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Nordic nuclear safety research

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Nuclear Emergency Preparedness

Bent Lauritzen
Risø National Laboratory, Denmark

February 2002

Nordic Nuclear Safety Research (NKS)

organizes joint four-year research programs involving some 300 Nordic scientists and dozens of central authorities, nuclear facilities and other concerned organizations in five countries. The aim is to produce practical, easy-to-use reference material for decision makers and help achieve a better popular understanding of nuclear issues.

To that end the results of the sixth four-year NKS program (1998 - 2001) are herewith presented in a series of final reports comprising reactor safety, radioactive waste management, emergency preparedness, radioecology, and databases on nuclear threats in Nordic surroundings. Each report summarizes the main work, findings and conclusions of the six projects carried out during that period. The administrative support and coordination work is presented in a separate report. A special Summary Report, with a brief résumé of all projects, is also published. Additional copies of the reports on the individual projects as well as the administrative work and the Summary Report can be ordered free of charge from the NKS Secretariat.

The final reports - together with technical reports and other material from the 1998 - 2001 period - will be collected on a CD-ROM, also available free of charge from the NKS Secretariat.

During the last few years a growing interest has been noted among sister organizations in the three Baltic States, especially in the field of emergency preparedness, radiation protection and radioecology. This has widened the scope of our joint Nordic work and fed new influences and valuable competence into the NKS program. The Baltic participation is therefore gratefully acknowledged.

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Nuclear Emergency Preparedness

Final Report of the Nordic Nuclear Safety Research Project BOK-1

Bent Lauritzen

Risø National Laboratory, Denmark

February 2002

This is NKS

NKS (Nordic Nuclear Safety Research) is a scientific cooperation program in nuclear safety, radiation protection and emergency preparedness. It is a virtual organization, serving as an umbrella for joint Nordic initiatives and interests. Its purpose is to carry out cost-effective Nordic projects producing seminars, exercises, reports, manuals, recommendations, and other types of reference material. This material, often in electronic form on the official homepage www.nks.org or CD-ROMs, is to serve decision-makers and other concerned staff members at authorities, research establishments and enterprises in the nuclear field.

A total of six projects were carried out during the sixth four-year NKS program 1998 - 2001, covering reactor safety, radioactive waste, emergency preparedness, and radioecology. This included an interdisciplinary study on nuclear threats in Nordic surroundings. Only projects of particular interest to end-users and financing organizations have been considered, and the results are intended to be practical, useful and directly applicable. The main financing organizations are:

- The Danish Emergency Management Agency
- The Finnish Ministry for Trade and Industry
- The Icelandic Radiation Protection Institute
- The Norwegian Radiation Protection Authority
- The Swedish Nuclear Power Inspectorate and the Swedish Radiation Protection Authority

Additional financial support has been received from the following organizations:
In Finland: Fortum (formerly Imatran Voima, IVO); Teollisuuden Voima Oy (TVO)
In Sweden: Sydkraft AB; Vattenfall AB; Swedish Nuclear Fuel and Waste Management Co. (SKB); Nuclear Training and Safety Center (KSU)

To this should be added contributions in kind by all the organizations listed above and a large number of other dedicated organizations.

NKS expresses its sincere thanks to all financing and participating organizations, the project leaders, and all participants, all in all some 300 persons in five Nordic countries and the Baltic States, without which the NKS program and this report would not have been possible.

Disclaimer

The views expressed in this document remain the responsibility of the author(s) and do not necessarily reflect those of NKS.

In particular, neither NKS nor any other organization or body supporting NKS activities can be held responsible for the material presented in this report.

Abstract

Final report of the Nordic Nuclear Safety Research project BOK-1. The BOK-1 project, "Nuclear Emergency Preparedness", was carried out in 1998-2001 with participants from the Nordic and Baltic Sea regions. The project consists of six sub-projects: Laboratory measurements and quality assurance (BOK-1.1); Mobile measurements and measurement strategies (BOK-1.2); Field measurements and data assimilation (BOK-1.3); Countermeasures in agriculture and forestry (BOK-1.4); Emergency monitoring in the Nordic and Baltic Sea countries (BOK-1.5); and Nuclear exercises (BOK-1.6). For each sub-project, the project outline, objectives and organization are described and main results presented.

Key words

Data Analysis; Emergency Plans; Gamma Spectroscopy; Interlaboratory Comparisons; Mobile Measurements; Nuclear Exercises; Progress Report; Quality Assurance; Radiation Monitoring; Radioactivity; Reactor Accidents; Remedial Action; Research Programs.

Acknowledgements

The author is indebted to the many BOK-1 participants for their active contribution to the project and for their commitment towards the project objectives. Special thanks for co-ordination of sub-projects are due to Sigurður Emil Pálsson (BOK-1.1), Hans Mellander (BOK-1.2), Magnus Brink (BOK-1.4), and Finn Ugletveit (BOK-1.6), and to Torkel Bennerstedt, NKS, for his enthusiastic support throughout the project period. The present report summarizes the results obtained and has drawn extensively from the technical reports published within the project.

Summary

The BOK-1 project, *Nuclear Emergency Preparedness,* was carried out as part of the 1998-2001 Nordic Nuclear Safety Research program. The BOK-1 project comprises a number of activities aimed at developing and improving nuclear emergency preparedness. The activities include surveys of techniques and equipment, workshops and exercises. The project includes research activities concerning monitoring and modeling the radiological impact of nuclear accidents, aiming at developing emergency response plans.

Radiation protection authorities, governmental agencies, universities, research organizations and laboratories have been partners in the project, which have had participants from all of the Nordic and Baltic Sea countries.

The project was divided into six sub-projects:

BOK-1.1 Laboratory measurements and quality assurance

The objective was to develop the quality of laboratory measurements of radioactivity, aimed both at emergency situations and at radioecology studies using radioactive tracer elements. To this purpose, two inter-comparison exercises of α-, β- and γ-measurements on environmental samples were carried out. Two consecutive inter-comparison exercises of gamma spectrometry software were conducted to check the ability to handle emergency situations. Seminars on accreditation and measurement techniques were arranged and a study of source preparation techniques for α-, and β-measurements was undertaken. In addition, a survey of sampling techniques employed in the Nordic countries was carried out.

The Nordic inter-comparison exercises of laboratory analyses revealed large differences in reported results, and were found to be important both for quality assurance/control reasons and as part of basic training for new staff. Also, inter-comparison exercises may assist the implementation of new equipment and techniques for laboratory measurements. Therefore, inter-comparison exercises are valuable for the Nordic laboratories performing radioactivity measurements as part of the nuclear emergency preparedness system.

BOK-1.2 Mobile measurements and measurement strategies

The objective was to test, compare and integrate different types of field measurements using mobile equipment. Mobile gamma spectrometry aims at mapping contamination levels following a nuclear accident or searching for lost radioactive sources. A Nordic exercise for car-borne gamma spectrometry (CGS), RESUME 99, was carried out at Gävle in Sweden in September 1999, and spectral data collected during the exercise has been used in a study of CGS techniques and interpretation of such data. As part of the Barents Rescue 2001 LIVEX in September 2001, the "Gamma Search Cell" exercise was aimed at the

search for and identification of lost radioactive sources by airborne and car-borne teams. The BOK-1 project has been engaged in the planning and evaluation of this exercise and has provided financial support for Nordic participation.

The two exercises on field measurements with mobile equipment have demonstrated increased capabilities for emergency monitoring of radioactivity, and in particular and for data processing and visualization. The exercises generated valuable data on mobile gamma-ray spectrometry, which can be used to test analytical and practical methods for integrating different platforms in an emergency collaboration on mapping fallout areas or for locating and identifying lost radioactive sources.

BOK-1.3 Field measurements and data assimilation

Data assimilation denotes the integration of available data following a nuclear accident, with the purpose of improving early prognoses on the radiological consequences of the accident. Activities within the sub-project included a Ph.D. program on data assimilation of atmospheric dispersion, focusing on making a source term estimate based on off-site dose rate measurements, and a ^{41}Ar field experiment for simultaneous monitoring of meteorology, source term, plume and radiation field.

The objective of the Ph.D. program has been to advance theoretical development in the data assimilation project. In a wider perspective, the Ph.D. program has served to support education in the field of radiation protection. The argon-41 field experiment was carried out successfully and has generated data that can be used both to validate atmospheric dispersion and dose rate models, and in the constructing and testing of data assimilation models for short-range atmospheric transport.

BOK-1.4 Countermeasures in agriculture and forestry

The main objective of the sub-project was to produce a Nordic handbook on agricultural countermeasures, intended for a target group of nuclear and agricultural authorities, the agricultural community and the food-industry end-users. Quantitative information has been compiled on dose-reducing countermeasures in agriculture and forestry, and presented in a datasheet report and in an electronic database. A late-phase exercise, Huginn, was conducted to test the ability, based on the datasheets, to calculate the radiological and economic consequences of an agricultural countermeasure following a nuclear accident. In addition, a survey of environmental transfer factors for nuclear emergency preparedness was undertaken. In a separate study, forest remediation techniques in the Nordic countries have been reviewed.

Increased collaboration between the Nordic agricultural and radiation protection communities has been a valuable outcome of this sub-project. The effective implementation of agricultural countermeasures relies on methods for consequence assessment be further developed and implemented into emergency preparedness decision support systems. Tools developed in this sub-project can be used as a basis for late-phase exercises on agricultural countermeasures, involving authorities within agriculture and radiation protection.

BOK-1.5 Emergency monitoring in the Nordic and Baltic Sea countries

A survey of radiological monitoring systems in the Nordic and Baltic Sea countries: Russia, Estonia, Latvia, Lithuania, Poland and Germany was carried out. The survey was presented in a joint publication of NKS and the Reference Group for Baltic Sea States on Emergency Monitoring Integrated Systems and Early Warning.

BOK-1.6 Nuclear exercises

A workshop, Baltic Nuclear, was held with participation by nuclear authorities and the top-management of nuclear power plants in the Baltic Sea Region, with the purpose of testing the ability to handle the information pressure encountered during a nuclear emergency. A study of a mobile Internet for nuclear emergency preparedness was undertaken and the system was tested at nuclear emergency exercises.

Many of the results obtained in the sub-projects have been communicated in project reports and through dedicated seminars, but also through the use of web pages and internally at numerous project meetings. The present summary report describes the main result obtained in the project. A more detailed account of the project results can be found in the BOK-1 technical reports.

Sammenfatning

BOK-1 projektet, Nukleart Beredskab, indgår i Nordisk Kernesikkerhedsforskning (NKS) programmet 1998-2001. BOK-1 omfatter en række aktiviteter, der alle sigter mod at udvikle og forbedre det nukleare beredskab i Norden. Aktiviteterne spænder fra kortlægning af beredskabsmetoder og –udstyr, afholdelse af seminarer, workshops og øvelser til udvikling og test af beredskabsplaner, metoder og udstyr.

Strålingsbeskyttelsesmyndigheder, forskningsinstitutioner og –laboratorier har været partnere i projektet, som har haft bred deltagelse fra alle nordiske lande og fra landene i Østersøområdet.

BOK-1 projektet består af seks delprojekter:

BOK-1.1 Laboratoriemålinger og kvalitetssikring

Formålet med delprojektet har været at sikre og forbedre kvaliteten af laboratoriemålinger af radioaktivitet, med henblik på såvel beredskabssituationer som på radioøkologiske sporstofstudier. To sammenligningsmålinger af radioaktivitet i miljøprøver har været udført med bred nordisk deltagelse, og to beredskabsøvelser i analyse af gammaspektre har været afholdt for at undersøge nordiske laboratoriers mulighed for at bistå ved nukleare ulykker. Seminarer om akkreditering og om detektorer og måling af radioaktivitet har været afholdt, og en analyse af prøveforberedelse og prøvehåndtering i forbindelse med alfa- og betamålinger er gennemført. Eksisterende metoder til indsamling af miljøprøver i de nordiske lande efter et nukleart nedfald er blevet kortlagt.

Sammenligningsmålingerne viste betydelige forskelle mellem de rapporterede resultater og har derigennem været værdifulde for kvalitetssikringen af laboratorieanalyser og til uddannelse og træning af nye medarbejdere. Sammenligningsmålinger er befordrende for udbredelse af nyt udstyr og metoder, og vil dermed også fremover være et nyttigt instrument for nordiske laboratorier, der udfører radioaktivitetsmålinger som en del af det nukleare beredskab.

BOK-1.2 Mobile målinger og målestrategier

Formålet med delprojektet har været at sammenligne og integrere feltmålinger med brug af mobilt måleudstyr. Mobil gammaspektrometri sigter mod at kortlægge landområder for nedfald efter en nuklear ulykke, eller at eftersøge forsvundne radioaktive kilder. En nordisk øvelse for mobil gammaspektrometri med anvendelse af biler (CGS), RESUME 99, blev gennemført i Gävle (Sverige) i 1999, og måledata fra denne øvelse er blevet anvendt i et studium af CGS metoder og fortolkning a CGS data. I øvelsen Barents Rescue 2001 LIVEX i september 2001 indgik ”Gamma Search Cell”, som havde til formål at eftersøge og identificere forsvundne radioaktive kilder ved hjælp af mobile land-baserede og luftbårne målehold. BOK-1 projektet bidrog til planlægning og evaluering af ”Gamma Search Cell”, og leverede finansiel støtte til nordisk deltagelse i øvelsen.

De to øvelser for mobil gammaspektrometri har påvist en forbedret kapacitet for beredskabsmålinger af radioaktivitet. Et resultat af øvelserne med mobile målinger er et værdifuldt datasæt, der kan bruges til at teste analytiske og/eller praktiske metoder til integration af forskellige mobile målesystemer, til kortlægning af radioaktiv forurening og til eftersøgning og identifikation af forsvundne radioaktive strålekilder.

BOK-1.3 Feltmålinger og dataassimilering

Dataassimilering ved en nuklear ulykke betegner inddragelsen af tilgængelige måledata til forbedring af prognoser over ulykkens radiologiske konsekvenser. Aktiviteter udført inden for projektet består af et Ph.D. program om dataassimilering af atmosfærisk spredning med fokus på bestemmelse af kildeleddet ud fra ”off-site” dosishastighedsmålinger, samt af et eksperiment over atmosfærisk spredning af argon-41, hvor samtidige målinger af meteorologi, kildeled, røgfane og strålingsfelt blev gennemført

Formålet med Ph.D. programmet har været at fremme den teoretiske udvikling i dataassimileringsprojektet, og mere overordnet, at medvirke til uddannelse inden for strålingsbeskyttelsesområdet. Argon-41 eksperimentet blev gennemført med succes og har frembragt et værdifuldt data sæt, der kan benyttes til at validere atmosfæriske sprednings- og dosisberegningsmodeller, samt i udviklingen af dataassimileringsmodeller for kort-distance atmosfærisk spredning.

BOK-1.4 Modforanstaltninger for landbrug og skovbrug

Hovedformålet med delprojektet har været at udarbejde en database, der beskriver de mulige modforanstaltninger inden for landbrug og skovbrug efter en nuklear ulykke, samt at skrive en håndbog over tiltag inden for landbrugsproduktion. Håndbogens målgrupper er nordiske myndigheder for strålingsbeskyttelse, beredskab og fødevareproduktion, samt nordiske landbrugsorganisationer og fødevareindustri. En elektronisk manual med databasen er blevet udviklet. En sen-fase øvelse, Huginn, er gennemført, for at undersøge mulighederne for med støtte i databasen at beregne de radiologiske og økonomiske følger af dosisbegrænsende modforanstaltninger inden for landbruget efter en nuklear ulykke. Et udredningsarbejde over Nordiske overførselsfaktorer til fødevarer, til brug for det nukleare beredskab, er gennemført. I et separat studium, er teknikker til afhjælpning af radioaktiv forurening af nordiske skovområder analyseret.

