants highlighted uncertainties regarding the radionuclide spectrum that may be encountered, as well as limited national capacity to analyse food, feed and drinking water. The organisation of measurements under disrupted conditions was therefore identified as an important preparedness issue.

The need for exercises under realistic and challenging conditions was emphasised. Such exercises could help identify practical limitations in measurement capacity, equipment, logistics and analysis, and clarify how measurements should be integrated with modelling during different phases of an event.

Participants identified the need to strengthen measurement capacity, including both the overall amount of equipment and the flexibility to adapt measurements to different scenarios and requirements. Further work was also considered necessary to characterise the different phases following a nuclear detonation, analogous to the different phases considered following a nuclear power plant accident. Modelling of nuclear detonations over the sea was identified as another area requiring further attention.

Priorities and recommended next steps
The most urgent area for Nordic cooperation was considered to be a joint exercise based on a nuclear detonation scenario. A REMSEM seminar could potentially be used as a platform for a joint tabletop exercise, combined with discussions comparing how different Nordic countries would handle selected aspects of the scenario.

The group recommended:

- Conduct a joint Nordic exercise involving measurements and modelling under a nuclear detonation scenario.
- Use future REMSEM seminars for tabletop exercises addressing practical emergency response.
- Compare national approaches to selected measurement and modelling challenges.
- Strengthen measurement capacity and flexibility, including equipment and analytical capabilities.
- Further develop understanding of different phases following a nuclear detonation, including the specific measurement requirements in each phase.
- Further investigate marine detonation scenarios.

4.3 Group 3: Prioritization – decision process and countermeasures
The discussion focused on the practical decision-making challenges associated with contaminated food, feed and drinking water following a nuclear detonation. Participants emphasised that determining whether food is safe to consume is not necessarily the same as applying regulatory levels for import and export. Clear guidance is therefore needed for decision-makers on how to manage contaminated food that is already available or in production, including the subsequent handling of contaminated food waste.

The need for appropriate measurement protocols was highlighted, particularly for milk, vegetables and feed during the later early phase of an event, and for fish at a later stage. Drinking water was also identified as requiring specific measurement protocols. The relevance of these issues varies between Nordic countries depending on food production, imports and available water resources.

A key issue was the timing of protective actions. Participants stressed that the appropriate action depends strongly on the phase of the event and the level of immediate health risk. Characterising the fallout and establishing situational awareness will therefore be important for determining which measures are appropriate and when they should be implemented.

The group also highlighted differences between Nordic countries in their experience and preparedness, particularly between countries with nuclear power plants and those without. In the longer term, however, food monitoring requirements may become more similar to those following other radiological contamination events.

Priorities and recommended next steps
Further research is particularly needed on radionuclide transfer to fish and the resulting consequences, which was considered especially relevant for Iceland and Norway. The group also identified a need for general Nordic guidance on food and feed following a nuclear detonation.

A Nordic tabletop exercise focusing specifically on contaminated food was recommended. Two contrasting scenarios could be considered: one involving a more distant detonation, where immediate health impacts are limited but food trade and import/export issues become important, and another involving a nearby detonation where immediate health concerns dominate.

The group recommended:

- Develop Nordic guidance on food and feed following a nuclear detonation.
- Develop and compare measurement protocols for food, feed, fish and drinking water.
- Investigate radionuclide transfer to fish, particularly for countries where fish constitutes an important part of the food supply, such as Norway and Iceland.
- Conduct a tabletop exercise focused specifically on contaminated food, covering both immediate health concerns and longer-term food management and trade.
- Strengthen cooperation through existing Nordic networks and groups, including NEP and NORMAN.

4.4 Group 4: Nordic preparedness and cooperation
The discussion identified competence and awareness as important gaps in Nordic preparedness. These gaps exist at several levels, including the strategic and administrative level, where authorities and organisations outside the radiation safety sector may have limited awareness of their responsibilities in a radiological emergency. Participants also noted that normal management and resource arrangements may be significantly disrupted during a major event, which is something that is difficult to prepare for or incorporate in an exercise.

At the tactical level, maintaining sufficient modelling competence was highlighted as particularly important. Nordic countries need to retain a critical mass of expertise capable of understanding and evaluating models, rather than relying exclusively on users of modelling tools who have limited insight into their underlying assumptions and limitations.

The group identified potential benefits from greater harmonisation between Nordic countries, including consideration of differences in dose and reference levels. Risk communication and the psychological aspects of a major emergency were also identified as important areas requiring attention.