Et værdifuldt resultat af dette delprojekt har været et øget samarbejde mellem nordiske landbrugs- og strålingsbeskyttelseskredse. En effektiv iværksættelse af modforanstaltninger inden for landbrug afhænger af, at metoder til konsekvensberegning bliver videreudbygget og implementeret i beslutningsstøtteværktøjer. Modeller udviklet inden for projektet vil kunne benyttes som grundlag for en sen-fase øvelse om tiltag indenfor fødevareproduktion, der involverer landbrugs- og strålingsbeskyttelses-myndigheder.

BOK-1.5 Nukleare målesystemer i de nordiske lande og i Østersøområdet

En oversigt over beredskabsmålesystemer i de nordiske lande og landende omkring Østersøen er fremstillet. Oversigten er publiceret som en fælles rapport fra NKS og ”Reference Group for Baltic Sea States on Emergency Monitoring Integrated Systems and Early Warning”.

BOK-1.6 Nukleare øvelser

En workshop, “Baltic Nuclear”, er afholdt med deltagelse af nordiske beredskabsmyndigheder og ledelsen af kernekraftværkerne omkring Østersøområdet. Workshoppen blev gennemført som en nuklear beredskabsøvelse med et stort informationspres (fra medierne) på deltagerne. Anvendelsen af mobilt Internet under en nuklear ulykke er undersøgt, og et udstyr til brug for mobilt Internet er opsat samt testet ved internationale beredskabsøvelser.

BOK-1 projektets resultater er i det væsentlige formidlet gennem projektrapporter, ved seminarer og ved brug af hjemmesider, samt internt i projektet ved afholdelse af en lang række projektmøder. Indeværende slutrapport beskriver projektets hovedresultater med henvisning til BOK-1 projektets delrapporter.

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Introduction

Nuclear emergency preparedness aims at the effective implementation of protective measures to mitigate the consequences of a nuclear accident or a radiological emergency. Important aspects of nuclear emergency preparedness are the development of an emergency response plan, and the ability to assess a nuclear or radiological accident through monitoring and modeling, thereby forming the basis for interventions.

The BOK-1 project comprises a number of activities aimed at developing and improving nuclear emergency preparedness. The activities supported by the project include surveys of techniques and equipment, workshops and exercises aimed at developing and testing emergency response plans and people, techniques and equipment. Also included in the project are research activities aimed at improving ways to monitor and model the radiological impact of nuclear accidents and develop response plans.

Many of the results obtained have been communicated in project reports and through dedicated seminars, but also through the use of web pages and internally at numerous project meetings. The present summary report describes the report outline and the main results obtained. A more detailed account of the project results can be found in the technical reports, listed in the reference section.

The BOK-1 project is organized into six sub-projects, dealing with various aspects of planning, improving and testing nuclear emergency response. The sub-projects range from quality assurance of laboratories performing radioactivity measurements (BOK-1.1), development and test of procedures for mobile gamma ray spectrometry (BOK-1.2), investigation of data assimilation techniques for atmospheric dispersion (BOK-1.3), to developing and examining procedures and guidelines for decision support for countermeasures in agriculture and forestry (BOK-1.4). Radiological monitoring system in the Nordic and Baltic Sea countries has been surveyed in the sub-project BOK-1.5, and finally, in BOK-1.6 the focus has been on information exchange during a nuclear emergency.

The objectives of each sub-project have been described in the BOK-1 project plan (NKS-5), and are summarized below.

BOK-1.1 Laboratory measurements and quality assurance

The main objectives have been

> *to establish quality assurance and quality control of laboratory measurements; to perform inter-comparison of sampling techniques and γ-spectrum analysis software; and to improve co-operation in establishing laboratory and accreditation procedures.*

BOK-1.2 Mobile measurements and measurement strategies

The main objectives have been

> *to investigate the feasibility of integrating different field measurements, mainly mobile equipment (car-borne and airborne), in the early phase of a nuclear emergency situation; to participate in a large European exercise on mobile γ-spectroscopy with the aim of acquiring experience in applying the results for emergency response purposes*

BOK-1.3 Field measurements and data assimilation

The main objectives have been

> *to develop a data assimilation system, which integrates field measurements in real-time emergency response so an improved prognosis for the consequences in the early phases of an accident can be achieved; to investigate how measurement strategies can be optimized with the aim of assisting in employing early countermeasures*

BOK-1.4 Countermeasures in agriculture and forestry

The main objectives have been

> *to prepare a Nordic data base (handbook) on agricultural countermeasures and clean-up operations; to develop guidance on the application of data bases in optimizing dose reduction by clean-up; to investigate the feasibility of different waste treatment operations following the clean-up of contaminated areas; and to exchange Nordic views on agricultural countermeasures with regard to their applicability and engage in discussions as to whether different measures should apply to the Nordic countries*

BOK-1.5 Emergency monitoring in the Nordic and Baltic Sea countries

The main objectives have been

> *to collect and examine emergency monitoring strategies and methods used in all Nordic and Baltic Sea countries; and to make updated information available on the Internet*

BOK-1.6 Nuclear exercises

The main objectives have been

> *to plan and participate in Nordic and international exercises with the aim of improving emergency plans in the Nordic countries*

In the following sections each sub-project is described in detail. The scope and contents of several of the sub-projects have been changed since the start of the project, as some planned activities have been cancelled or discontinued, while other activities have been initiated during the project period. The overall objectives of each sub-project however, as described above, have been maintained throughout the project period.

A list of Nordic participants is provided in Appendix 2. Radiation protection authorities, governmental agencies and laboratories, contracting laboratories, universities and research organizations have been partners in the project, which have drawn participants from all of the Nordic and Baltic Sea countries. In addition, private consultants have been engaged in the project, and people from the nuclear industry, radiation protection and agricultural community have participated in the project workshops, seminars and exercises.

Collaboration and interaction between authorities and experts in nuclear emergency preparedness has been a key factor in executing many of the activities, but has also by itself been a valuable outcome of the project.

The BOK-1 project has been sponsoring a Ph.D. program during the present NKS program period. In this program data assimilation techniques for modeling atmospheric dispersion of radioactive releases are investigated. The Ph.D. program, which has been an integral part of the BOK-1.3 sub-project, has served to advance theoretical developments in the sub-project, but has also served the more general purpose of supporting the education of scientists in the field of radiation protection.

An overview of the project economy is provided in Appendix 3. The Budget for the period 1998-2001 totals DKK 7,666,000 comprising NKS and non-NKS funding. In addition, national contribution to the project activities, comprising work and travel expenses, are estimated to be in the order of DKK 9,500,000.

BOK-1.1 Laboratory measurements and quality assurance

Laboratories performing radioactivity measurements have an important role in the nuclear emergency preparedness system. Measurements on environmental and industrial samples are carried out on a routine basis, monitoring for unexpected increases in activity levels, and following a nuclear accident fast and reliable laboratory analysis will be called for to assess the radiological situation.

In the Nordic countries laboratories performing radioactivity measurements include governmental, research, hospital, and industry laboratories. While some of these are contracted by the respective nuclear emergency authorities, many of the laboratories do not carry out emergency preparedness measurements on a regular basis. Emergency preparedness measurements may pose special problems to these laboratories: large numbers of samples to be analyzed, the demand for short reporting time and also, radionuclides may be encountered that are seldom observed, even by the contracted laboratories.

The emergency management needs to have confidence in results obtained in laboratories. Because decisions on intervention, e.g. with respect to the use of contaminated foodstuffs, may rely on laboratory measurements it is important to ensure the quality of these. A formal and generally accepted way of demonstrating quality of measurements is through accreditation. Benchmark exercises may help participating laboratories both in improving and demonstrating quality.

Quality of radioactivity measurements is often understood as accuracy of reported results. However, in the context of emergency preparedness, proper identification of radionuclides, short reporting time and consistency of results, e.g. with respect to a sequence of measurements on similar samples, may be even more important than high accuracy.

The objective of the BOK-1.1 project has been to develop the quality of laboratory measurements of radioactivity, aimed both at emergency situations but also at radioecology studies using radioactive tracer elements. To this purpose, two inter-comparison exercises of α-, β- and γ-measurements on environmental samples have been carried out. Two consecutive inter-comparison exercises of gamma spectrometry software have been conducted to check the ability to handle emergency situations. Seminars on accreditation and on detectors and radionuclide measurement techniques have been held and a study of source preparation techniques for α-, and β-measurements was undertaken. In addition, a survey of sampling techniques employed in the Nordic countries has been carried out.

A website, **http://www.gr.is/bok-1.1/**, was maintained throughout the project period to inform on project activities, and as a means of communicating Internet links relevant to the project.

Radioactivity measurements

Two inter-comparison exercises on radioactivity measurements of environmental samples have been carried out. By performing two exercises in a relatively short time interval, it has been possible to compare the measurement results obtained on similar samples in the two exercises and to examine possible improvements in measurement accuracy.

In the first exercise [NKS-19], environmental samples of dry milk, meat, sediment, hay, seaweed and seawater were packed, homogenized and distributed to a total of thirty-five laboratories in the Nordic and Baltic countries. The selection of materials and analyses were based on a questionnaire that was sent to potential participants in the summer of 1998. Based on the response the work was planned to include all types of radioactivity measurements: gamma (Cs-137, K-40, Co-60 and others), Sr-90, transuranics and Tc-99m. However, it was disappointing that very few laboratories reported values for Tc-99 as this had been specially requested before the start of the exercise. Luckily, most laboratories responded with gamma results (95% response) and partly with Sr-90 results (60 % response).

Participating laboratories were allowed to re-submit values if they felt that they had improved detector calibrations, a background determination, etc. This was done in order to encourage people to improve their general laboratory practice. About one-third of the participants made large or small changes to the first reported values. Two laboratories had reported activity values of bequerel per kilogram of ash weight rather than dry weight, some laboratories re-calibrated their Ge-detectors, and some again changed their background values.

The results of the gamma analysis have been mixed. For activity levels above 10 Bq kg^{-1} typically between 70 and 90% of the results could be included in a balanced (reduced) mean where outlying results have been excluded. For lower activity levels only 50 to 70 % of the results were included in a balanced mean value. The worst case was seawater where only 4 out of 14 results were included in the balanced mean. An effort has been made to identify the main sources of variance. The effect of ashing samples (to improve counting efficiency) was examined, but it could not be shown to improve results. Also, it could not be shown whether using single nuclide calibrations gives better results than using efficiency curves based on mixed calibration sources. There seemed to be a tendency that laboratories that handled many samples scored better than those handling fewer ones. This indicates that laboratory experience is the key to good results.

The Sr-90 analysis showed larger scatter than the gamma analysis. Between 33 and 75 % of the results could be included in a balanced mean. However, some of those results that were not included in the mean value were reported as “below detection limit”. The analysis of Sr-90 is complicated and this is clearly reflected in the large scatter.

Relatively few laboratories did analyses of transuranics. The results for transuranics in sediments (analyzed by most laboratories) were useless as it was realized that the sediment material was not homogeneous with respect to transuranics. Only three results were reported for seaweed, but they were all in agreement. Tc-99 was analyzed by only three laboratories. Good agreement was found between the reported values.

In the second inter-comparison exercise [NKS-2002c] the analyses of three sample materials from the first exercise were repeated (dry milk, seaweed and seawater) and three new materials were introduced (aerosols, soil and lake water). For each sample material weighted average radionuclide concentrations were calculated excluding outlying results.

The results for dry milk were very similar to those from the first round with 15 out of 19 results included in the weighted average for both K-40 and Cs-137. The results indicate an improvement for Cs-137, attributed to more realistic (higher) uncertainties and better background subtraction (fewer results being too high), cf. Figure 1. The results for seawater improved significantly: in the first exercise the results showed considerable scatter, while the scatter was reduced in the second exercise. However, with only 4 out of 8 results included in the weighted mean there is still room for improvement. Three laboratories analyzed the seawater for Tc-99 with reasonable agreement. For seaweed the results were not better than in the first inter-comparison exercise. The activity levels of the seaweed samples were quite similar for the two exercises, but the scatter in the results increased at the second exercise.

The soil samples were taken at Gävle in Central Sweden; they contained high levels of Cs-137, which were relatively easy to analyze with good counting statistics. However, the scatter in the results was relatively large compared to the reported uncertainties. One reason could be the presence of a variable moisture content due to incomplete drying. The soil samples were also analyzed for Pu, and very good agreement was found for six of the seven submitted results. The aerosol material was relatively difficult to analyze and only 60 % of the results were included in the weighted mean. The lake water also came from Gävle and represented a high-level sample for Cs-137 (approx. 170 Bq/kg). Eight out of eleven results were included in the weighted mean.

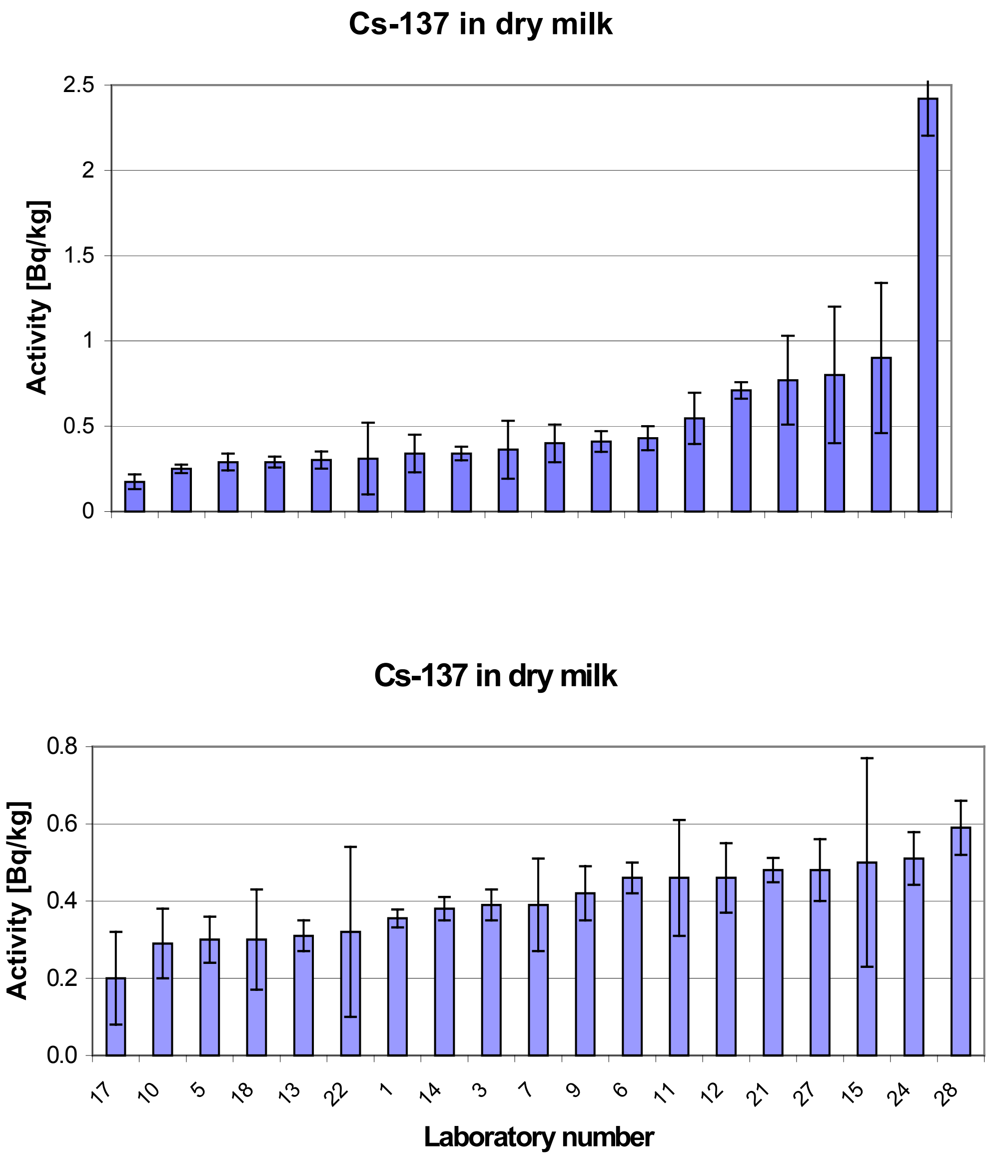


Figure 1. Laboratory measurements of radioactivity: Measurements of ^{137}Cs in dry milk in the first (top) and second (bottom) inter-comparison exercise.