Participants emphasised that Nordic emergency preparedness cooperation should extend beyond radiation safety authorities. Other relevant authorities and organisations need to develop their own preparedness arrangements and understand their roles in a radiological emergency.

Priorities and recommended next steps
Maintaining and increasing the exchange of information, experience and expertise was considered a key priority. Participants also highlighted the importance of promoting awareness of existing Nordic cooperation mechanisms such as NKS.

The group recommended:

- Expand the REMSEM network to include a broader range of authorities and stakeholders, especially food agencies in the Nordic countries that until now have not participated in the REMSEM discussions.
- Strengthen cooperation between radiation safety authorities and other organisations responsible for emergency preparedness.
- Maintain and develop modelling competence and critical expertise in the Nordic countries.
- Increase the exchange of information, experience and practical approaches.
- Consider involving industry and other relevant organisations in future activities, such as REMSEM, to provide additional practical perspectives on emergency preparedness and implementation.
- Consider hybrid or remote formats for future seminars to facilitate broader participation, potentially combined with separate events addressing different aspects of REMSEM.

A broader REMSEM network was seen as an opportunity to move beyond cooperation between radiation safety specialists and towards a more comprehensive Nordic preparedness perspective, involving the authorities and organisations that would be required to implement emergency measures in practice.

5. Summary and roadmap

The seminar identified a number of interconnected gaps and opportunities for strengthening Nordic preparedness for nuclear detonation scenarios. A common conclusion was that preparedness requires an integrated approach, linking scenario development, modelling, measurements, situational awareness and decision-making. At the same time, many of the identified challenges are shared across the Nordic countries and could benefit from continued exchange of expertise and coordinated activities.

Based on the presentations and breakout discussions, the following priorities are proposed as a forward-looking roadmap for REMSEM and related Nordic cooperation.

5.1 Modelling and uncertainty

Further work is needed to improve understanding of the uncertainties associated with nuclear-detonation modelling and to determine when different modelling approaches are fit for purpose. Rather than seeking a single "best" model, Nordic cooperation should focus on model comparison, benchmarking, sensitivity and uncertainty analysis, validation, and adaptation of models to Nordic conditions.

Particular attention should also be given to the relationship between complex research models and simpler operational models, as well as emerging approaches such as AI-based modelling and model emulation.

5.2 Measurements and integration with modelling

Measurement capacity and the practical organisation of measurements under difficult conditions were identified as important preparedness gaps. Future work should consider measurement and modelling as an integrated capability, including identifying what needs to be measured, when, and how the results can be used to improve situational awareness and decision-making.

Priority areas include comparison of national measurement capabilities and protocols, identification of important radionuclides and measurement priorities, and further consideration of marine and other specific detonation scenarios.

5.3 Food, environmental transfer and countermeasures

Further knowledge is needed on the behaviour and solubility of fallout particles and on radionuclide transfer through food chains and aquatic systems. Transfer to fish was identified as an area of relevance for several Nordic countries.

There is also a need for improved Nordic approaches to decisions concerning contaminated food, feed and drinking water, including measurement protocols, consumption advice, food restrictions, and management of contaminated food waste. These issues should be considered in relation to the different phases following a nuclear detonation.

5.4 Competence and broader preparedness

Maintaining sufficient Nordic competence in modelling, measurements and emergency preparedness was considered a long-term priority. Continued training, knowledge exchange and involvement of younger scientists are therefore important.

The discussions also highlighted that preparedness cannot rest solely with radiation safety authorities. Food authorities, emergency-management organisations and other relevant stakeholders need to understand their roles and responsibilities and should be more strongly represented in future Nordic cooperation.

The knowledge gaps identified during Groups 1-4 Breakout Discussions, will be communicated to NERIS for consideration in the forthcoming update of the Strategic Research and Innovation Agenda (SRIA) 2027 of the European Platform on preparedness for nuclear and radiological emergency response and recovery.

5.5 Future Nordic cooperation and the role of REMSEM

The discussion on future REMSEM activities indicated clear support for continued Nordic cooperation. However, participants also recognised that practical emergency exercises have a different function from an NKS seminar. Exercises are essential for testing national preparedness and operational procedures, but they naturally limit participation and are more appropriately organised by national radiation safety and emergency-preparedness authorities as part of their regular preparedness activities.

Nordic collaboration would be particularly beneficial in aligning radiological guidelines and intervention thresholds, as well as developing common approaches to presenting and communicating model outputs, uncertainties, decisions, and risks. Greater consistency would make national assessments easier to compare, reduce conflicting cross-border recommendations, build trust and support faster and more coordinated protective actions.

The NKS REMSEM format can instead provide a complementary forum for broader Nordic knowledge exchange, discussion and development of common understanding. Future REMSEM seminars should therefore continue to bring together experts from modelling, measurements, radioecology, food safety and emergency preparedness, while increasingly involving authorities and organisations beyond the radiation safety sector.

Future REMSEM activities could focus on:

- thematic seminars and expert discussions addressing emerging knowledge and preparedness needs with the possibility to invite international expertise,
- joint Nordic research and development projects targeting identified gaps,
- model and methodology comparisons where these can be conducted within the seminar/project framework,
- exchange of data, experience and good practices between Nordic countries, and
- building a broader REMSEM network, including food authorities, emergency-management organisations, research institutions and other relevant stakeholders.

Where appropriate, REMSEM seminars could also be used to prepare or follow up national or Nordic emergency exercises, without becoming an exercise programme in themselves.

5.6 Proposed overall direction

The discussions suggest that REMSEM should continue, but with a clear focus on its added value as a Nordic platform for expert exchange, scientific discussion and development of common approaches. Practical exercises should remain an important part of national preparedness activities, while REMSEM can provide the forum in which the underlying scientific, methodological and cross-border issues are explored.

The longer-term ambition should be to strengthen the connection between research, modelling, measurements and operational preparedness, and to identify areas where Nordic countries can achieve greater preparedness through cooperation than through separate national efforts.

This roadmap provides a basis for developing future REMSEM activities and for identifying potential joint projects, e.g. withing the NKS framework, addressing the most important gaps identified during the 2025 and 2026 seminars.

6. Conclusions

The REMSEM 2026 seminar brought together Nordic experts to further develop the understanding of modelling, measurements and decision-making in the context of nuclear detonation scenarios relevant to the Nordic region. The discussions confirmed that significant scientific, methodological and practical uncertainties remain, but also demonstrated the value of sharing knowledge and experience across disciplines and national borders.

A key conclusion was that modelling, measurements and decision-making need to be considered as interconnected parts of the same preparedness system. Important areas for further work include understanding modelling uncertainties, strengthening and adapting measurement capabilities, improving knowledge of radionuclide transfer and fallout behaviour, and developing a stronger basis for decisions concerning food, feed and other countermeasures.
The seminar also highlighted the importance of maintaining Nordic competence and broadening cooperation beyond radiation safety authorities to include food authorities, emergency-management organisations and relevant research communities.

There was clear support for continued REMSEM activities within the NKS framework. The seminar format was considered well suited to facilitating broad expert participation, knowledge exchange and discussion of emerging scientific and preparedness issues. Practical emergency exercises remain important but are more appropriately conducted as part of emergency-preparedness activities, with REMSEM-like activities providing a complementary Nordic forum for discussing the underlying challenges and sharing experience.

The proposed roadmap, see section 5, provides a basis for continued cooperation, with an emphasis on joint learning, targeted research, model and measurement development, competence building and broader Nordic collaboration. Continued REMSEM activities can thereby contribute to strengthening the scientific basis and practical preparedness for a nuclear detonation in or in the vicinity of the Nordic region.

7. Acknowledgements

The authors would like to thank all participants of the NKS REMSEM 2026 seminar for their valuable contributions, constructive discussions and active engagement throughout the seminar. The broad range of expertise and perspectives represented by the participants was essential to the success of the seminar and to the development of the conclusions and roadmap presented in this report.

NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

8. Disclaimer

9. Appendix – Group presentations

9.1 Group 1 – Plenary report from breakout discussion

What are the most important gaps identified?