Overall, 70 - 90% of the results of the gamma analysis were included in the weighted means for the traditional sample types. For the difficult samples (especially seawater and aerosols) these numbers dropped to 50 - 70%. In this respect, there was no significant difference between the first and second inter-comparison exercises. Five sample types were analyzed for Sr-90 by up to 10 laboratories. Generally the agreement was poorer than for the gamma analysis, but the variance in the results decreased significantly from the first to the second round. This may partly be explained by the lack of participation in the second exercise by a number of participants with low performance for the Sr-90 analyses in the first exercise.

In summary, both inter-comparisons have demonstrated that there is room for considerable improvement in the quality of the analysis of radioactivity in environmental samples. The improved results in the complex analyses for Pu-239/240 than those of relatively simple gamma spectrometric analyses indicates that a strong "operator dependence" is present. Training and improved quality control are essential in order to improve the analytical quality.

Sampling procedures

The aim of this work has been to compile information on the sampling techniques for radioactivity measurements currently in use in the Nordic countries [NKS-17]. The survey covers sampling of pasture, soil and deposition. The survey was restricted to sampling techniques for emergency preparedness, while monitoring and sampling for scientific studies of special processes were not included.

The survey is based on contributions from those radiation protection authorities and research departments in those Nordic countries that responded to a questionnaire about sampling methods, sampling equipment, sample preparation, methods of measurement, sample storage and reporting of results. All five Nordic countries have been represented in the study.

The participating laboratories apply similar sampling procedures for pasture. The cutting height of the grass varies between 1 and 5 cm above the ground and the sampled areas are usually about 1 m^2. Samples from an investigated area (field) are usually taken at random positions, but the number of samples taken varies. The gamma analysis is made with NaI or high-resolution gamma detectors on fresh and/or dried samples, depending on the fallout situation.

Soil samples are generally taken by some sort of corer of different diameter, down to a depth of 5 to 50 cm. The number of cores taken at the sampling site varies from 3 to 20 and the cores are usually sliced. The activity in the upper part of the soil is often determined in the first slice, with thickness in the range 2 – 5 cm. Different sampling patterns are used and the samples are then pooled by some of the laboratories. The analysis is made by high-resolution gamma spectrometry on fresh or dried samples, depending on the radionuclides expected to be present. Both fresh weight and dry weight are registered for comparison with field gamma spectrometry and determination of soil water content.

For deposition sampling, precipitation collectors of a range of sizes are used to determine the activity concentration in the precipitation. The precipitation collector may also be wiped to determine dry-deposited radionuclides. The analysis is made with high-resolution gamma spectrometry, either directly on a water sample or by measuring ion exchange resins.

Accreditation

In recent years there has been an increased need for laboratories to be able to demonstrate the quality of their results. This is, for example, due to increased international trade and cooperation, and a greater emphasis on quality control. It can also be a direct legal requirement, as is the case concerning the EU Council Directive 93/99/EEC of 29 October 1993 on additional measures concerning the official control of foodstuffs, which requires ‘Official laboratories’ to be accredited and participate in appropriate proficiency testing schemes. Accreditation is the internationally recognized way for laboratories to demonstrate their competence. It has thus received increased attention amongst Nordic laboratories that measure radionuclides in the environment and foodstuffs.

In the previous NKS period, 1994-1997, accreditation was taken up as a special topic within the EKO-3.2 sub-project on quality assurance in laboratory measurements. During the current period interest was focused on a new draft standard on accreditation, ISO/IEC DIS 17025, since there were claims that the new standard might offer more flexibility and/or make it easier to obtain accreditation. At least it was certain that the new standard, if accepted, would change the framework for accreditation.

The initial emphasis of the project was thus on drawing attention to the new draft standard, and to provide a forum for discussing the possible implications for laboratories that measure radionuclides. This was done at a BOK-1.1 seminar in Skagen, Denmark, 23 August 1999; at the NSFS meeting in Skagen, 23-27 August same year, and led to a BOK-1.1 seminar on accreditation in Oslo on 27 March 2000. Initially, there were some doubts as to whether the new standard would be accepted. The development in the final stages was rapid, however, and it now defines the framework for accreditation of laboratories as the approved standard ISO/IEC 17025:1999.

The new standard is structured in a similar way as other corresponding standards. It is therefore easier to work with it than previous ones. It also combines into a single document the requirements for accreditation, which were previously listed in different publications. The structure of the standard is such that it can be used as a model for building up a quality manual; this is done simply by using the same index and meeting the stated requirements one-by-one. In the project report [NKS-

47] the structure of the new standard is described together with a reference to where it can be bought. A reference is also given in the report to where a draft version of the standard can be downloaded from the Internet.

The report provides an elementary introduction to accreditation and to how it can be obtained. A laboratory considering accreditation should contact the accreditation body in its country, to obtain documentation on the accreditation process and the formal requirements in the country. A list of accreditation bodies in the Nordic and Baltic countries is given in an appendix to the report; contact information is also included in each case. Additionally, the report has references to more detailed material that can be downloaded from the Internet.

Accreditation involves being able to demonstrate the quality of the measurements. For most laboratories this means critically reviewing their own analytical procedures, and making improvements where needed. One of the often-neglected components is the assessment of uncertainty in the results. It can be performed and reported in various ways. Often it is not clear what is included in a stated uncertainty of a result. References to international standards and guidelines, which describe how uncertainty should be assessed and reported, are given in the report.

Gamma spectrometry is often assumed to be a simple procedure, but care must be taken to insure the accuracy of low-level results. The background can be variable, there can be considerable differences between parameters in nuclear libraries and for a given amount of sample material the measurement geometry can have a marked effect. A system of quality assurance measurements can help to identify problems and even predict detector failures.

Another important component of accreditation is documentation and a system of document control. Documentation needs to be detailed, but at the same time the information has to be accessible so it will be used, and the updating process must be efficient enough not to hinder progress. In many cases computerized document systems will make this work easier.

At the accreditation seminar the Finnish Radiation Protection Authority (STUK) and Norwegian Radiation Protection Authority (NRPA) discussed their experiences with the accreditation process. Possible strategies were discussed, e.g. whether to base the quality system on “Total Quality Management”, which is then applied to the institute as a whole, or to have it instead centered on the laboratory. Both authorities have laboratories, which have now obtained accreditation for measurements of radionuclides. The experience at STUK and NRPA has shown the procedure to be time consuming, but critical review of procedures has led to improved documentation and reporting. This is an experience shared by many other laboratories.

In the end each laboratory needs to decide whether accreditation is worth the effort or not. The needs of a research laboratory may be different from those of a laboratory performing routine measurements for an authority. Accreditation may be inappropriate for a university research laboratory. But all laboratories can benefit from studying what steps are needed for accreditation and possibly meeting some of the requirements.

Gamma-spectrum software analysis

To mimic the situation on the real nuclear emergency, new types of exercises were arranged [NKS-43]. In these exercises a set of gamma spectra consisting of traces of a severe nuclear accident were transmitted to a number of laboratories for further analysis. The laboratories were then asked to analyze the spectra as if they were internal samples from their own laboratories.

This kind of exercise with synthetic spectra has multiple benefits: the sample that contains radionuclides doesn't have to be transmitted to many laboratories, there is no problem with short-lived radionuclides, the analysis results can be assumed to be promptly available, and finally, the laboratories will receive spectra that they seldom see in routine operations. In the case of a real emergency, spectra to be analyzed could include radionuclides not encountered by most of the laboratories in the post-Chernobyl era.

Two exercises were arranged, the first in the autumn 2000 contained leakage from a VVER-440 type reactor (based on Origen calculation), whereas the spring 2001 exercise re-constructed the Chernobyl nuclear accident as seen in Finland in May 1986, cf. Figure 2. The first exercise was simpler; only 19 extra isotopes were added to the normal background spectrum. The Chernobyl sample did contain more than 30 extra isotopes as was observed in Finland after the accident. The response time of laboratories participating in the second exercise is shown in Figure 3.

The exercises placed emphasis on sample analyses needed for emergency preparedness purposes in the event of a nuclear accident. This kind of testing can be used also for in-house quality assurance. The exercise did prove that it is possible to share the measurement data following an accident to have second opinion or inform authorities abroad to foresee the situation in advance. For this purpose a conversion tool was supplied for participants to convert the spectra to a format more suitable for laboratory work.

In the two exercises arranged, an improvement was noticed in the analyses. After prompt analysis in the first exercise, 50% of the participants had good quality of results, while in the second, more difficult case, more than 75% of the participants did obtain good results, indicated by the number of isotopes correctly identified and the accuracy of quantitative results reported. The participants were able to provide a more comprehensive report after 2-3 weeks. The correctness of results did improve after a longer period of analysis.

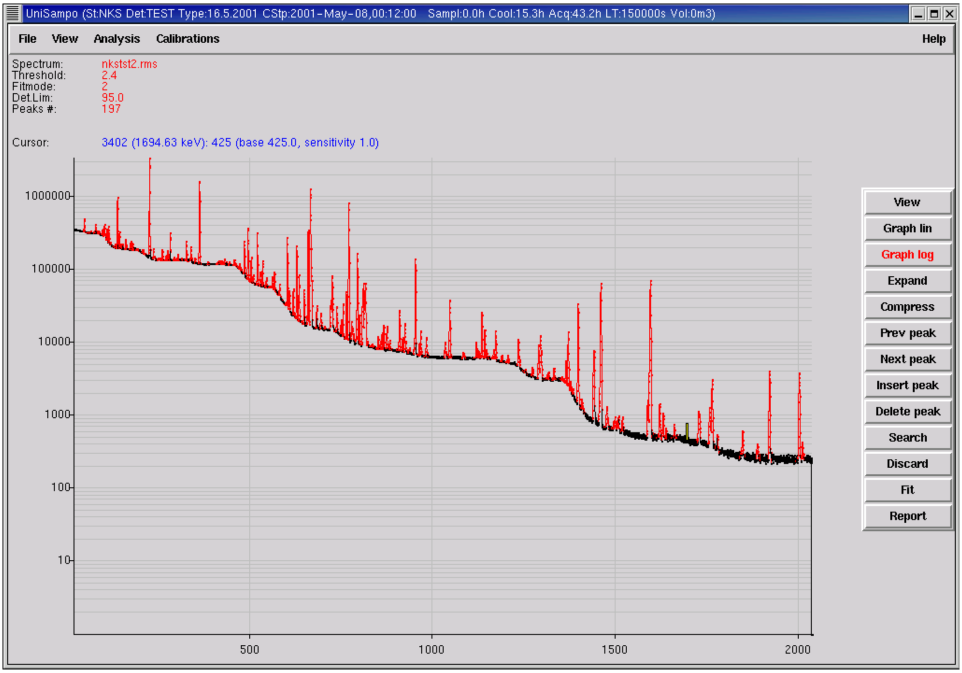


Figure 2.Gamma spectrometry: Spectrum with 235 peaks distributed at the second gamma-spectrum software analysis exercise.

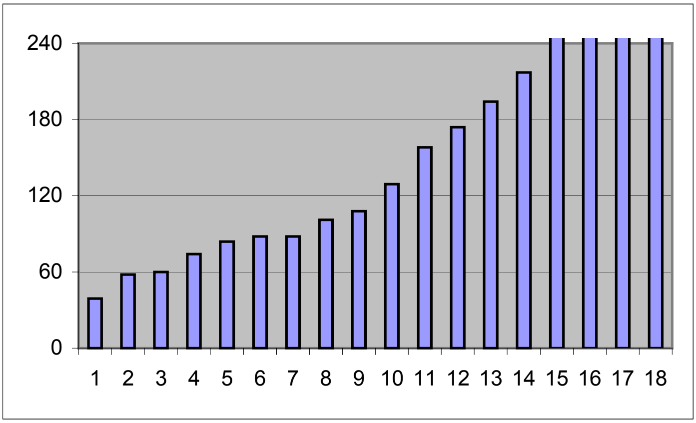


Figure 3. Gamma spectrometry: Response time (in minutes) of the laboratories participating in the second gamma-spectrum software analysis exercise.

In the case of an emergency, the time available for analysis is limited, but the quality of analysis results should still be high enough for the emergency response management to base decisions on the analysis. This is a dilemma, which can be solved only by testing difficult cases in advance. The synthetic data can be used for this purpose to estimate when the quality of the result is good enough and when it is safe to release the results.

Seminar on detectors and radionuclide measurements

A Nordic Seminar on detectors and radionuclide measurement techniques was held in Lund, Sweden, May 3-4, 2001 [NKS-53]. Its objective was to highlight recent progress and problems for instituting laboratory techniques to study environmental radioactivity. It covered aspects of detector sample geometries and methods for evaluating gamma pulse height distributions. Within the field of alpha-spectrometric techniques gridded ionization chambers, semiconductor detectors and a general description of methods of analysis of alpha-particle-spectra were presented.

Recent developments in mass spectrometric techniques were described along with AMS (Accelerator Mass Spectrometry) and ICPMS (Inductively Coupled Plasma Mass Spectrometry) for long-lived radionuclides. Principles of analysis of beta particle emitters, especially by liquid scintillation, were presented. The seminar also covered radiochemistry, such as advantages and disadvantages in ion exchange, solvent extraction, and extraction chromatography. The use of controlled laboratory conditions for discerning the dynamics of accumulation in organisms was demonstrated. Other techniques, such as neutron activation, were shown to be useful analytical tools for certain long-lived radionuclides. The results of the BOK-1.1 inter-calibration exercises within the Nordic countries show the importance of such analytical quality control.

Source preparation methods

Recent development of detector systems and the assessment of alpha and beta particle emitters in the environment have underlined the need for rapid and reliable methods for preparing sources. In alpha and beta spectrometry proper source preparation is important for maintaining a high quality in such measurements. Irrespective of the detector system, the source thickness may be a limiting factor and poorly resolved spectra will seriously affect analytical quality control. The source should have a minimum of foreign material present and should be capable of withstanding careful handling. Normally, a very thin source on a flat substrate is desired, and other configurations are generally not considered.

In the project, different methods for source preparation for alpha and beta measurements have been investigated [NKS-40]. Literature on the topic has been reviewed and some experimental work was carried out.

For preparing alpha sources the evaporation technique has in the past often been used in analyses of environmental samples. The possibility to prepare sources of actinides by electro-deposition however, has been known for over 40 years and applied to environmental assessment, and this technique gives a better energy resolution. Precipitation as fluorides with rare earths provides generally a sufficient resolution and has the advantage that it is a rapid method and the yield is high. Molecular plating can be applied also to elements such as radium, which is not accessible to normal electro-deposition. Other techniques such as vacuum sublimation and electro-spraying are used for optimal energy resolution, but the recovery is small.

For beta particle emitters, the most common source preparation methods are those for liquid scintillation. For other counting systems, such as GM-counters, electro-deposition and precipitation techniques are used similarly as for alpha particle emitters.

In the experimental study, different anode and cathode materials for electro-deposition were investigated. As anode material, platinum was found in general to be superior to graphite, while for the cathode, the use of nickel, silver and copper showed promising results.

BOK-1.2 Mobile measurements and measurement strategies

Mobile measurements of radiation have been performed at least since the 1950's using vehicles, and from the late 1960's also in the form of airborne gamma spectrometry. The initial use was in connection with uranium exploration. Airborne systems have since been developed also for geological mapping, environmental studies and emergency situations. For some applications high-resolution systems are needed, for others high sensitivity is necessary. Technical development during the last four decades has changed the measurement systems considerably. The single most important technical change is without doubt the introduction of satellite positioning systems (GPS). The rapid increase in available computer power and dedicated software has allowed for on-line processing of data. Ongoing development of mobile communication will eventually facilitate remote real-time data processing and analysis. Finally the growing market for geographical information systems has created a great variety of advanced software for processing and visualization.

In applications related to radiation protection, the technical and methodological development has been focused on techniques for mapping fallout and on source search techniques and strategies. The usefulness of airborne gamma spectrometry measurements was clearly demonstrated after the Chernobyl accident in 1986. Since then many countries in Europe and elsewhere have purchased or developed systems intended for environmental and emergency applications. Nordic cooperation, coordinated by NKS, started in 1994 and the exercise RESUME 95 took place in August 1995. The success of the exercise has stimulated further International cooperation under the framework of the R&D program of the European Commission. Focus in that program has been coordination and standardization.

The objective of the present BOK-1.2 project has been to test, compare and integrate different types of field measurements using mobile equipment. Different platforms are available for mobile gamma spectrometry: fixed-wing aircraft and helicopters for airborne gamma spectrometry (AGS) for surveying large areas, car-borne gamma spectrometry (CGS) e.g. for surveying densely populated areas, or even use of hand-held equipment for detailed investigation of areas not accessible by cars. In a nuclear or radiological emergency all these platforms may come into play in the attempt to utilize available resources in terms of hardware and manpower, and the coordination and integration of these different platforms will be an issue.

In September 1999 the exercise RESUME 99 was carried out in the Gävle area in Sweden. The aim of the exercise was to investigate the similarities and differences between airborne and car-borne systems and to what degree variations could be explained by physical parameters, e.g. road surface and land use. Another important aim was to demonstrate the possibility of international cooperation in an emergency situation. The exercise worked out well and data was produced by all teams. Following the exercise the data processing and analysis phase commenced. Similarities between results from airborne and car-borne systems were observed, but differences between individual systems introduced by different calibrations were observed. A discussion on the most relevant quantity for reporting fallout concentrations in an emergency situation resulted in an understanding and a set of recommendations for future operations.

In September 2001 the exercise “Barents Rescue 2001 LIVEX” took place. The exercise was a part of an international rescue exercise. NKS supported Nordic participation in the “Gamma Search Cell” sub-exercise. The exercise aim was to simulate a situation where lost sources were to be found by cooperating international teams using both airborne and car-borne systems. The exercise went well despite the fact that adverse weather conditions grounded many of the helicopters during the early hours of each exercise day. During a well-attended seminar in October experiences from different teams were presented and many interesting discussions took place. The seminar was the final activity within the BOK-1.2 program.

RESUME 99

The exercise RESUME 99 (Rapid Environmental Surveying Using Mobile Equipment) took place in the town of Gävle and surrounding areas on September 6-9, 1999 [NKS-15]. Gävle is located in the middle of Sweden on the east coast, about 200 km north of Stockholm.

The objective of the RESUME 99 participants was to measure and map the fallout from the Chernobyl accident in 1986. The area around Gävle received the heaviest fallout in Sweden from the accident, resulting in activity levels of Cs-137 of the order of 10 – 200 kBq/m^2 with smaller areas and "hot spots" of still higher activity. The area has been investigated since 1986 in different ways and is probably one of the best-documented areas in the world regarding the Chernobyl fallout. In 1997 and 1998, the Geological Survey of Sweden performed airborne measurements over the area and these data were used as a reference set for the exercise.

The exercise was primarily intended to include only mobile measurement systems carried by cars. During the planning period however, the exercise was expanded to include *in-situ* teams, which performed dose rate measurements and high-resolution gamma spectrometry in the area. In total, the exercise had close to sixty participants from ten countries. Beside Nordic participation, there were measurement teams from Poland and the three Baltic countries as well as observers/consultants from Scotland and Canada. A total of ten mobile teams and seven *in-situ* teams took part in the exercise. A web site, **www.nks.ssisweden.com**, was created for the exercise, containing information on the planning of the exercise as well as exercise results, maps, etc.

The base of the exercise was placed at Älvkarleö Herrgård, some 20 km southeast of Gävle city center. The exercise headquarters were situated in the conference building of Älvkarleö Herrgård. Here, all information meetings were held and the administrative staff handled status reports from the teams and other logistic details. Maps and other results of the exercise could be studied here and computer facilities were made available to the participants.

The heart of the headquarters was the computer and communications center (CCC), where data processing and presentation of results took place. To make the central processing work smoothly a special ASCII format for the data files, called the NKS-format, was developed. Results from all mobile measurements were reported to the staff at CCC in this format.

The CCC assisted the teams with exercise specific maps and road descriptions for the measurements. Data processing were performed both on local computers and on computers located at the Geological Survey of Sweden (SGU) in Uppsala. Data was transferred using ordinary e-mail and by means of a satellite connection (300-400 kbit/s). In this way large files could be transferred from the ftp-site at SGU without a serious time delay. Color-graded point maps and interpolated grid maps with the fallout levels in the area were printed out at the headquarters using a large format plotter. Maps and other results were also transferred to a web server for presentation on the web site.

Two days of the exercise were dedicated to measurements. On the first day, the mobile teams performed measurements along a specified calibration route, which was about 200 km long. All teams were to drive through the route in the same direction and at the same speed (but with different starting times to avoid crowding) to make the results comparable. Along the route there were four calibration points where the cars should stop to make stationary measurements. Three of these calibration points were situated on grass areas while one was an asphalt/forest site. This last point was included to compare the different systems measuring in a geometry similar to that of a road.

For the *in-situ* teams, 14 sites were selected, where measurements should be made during the two days. In addition, the four calibration points along the route for the mobile teams should be measured to be able to compare *in-situ* and mobile results. The *in-situ* sites were spread out over a large part of the Gävle region. They included sites with different type of soil and vegetation and activity levels of ^{137}Cs ranging from about 5 to 60 kBq/m^2. Beside high-resolution gamma spectrometry, dose rate measurements were performed and soil samples were taken. Soil samples were analyzed in the field or in the hotel rooms, as well as in laboratories.

The reported results displayed large differences between the teams. At the calibration points, differences of up to a factor of three in the equivalent surface activity of ^{137}Cs were observed, cf. Figure 4. Excluding the Baltic and Polish results, that were a factor of two too high due to a software error, there was still more than a factor of two in difference between the highest and lowest values reported. Even though the absolute levels displayed large differences, the ratio of the levels recorded by the different teams held more or less constant at the four calibration points. This indicates a large uncertainty in the calibration of the different systems.

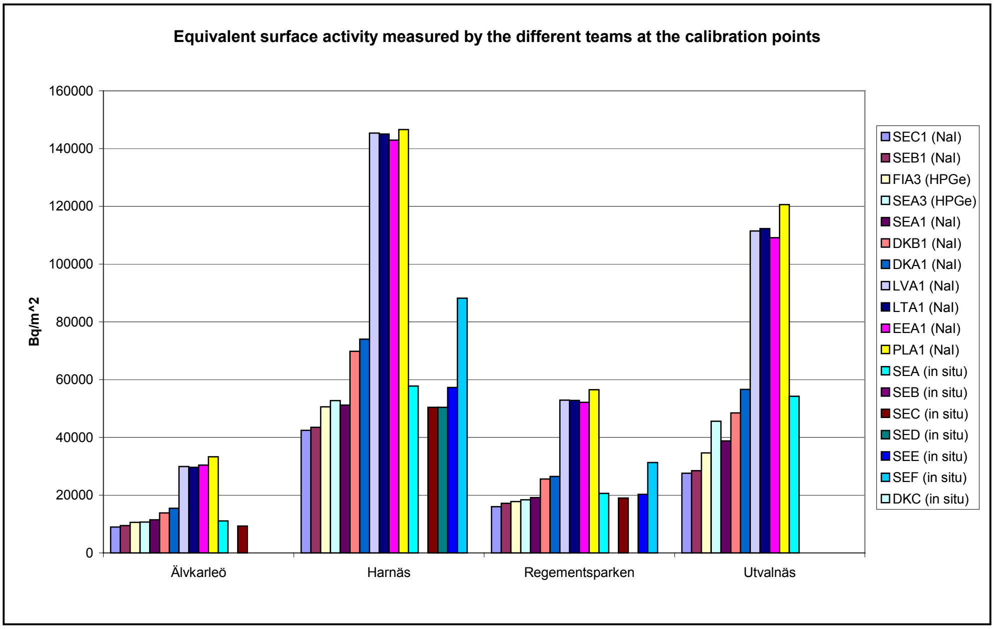


Figure 4. RESUME 99: Equivalent surface activity of ^{137}Cs (Bq/m^2) measured at four calibration sites by mobile and in-situ teams.

The second day, each mobile team was assigned an area of its own of about 15 x 15 km^2 for measurements. During a limited time, measurements were to be performed in the best possible way, with the aim of getting an accurate overview of the fallout within the team specific area. Thereafter, measurement data from all areas were combined to produce a map giving the entire picture of the fallout.

Although there were problems reaching many of the smaller roads due to locked road gates, the teams succeeded in delivering data and the fallout map was produced in the evening of the second day (cf. Figure 5). To account for the differences in the calibration of the systems, all values reported during this part of the exercise were scaled to give the same value at one of the calibration points.

The map production and the presentation of results on the web page were successful parts of the exercise as they were characterized by swiftness. After only a couple of hours following the delivery of the NKS-files, high quality results were presented to the public.

The performance of the teams and the co-operation between them showed that exercises like this is necessary to maintain the competence within the area and to reveal problems and weaknesses of the systems. Many teams were affected by problems during the first day of measurements, but as the exercise moved forward most problems were solved.

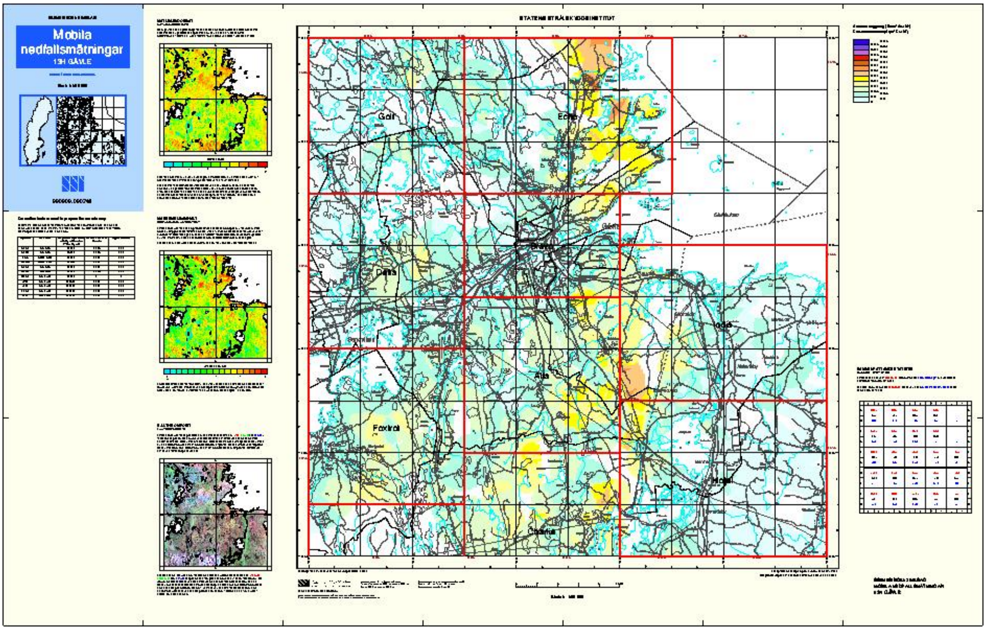


Figure 5. RESUME 99: Interpolated map of Cs-137 contamination measured by the CGS teams. Red lines indicate boundaries of area assigned to each team.

Mobile Gamma Spectrometry

In the surroundings of Gävle in central Sweden many places have high concentrations of radiocaesium (^{137}Cs), stemming from the Chernobyl accident in 1986. In 1997 and 1998 the Geological Survey of Sweden mapped the area for ^{137}Cs contamination using airborne gamma-ray spectrometry (AGS) [S. Byström et al., Geological Survey of Sweden, 1998], and in September 1999, the NKS exercise RESUME 99 was carried out, in which eleven teams from the Nordic and Baltic Sea countries performed car-borne gamma-ray spectrometry (CGS) in the area [NKS 2000].

In the present study [NKS-2002d], AGS and CGS data from the many mobile teams have been collected and are compared to each other. The data sets comprise CGS measurements taken at four calibration sites and common measurements along a 200 km calibration route. The AGS data cover a larger area, but AGS measurements taken above the same route as the CGS measurements have been selected for direct comparison with the CGS data. Possible correlations between the CGS and AGS results and detector type and position, and geographical information obtained for the area, such as land-use and road type, have been examined.

Some of the differences found between different CGS results can easily be attributed to simple software errors, or have their origin in different calibrations. CGS results are also found to depend on detector geometry, shielding and displacement. The overall differences between various CGS results however (disregarding software errors and different calibrations), remain small.

Larger differences are found between AGS and CGS results although the general pattern of the two data sets is similar (Figure 6). The differences have their origin in the fact that airborne detectors have a different field of view than a ground-based detector. For instance, a depth-distributed source may be visible to an airborne detector but may be partially shielded for the view of a detector placed on a ground-based vehicle. Also airborne measurements carried out at high traveling velocity effectively averages over larger areas than car-borne measurements. In order to integrate AGS and CGS data, care must therefore be taken to translate AGS results into equivalent CGS quantities (and vice versa), taking into account how the actual radionuclide spatial distribution (assumed or measured) will affect AGS and CGS measurements respectively.

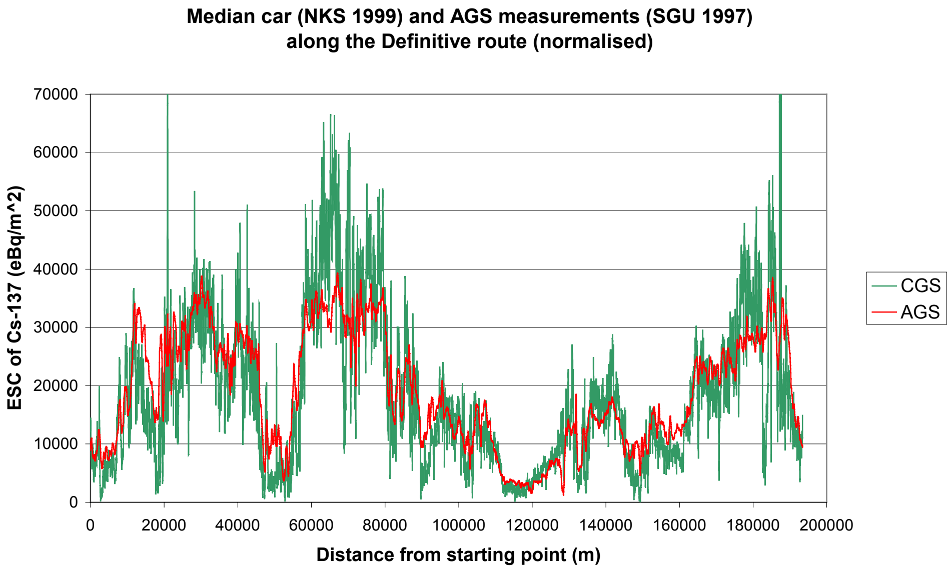


Figure 6. RESUME 99: Equivalent surface concentration of ^{137}Cs determined with AGS and CGS. AGS and CGS results have been normalized.