- Complex vs. simple model
    - Stakeholder involvement, clear expectations
    - evolve while we go
    - uncertainties difficult
    - complex models might need to many parameters, input

- AI: adding measurements while we go
- non-AI: bayesian updating
- More reliant on measurements data
- Must have understanding of new algorithms (Random forests, Fukushima)

- Simple vs complex, e.g. Gaussian/Eulerian
    - can give different results
    - structural / conceptual uncertainties
    - need multiple models
    - different assumptions in the models
    - transition from simple to complex?
    - need capacity to do probabilistic modelling
    - complex model might hide input parameters
    - models might have primitive errors (like wrong unit of input parameter)

- Gaps
    - regular model comparison needed
    - too many comparison might lead to "identical" models
    - allows to identify uncertainties

- Regulator and Universities might need to collaborate more/much

- Simple models can be built on top of complex models
    - in particularly for fast response (e.g. 100km radius)
    - model results need validation/quality control before being used by stakeholders,
    - might take longer than model-run

- Without sensitivity analysis, we don't know how to use in operation

- Coupling between models (or model and postprocessing/GIS) can be very challenging
    - might introduce new errors
    - often needs long time
- Regionalization of models
    - foodstuff models often not adapted to different countries
    - dispersion model tuned to Nevada dessert
    - both hidden and clear input parameters

Which issues are most urgent for Nordic preparedness, and which could realistically be addressed through Nordic collaboration?

- Preservation of competence (continuity on training/models)
    - 5-10 year perspective
- general preparedness
- harmonization
    - common model output (for comparison)
    - guidelines and threshold values
    - decision communication (might be out of our hands)
- benchmarking / validation exercises
- model-exchange platform (similar to IXP)
    - to exclude human errors
    - to understand modelling uncertainties
- Collate and structure information (whole process from modelling to decision making)
    - how to go back and forth in the change if new questions/results come up
- Nordic Exercise (start small, but get slightly bigger, and different phases)
    - enhance competence in running models (like FDMT)

What should be prioritised in future research and development?

- Utilize potential synergies between disciplines (climate change, marine modelling)

What concrete next steps should REMSEM recommend?

- Continuation of REMSEM
- Training courses
- Involve young scientists
- Exercises

9.2 Group 2 – Plenary report from breakout discussion

What are the most important gaps identified?

- How to organise the measurements? (there will be difficult conditions at a radiological event).
- Need for exercises at disturbed conditions.
- Limited capacity to analyse e.g. food, feed and drinking water.
- We don’t know what the exact spectra will look like.

Which issues are most urgent for Nordic preparedness, and which could realistically be addressed through Nordic collaboration?

- Organise a joint exercise with a nuclear detonation scenario.

What should be prioritised in future research and development?

- Better capacity for measurements
    - total amount of equipment
    - more flexibility

- Identification of different phases after a nuclear explosion (in analogue to after a NPP accident).
- Modelling an explosion event over sea.

What concrete next steps should REMSEM recommend?

- Use a REMSEM seminar for a joint tabletop exercise.
- Discuss selected topics and compare the countries case handling

9.3 Group 3 – Plenary report from breakout discussion

What are the most important gaps identified?

- When food is ”safe to eat” not the same issue as the import/export levels. What advice decision maker should be given about contaminated food (available or in production). How about waste handling from contaminated food?
- Measurement protocols for monitoring foodstuff, in particular milk, leafy vegetables and feed) after a nuclear detonation – not very early stage
- Measurement protocols for monitoring fish after a nuclear detonation – important at a later stage
    - For Iceland – rely on import thus more sensitive, Finland has some food stores, Sweden is at a planning stage
- Measurement protocols for drinking water.

Which issues are most urgent for Nordic preparedness, and which could realistically be addressed through Nordic collaboration?

- Which recommendations to give at an early stage after a nuclear detonation due to immediate health concern (much higher than 1 mSv)? For example, only to eat protected food? Need to investigate the distance where this would be of importance.
    - NEP – there will be an appendix for nuclear detonation to the flag book but maybe will not contain any details?
- Which reference level to use for drinking water? maybe not an issue for Iceland (ground water)
- Timing – need to do right thing at a right time. Good idea to characterise the fallout. Situational awareness for nuclear explosion compared to nuclear power plant accident. Sweden and Finland with NPPs have more experience compared to other Nordic countries? More early phase questions - in the long-term similar food monitoring as NPPs.

What should be prioritised in future research and development?

- More knowledge about transfer to fish and the consequences – important for Iceland and Norway
- General guidance for foodstuff and feedstuff for a nuclear explosion

What concrete next steps should REMSEM recommend?

- Tabletop exercise to focus on contaminated food (not focus on other protective action)
    - One case with a nuclear explosion further away (no immediate health concern but impact of import/export)

    - One case with a nuclear explosion near with immediate health concern

- Collaboration among already existing Nordic groups:
    - NEP group external dose group
    - New NORMAN group on monitoring for emergency and routine

9.4 Group 4 – Plenary report from breakout discussion

What are the most important gaps identified?