Observed local differences between AGS and CGS could often be explained by different field of view but in several cases no obvious cause was found. In general, however, only little correlation was found with land-use and with road-type and width. From an analysis of the depth-dependency of AGS and CGS data for a depth-distributed source, it is found that the mean mass depth may be inferred from the ratio of AGS to CGS spectral count rates.

The need to compare AGS and CGS data, and to a smaller degree comparing different CGS measurements, necessitates a precise definition of quantities and units for reporting activity concentrations in a complicated geometry. Various quantities are used for reporting deposited activity concentration of ^{137}Cs. The adoption of an agreed definition will facilitate cooperation between different mobile teams in a nuclear emergency where radionuclides are dispersed in the atmosphere, with the purpose of producing a fast overview of the fallout. More specific recommendations are provided in the project report.

Barents Rescue 2001

The Barents Rescue 2001 (BR) LIVEX exercise was carried out in September 2001, near Boden in Northern Sweden. Approx. 1500 participants from 25 countries took part in this exercise. A part of the Barents Rescue LIVEX was the monitoring exercise “Gamma Search Cell”, with the participation of airborne (helicopters and fixed-wing aircraft) and car-borne monitoring teams.

In the Gamma Search Cell a large number of radioactive sources were placed in the exercise area, the objective for the participants being to locate and identify the sources. Some of the sources were unshielded for easy discovery, while most of the sources were difficult to find due to shielding or because of insufficient source strength (Figure 7). Altogether 31 teams from 10 countries took part in the gamma search. Most countries performed both Airborne Gamma Spectrometry (AGS) and Car-borne Gamma Spectrometry (CGS) for source location and identification.

The Gamma Search Cell was set up to last three days, with the evenings used for data processing and analysis. Country by country cooperation between AGS and CGS teams was encouraged, in order to allow airborne search to be followed up on the ground with hand held equipment. Otherwise information on identified source locations was to be kept secret between teams until the end of the exercise. The exercise enabled comparisons to be made between the different measuring methods and data analysis used by the participating teams.

In addition to the Gamma Search Cell, the Radiological Emergency Assessment Center (REAC) was established to handle reporting, compilation, coordination and presentation of radiation measurements. A dedicated Air Wing from Sweden and assisting countries was responsible for planning flight slots and assisting the airborne measurement teams.

Figure 7. Barents Rescue 2001 LIVEX: Masked vehicle cart with hidden source inside, used for the Gamma Search Cell.

In 2001, the BOK-1 project received from NKS an extra financial support of one million DKK to cover project work relating to Barents Rescue 2001. The BOK-1.2 sub-project participated in the planning and evaluation of the Gamma Search Cell and provided financial support to Nordic participation in the exercise and workshops relating to the exercise.

Nordic participation in the BR Gamma Search Cell is summarized in Table 1. Iceland was present in the monitoring exercise as an observer. In addition to the organizations listed in the table, the defense forces of Denmark, Finland, Norway and Sweden participated in the exercise by providing helicopters or personnel for the AGS measurements.

Table 1. Nordic monitoring teams in Barents Rescue LIVEX Gamma Search Cell.

Country	Organizations	AGS	CGS
Denmark	DEMA, DTU	1	1
Finland	STUK, DFRIT	1	2
Iceland	GR	Observer	
Norway	NGU, NILU, NRPA	1	2
Sweden	SSI, FOI, SGU, Lund University, Linköping University, Göteborg University	3	4

An evaluation seminar and workshop was held at Rosersberg, Stockholm in October 23-24, 2001, with participation from twenty of the mobile teams that took part in the Gamma Search Cell [NKS-54]. At the seminar the results of the gamma search were presented, and the equipment, methods and strategies for source location and identification were discussed. During the workshop, small groups were formed to discuss the role of mobile gamma spectrometry in nuclear emergency preparedness, and to evaluate the Gamma Search Cell.

The Gamma Search Cell exercise demonstrated that it is not an easy task to find and identify hidden radioactive sources. In Figure 8, the fraction of sources found and/or identified is depicted. No team found all sources and a few sources were not found at all. AGS teams were in no case able to correctly determine the source activity.

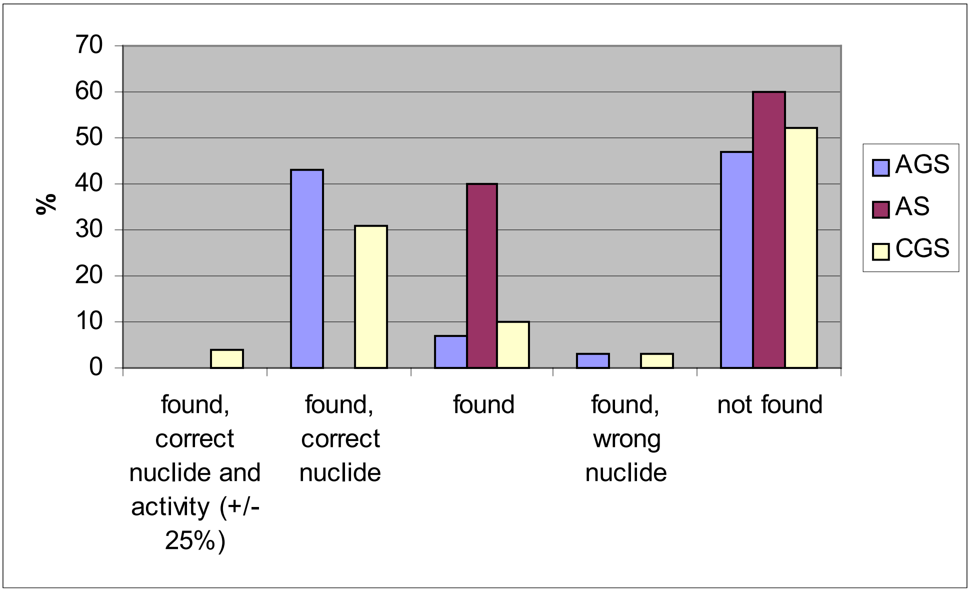


Figure 8. Barents Rescue 2001 LIVEX: Radioactive sources located and identified by the mobile teams at the Gamma Search Cell. AGS: Air Gamma Search; AS: Air Search (with simple equipment, like dose rate meters; CGS: Car Gamma Search.

BOK-1.3 Field measurements and data assimilation

In the early phases of a nuclear accident, where radioactive material is released to the atmosphere, it is important to obtain fast and reliable information on the amount and composition of the release. Automatic gamma monitoring systems around major nuclear installations provide real-time information on radiation levels, and this information may be used to update prognoses on the release and atmospheric dispersion of activity.

Atmospheric dispersion models of radioactive releases require as input parameters information on the source term and meteorology (cf. Figure 9). Especially the source term may be unknown during a nuclear accident, e.g. because of an unmonitored release, rendering the prognoses of the atmospheric dispersion very uncertain. However, calculated radionuclide activity concentrations or radiation fields may be compared to measurements recorded by (automatic) off-site monitoring stations. By adjusting the input parameters to make the model predictions agree better with observations, it is possible to make an improved assessment of the source term and reduce the overall uncertainty.

The process of continued updating and improving prognoses based on incoming measurement data is termed data assimilation. Data assimilation models go beyond standard atmospheric dispersion modeling. While atmospheric dispersion models make predictions on the radionuclide concentrations and radiation fields, data assimilation models also updates the uncertainty associated with such prognoses.

The aim of the BOK-1.3 sub-project has been to develop data assimilation algorithms for atmospheric dispersion that may be used in Nordic decision support systems. To advance the theoretical development, a Ph.D. program was initiated during the NKS program period. The Ph.D. program has focused on making source term estimates based on off-site dose rate measurements. To improve and test models for atmospheric dispersion and data assimilation, an argon-41 field experiment for simultaneous monitoring of meteorology, source term, plume and radiation field was carried out.

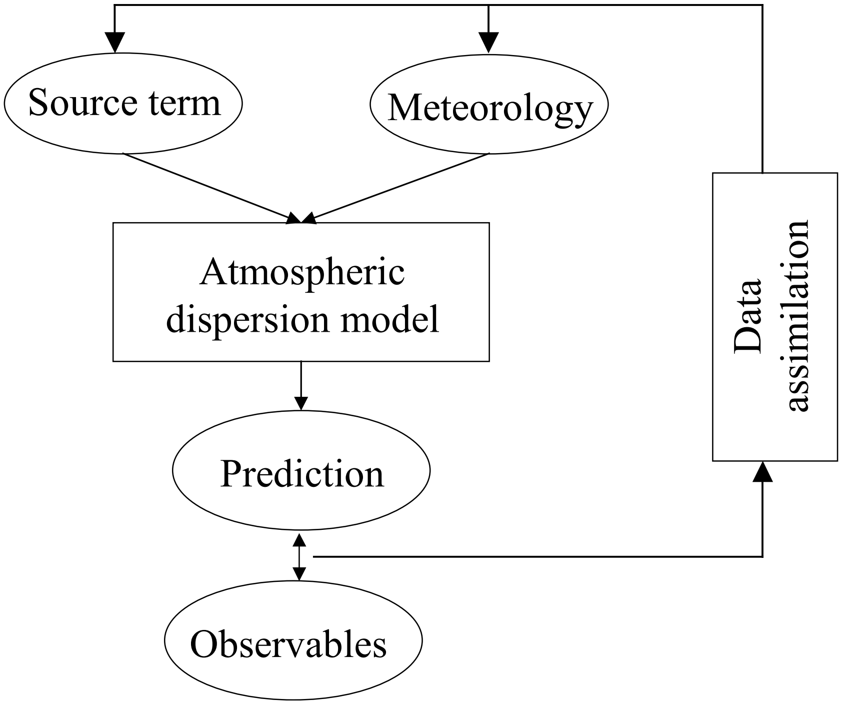


Figure 9. BOK-1.3: Schematic illustration of data assimilation of atmospheric dispersion.

Ph.D. program

A Ph.D. program, "Data assimilation in atmospheric dispersion of radioactive material", was initiated in October 2000, in the middle of the project period. The Ph.D. program is viewed both as a cost-effective method for promoting research within the BOK-1.3 project, but also as a means of providing support of the education of scientists within the field of radiation protection.

The objective of the Ph.D. program is to investigate data assimilation techniques for atmospheric dispersion of radioactive material, and in particular to develop methods for making improved source term estimates based on off-site radiation monitoring. The long term goal is to develop numerical models that can be integrated with Nordic decision support systems.

The Ph.D. program is sponsored by NKS until December 2001 and is carried out at The Technical University of Denmark and Risø National Laboratory, Denmark. An outline of the Ph.D. program is given in Table 2 and a status report of the program (December 2001) is given in Appendix 4. The program is expected to be completed in October 2003.

Table 2. NKS/BOK-1.3. Ph.D. study plan.

Period	**Activities**
Autumn 2000 -	**Survey of the existing literature** The Ph.D. program involves elements of radiation physics, meteorology, statistics, Monte Carlo techniques and fast computing. Specifically, existing methods for data assimilation and source term estimation will be examined. A report over existing methods for making source term estimates will be made.
Spring/summer 2001	**Modeling atmospheric dispersion** A numerical gaussian plume model will be constructed for the calculation of activity concentration and dose rates for short ranges, i.e., up to a few kilometers from the release point. The dose rate calculation involves a three-dimensional integral, and methods will be developed for fast calculation or approximation of this integral. A detailed parameter sensitivity study of the model will be carried out in order to estimate parameter covariance matrices needed for data assimilation purposes. The results and documentation of the numerical model will be published in a suitable format.
Autumn 2001	**Experimental work** Planning and participation in the Mol/NKS field study of routine ^{41}Ar releases carried out in the beginning of October 2001 at SCK•CEN in Belgium. The aim of the experiment is to measure simultaneous values of the source term, atmospheric dispersion parameters and the ^{41}Ar radiation field. The experimental data can be used both for the validation of existing models for atmospheric dispersion and dose rate estimation, and to test data assimilation models.
Autumn/winter 2001	**Data analysis of argon-41 experiment** Data collected in the experiment will be analyzed and compiled into a common database for the future development and testing of methods for data assimilation of atmospheric dispersion. A major issue is the calibration of the individual measurements as several different types of detectors are to be used. The results of the numerical gaussian plume model will be tested against the experimental results. An experimental report as well as scientific publications will be made.

Spring 2002 / winter 2002	**Data assimilation modeling** A data assimilation model for estimating the source term using off-site gamma measurements will be developed based on the Bayes-Monte Carlo approach. The model will be based on the gaussian plume model for short-range atmospheric dispersion. The gaussian plume model is used because of the simplicity of this model combined with the anticipated sparseness of data in a nuclear emergency. The data assimilation model will be tested using simulations and experimental data from the ^{41}Ar field study. Publications will be made.
Winter 2002 / spring 2003	**Data assimilation code implementation** Based on the model, a numerical data assimilation module will be developed. The code is tested using experimental data. Documentation is made, including technical documents.
Summer / autumn 2003	**Thesis**

Argon-41 experiment

The ^{41}Ar experiment was carried out at the BR1 research reactor at Mol, Belgium, as a collaboration between NKS and SCK•CEN/Mol, with participation from SCK•CEN, Risø National Laboratory, the Technical University of Denmark and the Danish Emergency Management Agency [NKS-2002a].

The main objective of this collaborative study was to gather information on the characteristics of a radioactive plume, which mainly consists of ^{41}Ar originating from the nuclear research reactor, and to correlate these features with observed downwind spectral measurements. The resulting database of environmental monitoring measurements will be used to validate atmospheric dispersion and dose rate models and data assimilation algorithms currently under development both within NKS and under the European Union's Fifth Framework Radiation Protection Key Action Program.

The experiment consisted of four main components, which were carried out simultaneously: a) characterization of the ^{41}Ar source term originating from the emission stack of the BR1 research reactor, b) characterization of the meteorology during release c) characterization of the plume by lidar scanning, and d) the monitoring of the gamma ray signals obtained by a set of NaI and HPGe detectors.

The plume geometry was determined by a lidar scanning technique: artificial smoke was injected into the reactor stack and the visible plume monitored with the help of a pulsed laser beam (cf. Figure 10). The wavelength of the laser beam is of the same order as the mean aerodynamic diameter of the smoke particles and through Mie scattering it is possible to study the shape and location of the plume.

Figure 10. Argon-41 experiment at Mol, Belgium. Artificial smoke released from the sixty-meter stack of the BR1 research reactor.

The radiation field was monitored at a distance of 500 – 1000 meters downwind from the emission stack by an array of eight NaI-detectors mounted in a setup perpendicular to the main advection direction. From the spectral information, the ^{41}Ar full-energy peak count rate is derived. In addition, two high resolution Ge-detectors were set up to calibrate the NaI-signals and provide additional information on the variation of the radiation field along the plume centerline.

A schematic illustration of the experiment objectives is shown below in Figure 11. Data obtained in the experiment serves to validate atmospheric dispersion and dose rate models: These models assume the source term and meteorological data to be known quantities and enable the plume geometry and radiation field to be calculated. However, the same data set can also be used to test and develop data assimilation models for making source term estimates. Here the meteorology and radiation monitoring data are input parameters and the aim is to assess the plume geometry and release rate.

The argon-41 experiment is the first attempt to conduct a full-scale atmospheric dispersion experiment in which plume geometry and the radiation field are determined simultaneously. Data collected in the experiment may form a basis for the further development of atmospheric dispersion model tools in the Nordic countries.

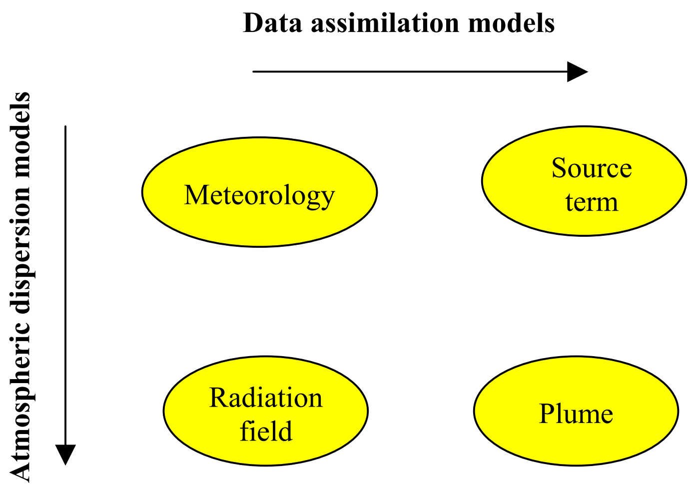


Figure 11. Components of the argon-41 field experiment. The experimental data may be used to test both atmospheric dispersion models and data assimilation models.

BOK-1.4 Countermeasures in agriculture and forestry

A nuclear accident in which radionuclides are dispersed into the environment may have far-reaching consequences for agriculture and forestry within the affected area. A nuclear emergency preparedness system should include a set of protective measures for agricultural land and forest and park areas, to mitigate the environmental and economic consequences of a nuclear fallout occurrence. Nuclear accidents affecting food-producing areas require immediate resolutions on the use and treatment of foodstuffs that may be contaminated from the accident, and they call for decisions to be made on future agricultural production.

A number of agricultural countermeasures exist to prevent or reduce radionuclide contamination in foodstuffs. These measures include decontamination procedures, the use of additives in livestock and plant production, and foodstuff processing and treatment. An effective emergency response requires a strategy for intervention and for how to select the best agricultural countermeasures among many possible ones.

The focus of the BOK-1.4 sub-project has been to prepare a Nordic Handbook on agricultural countermeasures following a nuclear accident [NKS-51] (cf. Figure 12). The preparation of the handbook is a continuation of the EKO-3.4 project of the previous NKS program, which presented a first step towards a regular collaboration on nuclear preparedness in agriculture and food production among the Nordic authorities within agriculture, food production and radiation protection.

The Nordic Handbook is attempted as a planning and decision support tool, describing the basis for and strategy behind the introduction of agricultural countermeasures. To document and to develop strategies for agricultural countermeasures a number of activities have been taken up within the sub-project. These include the construction of a database on agricultural countermeasures and an electronic manual describing these measures. An exercise, Huginn, was carried out to test the database as means of providing decision support. Finally, a survey of environmental transfer factors to be used in emergency preparedness planning was undertaken, following recommendations from the Huginn exercise evaluation.

In a separate study, forest management and remediation techniques in the Nordic countries have been reviewed.

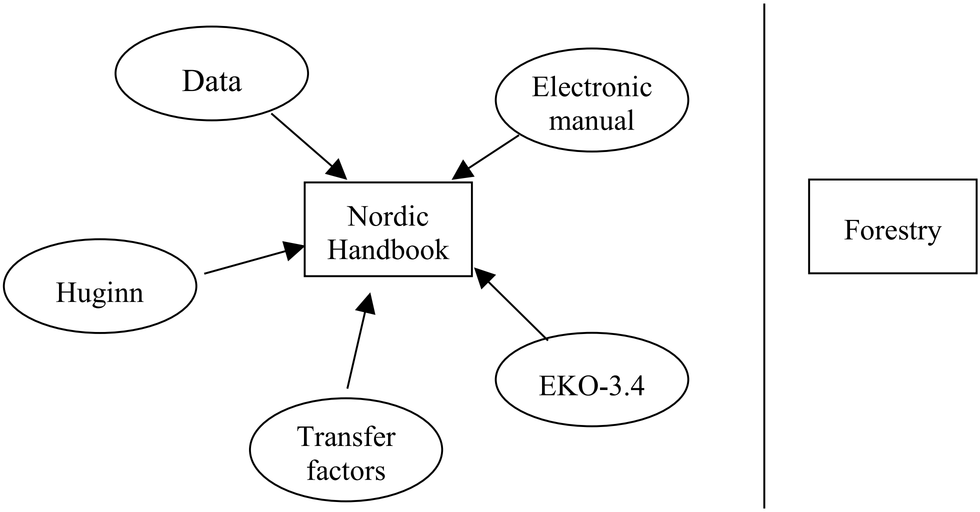


Figure 12. BOK-1.4 outline.

Nordic handbook on agricultural countermeasures

The project report, “Agricultural countermeasures in the Nordic countries after a nuclear accident” is intended as a joint Nordic handbook concerning consequence limiting measures within the agricultural and food producing area, subject to reviewing by the relevant Nordic authorities [NKS-51]. The target groups for the report are the Nordic authorities for agriculture and food production and for radiation protection, people working at all levels in the preparedness systems and the people working in the agricultural sphere: Farmers, farming advisors, farmers associations and people from the food (and feed) industry.

It has been the intention of the project to collect information based on common understanding, which can be used in further developments of the national preparedness systems and to spread knowledge and understanding for the necessity of having a common base for agricultural countermeasure strategies. Background material for the handbook is a survey of agricultural countermeasures [NKS-16] and the Huginn late-phase exercise [NKS-23], both carried out by the project group. In addition, a seminar was held in Copenhagen on October 10-11, 2000, with participation by agricultural and radiation protection authorities and experts, providing valuable input to the handbook.

The report covers two key areas. They are: 1) the gathering and dissemination of information under both normal conditions and in emergency situations, hereunder the responsibilities of the authorities, specialist institutions and agricultural organizations, and 2) agricultural countermeasures and their application.

The handbook discusses the responsibilities of the agricultural and preparedness authorities, of the media and authorities disseminating and relaying information, and the recipients of information (farmers, farmers' organizations, the public). The need for adequate and coherent paths of communication, the necessary legal framework and predetermined chains of command are discussed.

Factors influencing a countermeasure strategy are described. Agricultural countermeasures in general cannot eliminate, but only reduce the dose committed through the consumption of food products. A number of factors of natural, technical, economic and political origin influence the final choice of countermeasure(s). Specific countermeasure may impact on the future "degrees of freedom" to act. It is important that limited (economic) resources are used cost-effectively, and it may be necessary to take special care of high-risk groups (e.g. children). Finally, a brief explanation on the transport of nuclides through the food chain with reference to key transport factors is given.

The agricultural countermeasures are divided into three main production categories: one for plant production, one for livestock production and one for food processing. The three categories are not mutually exclusive. A list of specific countermeasures is given, with references to more detailed descriptions of each measure. Also, the transfer factor concept is described and a number of specific factors are tabulated according to relevant nuclide and production category.

Finally, an example is provided on how to assess the costs and benefits of the countermeasures. The background situation is stipulated and possible countermeasures are discussed. The example shows the dose averted and the economic costs by introducing the specific countermeasure. Real conditions require evaluation of a number of countermeasures, ending with ranking the choices.

It is important to stress, that the cost-benefit method for evaluating countermeasures do not remove the fact that political decisions still have to be made, but it does provide a basis on which decisions can be taken.

Data sheets for agricultural countermeasures

Based on a literature review, methods for managing nuclear accidents affecting food-production in the Nordic countries have been reviewed. Each method is described in a common data sheet format to facilitate a rapid assessment of the methods [NKS-16]. Recommendations and examples are given as to how the individual data sheets may be used in emergency management.

The data sheets describe agricultural countermeasures, which are applicable for reducing radiation doses arising through the consumption of contaminated food. Only methods that are relevant in the event of a major nuclear accident affecting Nordic areas have been included. The three radionuclides ^{137}Cs, ^{90}Sr and ^{131}I have a special status in this context, as these are likely to dominate the ingestion dose following a major nuclear accident.

Each data sheet contains a short general description and an estimate of the expected dose reduction. Cost elements are described in relation to personnel requirements, equipment and other remedies, as well as waste that may be generated by the method and must be treated and disposed of. The practicability and acceptability of the measures are discussed, and literature is recommended for further information. Recommendations are given on simple measures that may be implemented during the earliest phase of an accident, where deposition has not yet occurred. These methods require early warning and there may only be short time to carry out such countermeasures.

The agricultural countermeasures are categorized according to the food production line: plant production, livestock production or food processing, to illustrate which methods might have relevance in a particular situation. Criteria are described that may influence the making of decisions on the introduction of countermeasures. As guidance to the use of the data sheets, examples are given on the calculation of monetary costs and radiological benefits of selected countermeasures.

Electronic manual of countermeasures

To facilitate the use of data sheets for nuclear emergency preparedness, an electronic manual with countermeasures for contaminated agricultural systems has been developed, and is accessible at the NKS home page, **http://www.nks.org/** [BOK-1.4]. Various countermeasures are described for a range of scenarios: after the incident has occurred but prior to fallout; a short time after fallout; during the first growing season after fallout; and for the longer term. The web version can be used to identify various countermeasures and to compare their potential effectiveness for given contamination scenarios. The facility may be used in conjunction with exercises and in calculations for emergency preparedness.

The web version can be used and further developed by the relevant authorities in the Nordic countries. In Figure 13 the front page of the electronic manual is displayed. From here it is possible to select the relevant food production category and time frame, to access the list of possible countermeasures.

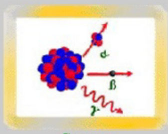
Countermeasures  Stages	1: *Prior* to deposition	2: *Short* time after deposition	3: *First* season after deposition	4: *Long* term after deposition
W: water/snow	W1 prior-water	W2 short-water	W3 first-water	W4 long-water
P: plant	P1 prior-plant	P2 short-plant	P3 first-plant	P4 long-plant
A: animal	A1 prior-animal	A2 short-animal	A3 first-animal	A4 long-animal
FP: food products	FP1 prior-food	FP2 short-food	FP3 first-food	FP4 long-food
FM: farm worker (man)	FM1 prior-man	FM2 short-man	FM3 first-man	

Figure 13. Front page of the electronic manual of agricultural countermeasures.

Huginn late-phase exercise

In order to examine and promote decision making on agricultural countermeasures based on radiological principles of optimizing the effect of the measures, taking into account monetary costs and dose reduction, the late-phase exercise Huginn[1] was designed [NKS-23]. The exercise aimed mainly at the group of experts and advisors within the BOK-1.4 project, and project members from Denmark, Finland, Norway and Sweden took part in the exercise. The exercise was designed as a "table-top" exercise, in which the four national teams were given sufficient time to carry out the required work.

In the Huginn exercise, similar fallout situations were postulated for each of the Nordic countries: the accident taking place in the midst of the growing season and the fallout containing radioactive isotopes of iodine and cesium. Other radionuclides were omitted to keep the exercise simple. The four national teams were given the task, independent of each other, to identify appropriate countermeasures, and to carry out cost-benefit calculations for selected countermeasures.

The Huginn exercise demonstrated that it is possible based on existing information to carry out cost-benefit analysis for a number of agricultural countermeasures, e.g., administration of Prussian Blue to cattle and sheep. For other countermeasures, however, more detailed and scenario-specific information will be needed to assess the radiological and economic consequences of the countermeasures. In particular, the necessary information on transfer factors to plants was not readily

[1] The Huginn exercise builds upon a previous NKS exercise, Odin. According to Nordic mythology, Huginn and Muninn are the two ravens of Odin.

accessible, and it was recommended that a study of transfer factors for nuclear emergency preparedness be undertaken (see below).

The results of the exercise showed that large differences exist among the national groups, both with respect to which countermeasures were deemed applicable, and in the cost-effectiveness estimates of the selected countermeasures. Such differences may hinder Nordic harmonization following nuclear accidents. In Table 3, countermeasures agreed upon as being applicable in all of the Nordic countries have been summarized. One or more of the four national groups for various reasons ruled out other countermeasures than those shown.

Table 3. Huginn exercise: Nordic consensus on possible countermeasures after cesium and iodine fallout [NKS-23].

Countermeasure
Early removal of vegetation
Ploughing
Ploughing and K-fertilization
Changing slaughter time

It was agreed that the Huginn exercise has been useful, but that it should be followed up by discussions on the decision process and methods employed by the Nordic countries for handling nuclear accidents. Furthermore, the exercise format using questionnaires was deemed to be useful for testing the response of the Nordic authorities to a nuclear accident.

Environmental transfer factors for nuclear emergency preparedness

During or immediately after a fallout occurrence, where radionuclides are deposited on the arable land, it is important to assess the radioactive contamination of agricultural products. The first quantitative information on the deposition is likely to be in terms of the deposition density of radionuclides (in Bq m^{-2}). Compilations exist of transfer data, from soil concentration to plant concentration of a radionuclide, but such data are not readily usable when only deposition data are known. However, (aggregated) transfer factors can be defined, which relate the activity concentration of foodstuffs and feeding stuffs directly to the deposition density.

The objective of the project has been to find tools to assess the order of magnitude of such (aggregated) transfer factors, for caesium, strontium and iodine, aiming at deriving default values that can be used for emergency preparedness in Nordic environments [NKS-2002b].

The project is based on a literature survey of transfer factors needed for making early assessments of radionuclide concentrations in agricultural products. The review of literature carried out within the project has concentrated in the Nordic data, but other international literature has also been reviewed, as well as data from environmental calculation models.

The suggested transfer factors for radiocaesium and radiostrontium for the fallout year and the years following fallout are intended to be used for making rough estimates of the contamination of agricultural products soon after the deposition density and radionuclide composition are known. These first assessments can be used to indicate a need of measurements, and provide a basis for plans of monitoring foodstuffs and countermeasures needed in agriculture.

Remediation of forests and park areas

In the forest remediation project [NKS-52] background information has been compiled that can be used in planning appropriate countermeasures for forest and park areas in Denmark, Sweden, Finland and Norway, in case a nuclear accident results in large-scale contamination of forests. The information is formulated to inform the forestry sector and radiation protection experts about the practicality of both forest management techniques and mechanical cleanup methods, for use in their planning of specific strategies that can lead to an optimal use of contaminated forests. Decisions will depend on the site and the actual situation after radioactive deposition to forested areas, but preparing background information from investigations performed before an accident occurs will make the process more effective.

Forests cover large areas of land in Denmark, Finland, Norway and Sweden. The majority of the forested land in these countries lies in the boreal coniferous zone, with coniferous species dominant. Boreal mountainous forests are found in Norway, while Denmark belongs to the temperate zone. The length of winter varies in the Nordic countries, with snow cover lasting an average of 4 to 6 months, and even longer in the northernmost parts. Forests are vulnerable to both the northern climate and to environmental conditions. Therefore, it is particularly important to understand the influence remedial measures will have on different types of forests.