- Competence and awareness gaps:
    - Different levels:
        - Administrative/strategic level
            - Other agencies need to have EP plans – lack of awareness
            - Disruption of normal resource behaviour during incident – management, administration
        - Tactical level:
            - Modelling capabilities – importance to maintain a critical mass - not only "black box" users

Which issues are most urgent for Nordic preparedness, and which could realistically be addressed through Nordic collaboration?

- Harmonization needs:
    - Dose levels harmonized across all Nordic countries?
    - Addressing psychological aspects of an emergency – risk communication
- Nordic collaboration between not only RS agencies
    - More authorities need to develop emergency preparedness plans and be made aware of the challenges

What should be prioritised in future research and development?

- Maintain and increase information and experience exchange
- "Spread the word" on initiatives like NKS
- Development of comprehensive models and identification of data knowledge gaps
- Funding aspects differ in the EP sector – not a red flag (?) to involve both regulator and industry to finance projects

What concrete next steps should REMSEM recommend?

- Include more stakeholders/authorities in the "REMSEM" network
- Increase the scope to include more organisations
- Make future seminars also remote seminar
    - Or two events with different focus
- Reach out more to industry for future collaborations (future REMSEM-like seminars) for practical input
    - More practical knowledge of EP implementation

Bibliographic Data Sheet	**NKS-514**

Title	NKS-B REMSEM – Modelling and Monitoring of Fallout Impacts After a Nuclear Explosion: Enhancing Nordic Preparedness
Author(s)	Henrik Öberg[1], Eyjólfur Guðmundsson[1], Pernille Ahlmann Jensen[1] Anders Axelsson[2], Anna Maria Blixt Buhr[2], Lars Ideström[2], Catharina Söderström[2] Justin Brown[3], Ali Hosseini[3] Jenny Aasa[4], Daniel Edgar[4], Amelie Fondell[4] Pia Keski-Jaskari [5], Päivi Roivainen[5], Mikko Voutilainen[5] Fredrik Lidman[6], Annika Tovedal[6] Elias Pagh Senstius[7], Joakim Hoff-Møller [7] Ole Christian Lind[8] Violeta Hansen[9], Mats Isaksson[9]
Affiliation(s)	[1]Icelandic Radiation Safety Authority [2]Swedish Radiation Safety Authority [3]Norwegian Radiation and Nuclear Safety Authority [4]Swedish Food Agency [5]Finnish Radiation and Nuclear Safety Authority [6]Swedish Defence Research Agency [7]Danish Emergency Management Agency [8]Norwegian University of Life Sciences [9]University of Gothenburg
ISBN	978-87-7893-614-1
Date	September 2026
Project	NKS-B / REMSEM
No. of pages	44
No. of tables	0
No. of illustrations	0
No. of references	0
Abstract max. 2000 characters	The NKS REMSEM 2026 seminar was held in Reykjavík on 19–20 August 2026, bringing together Nordic experts to discuss modelling, environmental measurements and emergency preparedness in relation to nuclear detonation scenarios relevant to the Nordic region. The seminar followed the first REMSEM seminar in 2025, which identified scientific and practical challenges related to modelling radionuclide transfer following nuclear explosions. The 2026 seminar focused on strengthening the connection between scenario development, modelling, measurements, situational awareness and decision-making. Presentations addressed modelling approaches and

development needs, food-chain impacts and countermeasures, measurement integration and data use, and urgent protective actions.

Breakout discussions focused on four themes: modelling under high uncertainty; integration of measurements and modelling; prioritisation and countermeasures; and Nordic preparedness and cooperation. Common challenges included uncertainties in modelling and source terms, limited measurement and analytical capacity, knowledge gaps concerning radionuclide behaviour and transfer to food and aquatic systems, and differences in national preparedness arrangements.

Several priorities for continued Nordic cooperation were identified, including model comparison and benchmarking, strengthened measurement capabilities and protocols, improved guidance for food and feed, competence development, and broader involvement of relevant authorities and organisations.

The seminar confirmed the value of continued REMSEM activities within the NKS framework. While practical exercises remain important for Nordic and national emergency preparedness, REMSEM provides a suitable Nordic forum for expert exchange, scientific discussion and development of common approaches. The seminar outcomes are consolidated into a forward-looking roadmap for strengthening Nordic decision support and preparedness for nuclear detonation scenarios.

Key words — Nuclear detonation, radioecological modelling, environmental monitoring, emergency preparedness, Nordic cooperation