The Nordic countries currently have no documented strategic plans for mitigating radioactive contamination in forests and parks. Finland, Norway and Sweden have large-scale forest industries, and regional and local level actors are responsible for sustainable forest management.

Remediation techniques for radioactive contaminated forest and park areas can be divided into mechanical methods for cleanup and forest management techniques. The project report describes technical aspects of mechanical cleanup of forest and park areas, e.g., methods, technical constraints, treatment and disposal of waste, etc., that need to be considered in developing a remediation strategy. The discussion of forest management focuses on advice for applying or altering otherwise normal forest management techniques.

Mechanical removal of some fractions of the contaminated biomass or soil can be considered for a limited land area after heavy fallout. Mechanical techniques include felling, chipping and grinding of forest biomass or litter. Mechanical cleanup can lead to the removal of a large fraction of the contamination, although protection of the workers must be considered and the waste must be deposited properly. Change of land use may be necessary after a radical mechanical removal of forest soil. Practices that are possible in a limited land area are not realistic in large forests.

Techniques for chipping and transport are described for the possible purpose of using the contaminated forest biomass as fuel in power plants. The radiological safety during the whole process of wood energy production is discussed in the report. The special radiological circumstances that occur following a heavy contamination can favor the decision to burn heavily contaminated wood in power plants specially designed to contain the radioactive emissions to an acceptable level.

Normal and modified forest management practices are approaches that can be used in planning a strategy for contaminated forests. These practices must be tailored locally to consider the site qualifications and the contamination situation of the forest biomass and soil. Appropriate uses of contaminated wood and advice on restrictions on consumption of contaminated forest foods are the simplest forms of reducing human radiation exposure in a wide variety of situations.

In the last decade, emphasis has been focused on defining sustainable forestry. Regeneration methods have been discussed, investigated and developed towards ecologically safe practices. Treatments that damage the forest ecosystem are increasingly not allowed. Forests have a stabilizing function against soil erosion and groundwater contamination, which has been emphasized in the reviews of countermeasures in the 1990's. After the Chernobyl accident afforestation has often been suggested for contaminated agricultural land.

Operations in forests differ from those applied in urban parks. Park areas are not maintained for production of timber; they are mostly grown for landscape and recreation, and sometimes for picking berries and mushrooms. Protected forests, such as national parks and nature conservation areas, demand very delicate management methods due to their role as areas of minor human influence. The content and scale of operations is different in timber producing forests versus urban forests where local citizens visit.

Currently, a comparatively large fraction of the energy supply in the more intensively forested Nordic countries, such as Sweden and Finland, is provided by combustion of biofuel in power plants. Combustion of biofuels can lead to waste products enriched in radionuclides. In those forested areas of the Nordic countries that received the most fallout from Chernobyl, significant amounts of ^{137}Cs remain in different parts of the forest ecosystem. The highest concentration in the prevalent pine trees is in the needles, with decreasing concentrations respectively in the branches, bark and wood. The use of the needles, branches, and bark for biofuels is an increasingly common practice, with the wood left for lumber. Thus, the parts of the trees most concentrated in ^{137}Cs are often used for biofuel. Time-series measurements of the concentration of ^{137}Cs in the trees in Chernobyl-affected forests have shown that the ^{137}Cs-concentration was still increasing 13 years after the accident.

The most significant exposure pathways to the general population from ^{137}Cs-releases from biofuel plants, including both external and internal doses, are found to be 1) depositing of the ashes, 2) recycling of the ashes to the forests for nutritional purposes, 3) releases of condense-water, and 4) exhaust from the smokestack (flue gas). Assuming an activity concentration of 5 kBq/kg ^{137}Cs in the ashes, which is the recommended limit for the ^{137}Cs concentration in ashes for recycling in Sweden, the largest dose is estimated to occur during occupation with ash deposition, and is on the order of 0.1 – 0.5 mSv/yr. It is estimated that approximately 6-7 percent of the current forested area in Sweden can produce ashes with levels over 5 kBq/kg.

The most significant exposure pathways to workers at a biofuel plant are to people standing next to ash containers, conveyors, or at ash-handling locations. Calculations show that plant workers in a power plant fired with wood from an area with a contamination level of 1 MBq m^{-2} of ^{137}Cs could receive an annual dose contribution of 1-2 mSv.

BOK-1.5 Emergency monitoring in the Nordic and Baltic Sea countries

Within the NKS program 1990-1993, a project, BER-2, was carried out describing the methods and equipment used in the Nordic countries for monitoring fallout radionuclides. The survey thus covered Denmark, Finland, Iceland, Norway and Sweden. The final project report, "Monitoring Artificial Radioactivity in the Nordic Countries", issued in 1995 (TemaNord 1995:559) included a description of methods for radiological data exchange between the Nordic countries, and methods for on-line airborne measurements.

In 1998, NKS and the Reference Group for the Baltic Sea States on Emergency Monitoring Integrated System and Early Warning (the Reference Group) in a joint undertaking decided to update and extend the survey also to include the Baltic Sea countries: Estonia, Germany, Latvia, Lithuania, Poland, and the Russian Federation. The final survey is presented in the project report [NKS-28]. The aims of issuing this report were to

- account for the radiological emergency monitoring systems presently applied in the Nordic and Baltic Sea countries;
- describe the methods employed in emergency monitoring and the characteristics of the monitoring equipment;
- describe future developments in emergency monitoring in the countries;
- facilitate cooperation on radiological emergency monitoring within the region, hereunder the exchange of radiological data between the countries;
- create a common basis for harmonization and improvements.

Radiological emergency monitoring systems comprise systems intended for early warning about unexpected increases in the background radiation levels, and systems for mapping radioactivity in the environment, resulting from radiological accidents that occur domestically or abroad. The Nordic and Baltic Sea countries all possess automatic early warning systems and most countries have established strategies, equipment and routines to map the national territory after fallout of radioactive material. National programs also exist for determining contamination levels of food, environmental samples, vehicles, goods etc., as well as any external or internal contamination of people.

The major radiological threats arise from nuclear power plant inside or outside the country in question, while nuclear research reactors, nuclear-powered naval vessels, and the general use of radioactive materials constitute other radiological threats. The situation in this respect is not identical for the countries in the region.

The national strategies and their practical applications regarding the various types of measurements often coincide or turn out to be equivalent or very similar; however, in certain cases there are important differences. Some of these differences are easy to explain or justify, due to radiological differences (such as the variation in normal background radiation levels or radon concentrations) and different nuclear threat scenarios. Others, however, reflect differences in national organizations, available equipment, experience or the historic development of procedures and equipment.

In Table 4, the available radiometric equipment and systems in the Nordic and Baltic Sea countries are summarized. Automatic gamma monitoring stations form the most important part of the national early warning system. They constitute a fast, sensitive and reliable method for total gamma measurements. The stations monitor the total gamma radiation level on the ground, and may also detect a passing radioactive cloud, thus providing early warning as well as radiation data both under normal circumstances and in the acute phase and later stages of emergency situations. All countries possess automatic gamma monitoring networks. However, the number of stations varies greatly between the countries (see Table 4), with Finland, Germany and the Russian Federation having large numbers of stations. The national automatic gamma monitoring networks are described with respect to the type(s) of detector(s) used, dynamic range, polling periods, radon compensation and alarm criteria. In some cases, semi-automatic or manual stations supplement the automatic networks.

High-resolution measurements of airborne activity using air filter stations are made in all countries. High volume sampling stations, with or without on-line detectors, can detect trace amounts of activity and allow for radionuclide specific analysis of sampled aerosols. As in the case of gamma stations the number of filter stations varies from country to country. The national programs include combinations of stationary and mobile units; low, high and ultra high volume air samplers; equipment for measuring aerosols and/or gaseous iodine, xenon etc.

Most countries have programs or plans for survey teams and local measurements at predetermined points to get fast and detailed information on local dose rates. Several countries have a program for airborne fallout mapping. Mobile gamma monitoring stations and/or air filter stations are used or planned to supplement the stationary network.

Field measurements of the following types can be made in areas of special interest in most countries: gamma spectrometry, total gamma measurements, gamma analysis of air filters, alpha and/or beta measurements. In addition, extensive programs exist for field and/or laboratory analysis of environmental and food samples.

External contamination checks (gamma, beta/gamma, or alpha) of people, vehicles, buildings etc. may be performed whenever needed. Ordinary survey meters are used in most instances; more sophisticated equipment, however, is available, should the need arise.

Whole body counters for making nuclide-specific measurements of internal contamination levels are available in several countries. In many countries, some hospitals and other institutions are equipped and staffed to detect and assess internal contamination by means of organ measurements or analysis of urine samples.

The development of radiological emergency monitoring systems in the region has been advanced by bilateral and international cooperation. Future development to a large extent depends on continued international cooperation, especially for promoting the exchange of monitoring data and development of comprehensive decision support systems.

Table 4.Emergency monitoring: Available radiometric equipment and systems in the Nordic and Baltic Sea Countries.

	DK	EE	FI	DE	IS	LV	LT	NO	PL	RU	SE
Gamma monitoring; automatic	11	11	298	2150	1	16	14	22	20	152	37
Gamma monitoring; manual or semiautomatic	0	3	150		0 [c)]	0	74	no	36	1255	
Survey teams	yes	yes	yes	yes	yes [d)]	yes	yes	yes	yes	yes	yes
Aerosol sampling stations	1 [a)]	3	31	5 [b)]	1	3	1	7	19	40	5
Aerosol on-line monitoring	0	1	15	51	0	yes	1	0	8	0	0
Airborne measurements; mapping	yes	no	yes	yes	no	no	no	yes	yes	yes	yes
Airborne measurements; sampling	no	no	yes	yes	no	no	no	yes	yes	yes	no
Environmental sampling	yes		yes	yes	yes	yes		yes	yes	yes	yes
Food sampling	yes		yes	yes	yes	yes		yes	yes	yes	yes
Field gamma spectrometry	yes	yes	yes	yes	no	yes		yes	yes	yes	yes
Contamination checks of cars, goods	yes		yes	yes	yes	yes		yes	yes	yes	yes
Whole body counters	yes	no	yes	yes	no	no	no	yes	yes	yes	yes

a) 1 on standby, b) High-volume samplers, c) 2 stations planned, d) Organized as needed

BOK-1.6 Nuclear exercises

Emergency exercises are instrumental for maintaining and developing emergency preparedness. Within several of the BOK-1 sub-projects topical exercises have been carried out, to advance specific tools or methods for nuclear emergency preparedness, e.g., radioactivity measurement inter-comparison exercises (BOK-1.1), mobile gamma spectrometry exercises (BOK-1.2) and a late-phase exercise on agricultural countermeasures (BOK-1.4).

The BOK-1.6 sub-project has dealt with nuclear emergency exercises in a wider context, the objectives being to plan and to assist Nordic participation in international nuclear exercises, but also to develop tools for planning and conducting emergency exercises and improve systems for exchanging information between an accident site and the emergency management and between Nordic authorities.

During this program, the BOK-1.6 sub-project has focused on systems for exchange of information. The use of mobile Internet as means of information during an emergency has been introduced to the Nordic nuclear authorities, and a workshop on information and communication during a crisis has been carried out.

Mobile Internet for nuclear emergency preparedness

The merging of telephone and Internet technology offers new possibilities for an emergency response management. By mirroring information between the World Wide Web and the Mobile Internet, management and experts may exchange information about an accident while away from their offices, and such a system therefore allows for a more flexible use of manpower.

The WAP (Wireless Application Protocol) standard has formed the basis in Europe for these developments. The first generation of WAP phones became available early in 2000 but often caused disappointment: some of these phones were unreliable, the gateways to the Internet were often of poor quality, and the GSM phone system had a limited capability for transferring data.

Since then, the situation has improved dramatically. The phones have become more reliable, better and more powerful gateways have come into general use, and not the least, Nordic countries have or are launching GPRS services, which offer faster rates of data transfer than GSM.

The objectives of the project have been to introduce and demonstrate the Mobile Internet to the Nordic nuclear emergency preparedness authorities, and to test the technology during exercises [NKS-2002e]. To this purpose, a prototype WAP mirror was designed. The WAP mirror, located at **http://www.gr.is/wap/info/**, was set up using basic components on the mass market, and Nordic emergency preparedness authorities were invited to suggest web sites to be used in a test of the WAP mirror. Relevant information and links are provided on the web site: **http://www.gr.is/bok-1.6/minep/**, created for the project.

In testing the system, the following links were mirrored:

- IAEA ENAC (SSL closed web site of Emergency Response Center)
- SWEREM (Swedish emergency response web site)
- NRPA – exercise information site
- Exercise summary information (by Geislavarnir ríkisins, Iceland)
- NEP contact information (telephone, fax numbers, etc.)
- STUK's information to the public

Data from these six web sites was transformed to become accessible upon request from a WAP-enabled mobile phone. When a WAP phone requests information from one of the mirrored web sites, the chain of events is as follows:

- The WAP phone connects to a WAP gateway, normally in the same country as the user
- The gateway contacts the WAP mirror program via the Internet (in this case the mirror was running on a computer in London)
- The WAP mirror program contacts the Web site of interest and requests the required information
- The WAP mirror program then sends the information back to the WAP gateway in a changed format suitable for the particular WAP device requesting the information (the format is optimized for the device requesting information)
- The WAP gateway sends the information to the WAP phone.

The initial test was carried out during the Barents Rescue 2001 Alarm exercise (ALEX) in March 2001. The main testing was done during the JINEX-1 exercise in May 2001, after some minor improvements.

The essential information distributed during the JINEX-1 exercise was made accessible in a summarized form via a WAP telephone. Not only was the latest information summary available in this manner; all information summaries were available from a time-indexed list. Update alerts were sent out via e-mail and to most participants also as SMS messages. These alerts were generally received within a few minutes, even between countries.

During the exercises, it was possible to monitor the progress of the exercise in real time using an ordinary WAP phone and it was easy to catch up on events later on due to the time-indexed information summaries.

The exercises demonstrated that the Mobile Internet has great potential to be of use in emergency response management. It is easy to mirror information between the traditional World Wide Web and the Mobile Internet, provided that the web sites are designed properly. To make information easily transportable to other platforms, the web site must have a consistent format and its structure should be as simple as possible.

At the time of the ALEX and JINEX-1 exercises, WAP telephones had not come into widespread use. Testing the mobile Internet system during the two exercises also proved difficult as many participants had formal duties during the exercises and could not add the extra component to their work. The exercise could therefore be repeated at a later stage in a dedicated exercise, when WAP phones have become more commonly available.

Baltic Nuclear workshop

The Baltic Nuclear workshop took place in Lidingö near Stockholm, Sweden on March 19 – 20, 2001 [NKS-39]. The objective of the workshop was to exercise the top-management of the nuclear power plants and the authorities in crisis communication. The workshop brought together a qualified group of twenty-five people from the nuclear community around the Baltic Sea: from Russia, Lithuania, Sweden, and Finland. The workshop also functioned as a platform to get experiences ahead of the "Barents Rescue 2001" exercise in September 2001.

The theme of the workshop was defined as "information and communication during a crisis", aiming at increasing the possibilities for maintaining public confidence in case of a serious event or an accident at a nuclear power plant. Hence, the objectives were to

- provide the participants with a practical view on how different types of events can be handled;
- provide the participants with a view on today's massive search of information of different media and how the created pressure can be handled;
- give the participants experiences that can improve their emergency plans;
- give the participants knowledge on how information responsibilities of the authorities and the nuclear power plants vary in the different countries;
- create personal contacts, thereby improving the flow of information in case of an emergency.

The workshop contained a practical part as well as three lectures on the themes "Crisis management", "Human behavior in a crisis", and "How to handle media in a crisis".

The practical part consisted of three exercises:

- An “action exercise”. In this the participants were divided into small groups and five short video films were shown to the groups. Each video lasted a couple of minutes and presented a problem. After the video presentations the groups had four minutes to answer a specific question regarding this problem. The “action exercise” ended with a short discussion of the results and what was learned by this exercise.
- Two “simulations”. Two different scenarios were prepared as background for these simulations. Each scenario was a set of serious events taking place at the Oskarshamn Nuclear Power Plant. The events served as triggers to the “Crisis Management Teams” (CMT) communicated via telephones, fax and by other means. The simulation-staff played all the different contacts that the CMT-groups needed to or wanted to get in contact with, such as different members in the plant organization, the authorities, the media and the public. A short sum-up and discussion about the immediate experiences was held after each simulation.

The workshop ended with a three-hour evaluation of the workshop, leading to recommendations for changes in the NPP accident contingency plans. The workshop showed that there is a real need in the nuclear community for a system of contacts to ensure fast information flow in case of any event in a nuclear power plant, between authorities and nuclear power plants and between the nuclear power plants themselves.

Many of the participants stated that there is a need for exchange of information about preparations, planning and training regarding emergency situations. The importance of learning from each other was strongly emphasized. Some of the participants also suggested that this kind of workshop should be repeated in a couple of years.

Conclusions

The overall objective of the BOK-1 project has been to develop a Nordic "common understanding" on nuclear emergency preparedness. The "Nordic added value" of seeking such a common understanding is two-fold:

1) It helps to maintain and develop network(s) of people from Nordic authorities and research institutions working on nuclear emergency preparedness, and
2) It promotes harmonization of intervention strategies and protective measures taken after a nuclear or radiological accident.

With this in mind, the BOK-1 project has been organized as a Nordic research collaboration, aiming at the participation of all of the five Nordic countries in each sub-project, and when possible expanded to include Baltic or European participants.

In the following, some of the main achievements of the BOK-1 sub-projects have been summarized, including discussion of outstanding problems and suggestions for future work.

Laboratory measurements (BOK-1.1)

Nordic inter-comparison exercises of laboratory analyses are important for QA/QC reasons and as part of basic training for new staff. Also, inter-comparison exercises may assist the implementation of new equipment and techniques for laboratory measurements. Therefore, inter-comparison exercises are valuable for the Nordic laboratories performing radioactivity measurements as part of the nuclear emergency preparedness system.

NKS is able to provide the framework for Nordic inter-comparison exercises. The high level of participation in the exercises carried out within the present project on radioactivity measurements and gamma-spectrometry software demonstrates the interest and usefulness of such exercises.

Mobile measurements (BOK-1.2)

Field measurements with mobile equipment for gamma spectrometry are used for mapping large areas for fallout radionuclides and searching for orphan sources. Exercises for emergency teams using mobile equipment serves to test both people and equipment with respect to emergency situations.

Two large exercises were carried out in the present period; the RESUME 99 exercise and the Barents Rescue 2001 Gamma Search Cell. These exercises have demonstrated increased capabilities for emergency monitoring of radioactivity. They have also generated valuable data on mobile gamma-ray spectrometry, which can be used to test analytical and practical methods for integrating different platforms in an emergency collaboration and for locating and identifying lost radioactive sources.

Data assimilation (BOK-1.3)

Around nuclear installations and throughout the Nordic countries stationary equipment exists for monitoring radioactivity. These systems are intended to provide early warning about increased levels of activity, indicating that a nuclear accident has occurred, but can also be used for estimating the source term during a nuclear accident and thereby update and improve prognoses on the dispersion of radionuclides in the environment.

Within the present project, NKS has funded a Ph.D. project on data assimilation. Its objective has been to advance theoretical development in the data assimilation project, aiming at the development of methods for making source term estimates based on off-site gamma measurements. In a wider perspective, the Ph.D. program has served to support education in the field of radiation protection.

An argon-41 field experiment has successfully been carried out in Mol, Belgium. Data generated in the experiment can be used both to validate atmospheric dispersion and dose rate models, and in the constructing and testing of data assimilation models for short-range atmospheric transport. Furthermore, the data can also be used in benchmark testing of short-range (~1 km) atmospheric dispersion models, e.g., in the form of an NKS exercise.

Countermeasures (BOK-1.4)

Agricultural countermeasures aim at reducing radiation doses to humans from the ingestion of radioactive contaminated foodstuffs. The BOK-1 project group has written a Nordic handbook discussing countermeasure strategies for intervention after a nuclear fallout episode, and an electronic manual has been developed for presenting data sheets of individual countermeasures. The Huginn late-phase exercise was carried out to test these data sheets as a means of providing decision support.

Collaboration between the Nordic agricultural and radiation protection communities has been a valuable outcome of the project. Some of the activities taken up in the project could be continued; continuation of the project will benefit from a more active involvement of the authorities, however, both within radiation protection and agriculture:

a) The electronic manual being designed in the present project displays and compares different agricultural countermeasures. The manual could be further developed into an interactive one that can be used for calculating cost/benefits associated with each countermeasure.

b) Nordic handbook on agricultural countermeasures: The report developed in the present program is intended as a Nordic handbook aimed at a broad audience of agricultural and radiation protection authorities, experts and organizations. This handbook needs to be evaluated by the Nordic competent authorities.

c) Follow-up on the Huginn exercise. This exercise was carried out as an internal exercise of the BOK-1.4 project group. In order to test whether decision support tools developed in the project are useful to the authorities, a new late-phase exercise could be carried out with participation of the agricultural authorities and radiation protection authorities.

Information topics (BOK-1.5, BOK-1.6)

A comprehensive report on radiological emergency monitoring in the Nordic region has been completed (BOK-1.5). This report should ideally be updated in the future: either as a new report a few years from now, or even better by making a web-based version of the report that can be updated regularly.

Several seminars and workshops were conducted during the project period. Some of these were intended for specialized target groups, e.g. the Baltic Nuclear workshop, designed for the top-managements of nuclear power plants (BOK-1.6), and the Barents Rescue evaluation seminar/workshop, intended for mobile measurement teams taking part in Barents Rescue LIVEX. In general, the participants have deemed these specialized workshops to be very useful.

Exercises

Exercises in some form were conducted within most of the BOK-1 sub-projects. The most successful exercises within BOK-1 have been the functional exercises, in which a single topic has been exercised. The fact the responsibility of all stages of these exercises was given to the project groups, including planning, execution and evaluation, has probably had a positive effect on the outcome. It has been more difficult to engage in and to benefit from the large international exercises, such as the INEX exercises. An exception to this is the Barents Rescue 2001 LIVEX, in which NKS took responsibility for evaluation of the Gamma Search Cell.

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Appendix 1: Acronyms

AGS	Airborne gamma spectrometry
ALEX	Barents Rescue 2001 Alarm exercise
AMS	Accelerator Mass Spectrometry
CGS	Car-borne gamma spectrometry
CCC	Computer and communications center
DE	Germany
DEMA	Danish Emergency Management Agency
DK	Denmark
DFRIT	Defence Forces Research Institute of Technology (FI)
DTU	Technical University of Denmark
EE	Estonia
EU	European Union
FI	Finland
FOI	Swedish Defence Research Agency
GR	Icelandic Radiation Protection Institute
GPS	Global positioning system
ICPMS	Inductively Coupled Plasma Mass Spectrometry
IS	Iceland
INEX	International Nuclear Emergency Exercises (Nuclear Energy Agency)
JINEX	Joint International Nuclear Emergency Exercises (Nuclear Energy Agency)
LIVEX	Barents Rescue 2001 Live exercise
LV	Latvia
LT	Lithuania
NEP-group	(Nordic) Nuclear Emergency Preparedness group
NGU	Geological Survey of Norway
NILU	Norwegian Institute for Air Research
NKS	Nordic Nuclear Safety Research

NLH	Agricultural University of Norway
NO	Norway
NRPA	Norwegian Radiation Protection Authority
PL	Poland
QA/QC	Quality assurance / quality control
RALA	Agricultural Research Institute (IS)
REAC	Radiological Emergency Assessment Center
RU	Russian Federation
SCK•CEN	Belgian Nuclear Research Center
SE	Sweden
SGU	Geological Survey of Sweden
SLU	Swedish University of Agricultural Sciences
SRV	Swedish Rescue Services Agency
SSI	Swedish Radiation Protection Authority
STUK	Radiation and Nuclear Safety Authority (FI)
WAP	Wireless Application Protocol

Appendix 2: Participants

Nordic project participants	
BOK-1.1	**Sigurður Emil Pálsson, GR** Christian Fogh, Risø Sven P. Nielsen, Risø Elis Holm, Risø Finn Ugletveit, NRPA Mats Isakson, Göteborg Seppo Klemola, STUK Mika Nikkinen, Doletum Oy
BOK-1.2	**Hans Mellander, SSI** Simon Karlsson, SSI Uffe Korsbech, DTU Helle Karina Aage, DTU Kim Bargholz, DEMA Frank Andersen, DEMA Finn Ugletveit, NRPA Mikael Moring, STUK Jonas Lindgren, SSI Robert Finck, SSI Christer Samuelsson, University of Lund Tomas Hjerpe, University of Lund Kaj Vesterbacka, STUK Mark Smethurst, NGU Sören Byström, SGU Thomas Ulvsand, FOI Sven-Erik Lodén, SRV
BOK-1.3	**Bent Lauritzen, Risø** Torben Mikkelsen, Risø Hans Jørgensen, Risø Martin Drews, Risø Kim Bargholz, DEMA Uffe Korsbech, DTU Helle Karina Aage, DTU

Nordic project participants	
BOK-1.4	**Magnus Brink, Danish Plant Directorate** Jan Preuthun, Swedish Board of Agriculture Riitta Hänninen, STUK Aino Rantavaara, STUK Eila Kostiainen, STUK Ritva Saxén, STUK Sigurður Örn Hansson, Ministry of Agriculture (IS) Sven P. Nielsen, Risø Jørn Roed, Risø Kasper Andersson, Risø Klas Rosen, SLU Kettil Svensson, University of Uppsala Brit Salbu, NLH Lindis Skipperud, NLH Robert Finck, SSI Lynn Hubbard, SSI
BOK-1.5	**Bent Lauritzen, Risø** B. Åke Persson, SSI Kim Bargholz, DEMA Lennart Devell, consultant to SSI
BOK-1.6	**Bent Lauritzen, Risø** Finn Ugletveit, NRPA Sigurður Emil Pálsson, GR Lars-Göran Wahlberg, consultant

Appendix 3: Financing

Funding of the BOK-1 project comprises contributions from NKS, including extra support obtained during the program period, and contributions from SSI. An overview of the project economy is shown in Table 5.

Table 5. BOK-1 economy. All amounts in kDKK.

	1998	1999	2000	2001	Sum
NKS budget	1,130	1,100	1,650	1,300	5,180
NKS, extra budget	150		50	1,455	1,655
SSI contribution	518	313			831
Total budget	1,798	1,413	1,700	2,755	7,666
Payments	263	872	1,359	4,306	6,799
Transfer to following year	1,535	2,077	2,418	867	

The distribution on each sub-project is shown in Table 6, where the payments have been compared to the distribution suggested in the BOK-1 plan [NKS-5].

Table 6. Financing of BOK-1 sub-projects according to the project plan [NKS-5] *and actual payments* (*in kDKK*).

Sub-project	Project plan	Payments 1998-2001	Commitments 2002
BOK-1.1	1,005	971	75
BOK-1.2	1,040	1,954	273
BOK-1.3	690	688	
BOK-1.4	945	1,511	125
BOK-1.5	50	132	
BOK-1.6	1,050	678	100
Management	720	710	75
Miscellaneous	530	154	150*
Total	6,030	6,799	798

* *Expected miscellaneous commitments, December2001.*

A number of BOK-1 activities have received partial or full financial support from the project. In most cases, financial support exceeding DKK 40,000 has been paid according to a contract issued between NKS and the institution(s) involved. In total, 41 contracts have been drawn up for the total amount of DKK 5,137,000. In addition, DKK 770,000 has been paid out according to the BOK-1 plan for the Barents Rescue 2001 exercise, in direct financial support of Nordic participation in the exercise.

The project policy has been to seek the highest quality of work carried out and the involvement of all Nordic countries. However, an even allocation of financial support between the Nordic countries or institutions has not been a priority.

Appendix 4: Ph.D. status report December 2001

Title: **Data assimilation in atmospheric dispersion of radioactive material**

Name: Martin Drews, Risø National Laboratory**.**

Supervisors: Ass. Professor Helle Rootzen, Department of Informatics and Mathematical Modelling, Technical University of Denmark.

Senior Scientist Bent Lauritzen, Risø National Laboratory, Denmark.

This is a short description of the scientific work[2] conducted October 1st 2000 – December 31st 2001 by Ph.D. student Martin Drews. The Ph.D. program is sponsored by the NKS/BOK-1.3 project until December 2001. An outline of the full Ph.D. program, which is expected to be completed by October 2003, is to be found in Table 2 of this report.

Survey of the existing literature

Since the beginning of the Ph.D. study on October 1st 2000, theoretical studies have been conducted mainly in the fields of atmospheric dispersion, radiation physics, radiation protection, data assimilation and numerical computation. Some key references are given below. Furthermore, a publication is under preparation, compiling methods of data assimilation used currently within the fields of dispersion of radioactive material and tools for nuclear emergency response. The paper is expected to be published in 2002.

Modeling atmospheric dispersion

With respect to atmospheric dispersion modelling, a numerical code implementing the Gaussian plume model is currently under development, employing the theoretical works of Gorshkov and Tarasov [2, 3]. The code is written in C on a LINUX PC and uses the automatic integration procedures by Piessens [4]. The aim with this code is twofold: 1) to perform numerical and statistical studies of the Gaussian plume model in order to evaluate the sensitivity of the model parameters needed by various data assimilation models. 2) to develop numerical methods for performing fast and reliable model calculations and eventually parameter estimation using an atmospheric dispersion model.

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[2] In addition to the scientific work described here, the student has completed three courses in statistics and mathematical modeling at the Department of Informatics and Mathematical Modeling, the Technical University of Denmark. The total “weight” of the courses equals about 2/3 of a full academic semester.

Experimental work

An argon-41 experiment was conducted in October 2001 as a collaboration between NKS and SCK·CEN/Mol. Preparations for this experiment took place in the spring and summer 2001, and included logistics and numerical computations. The experimental site in Belgium was visited twice during this work. In the actual experiment, general experimental work and radiation measurements were performed using NaI(Tl) detectors. For a more detailed description, see ref. [1].

Data analysis of argon-41 experiment

Presently, an analysis of the data from the argon-41 experiment is under progress. This includes the processing of data from several different detection systems and the compilation of a database useful for the development and verification of data assimilation models as well as for atmospheric dispersion modelling. This analysis is to be published in the spring of 2002 together with the database compiled during the experiment. The database will be made available to the participants in the experiment and to NKS. One ore more articles on the experiment and the data analysis will be submitted for publication in a scientific journal.

Future work 2002-2003.

During 2002 and 2003 the emphasis of the Ph.D. studies will be on the development and implementation of a data assimilation model for short rage atmospheric dispersion. The aim of the model is to make source term estimations based on off-site dose rate measurements. The model will employ Bayesian methods for estimating the source term and other model parameters. Data obtained in the argon-41 experiment will be used both in developing and in testing the model.

Martin Drews

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Title	Nuclear Emergency Preparedness. Final Report of the Nordic Nuclear Safety Research Project BOK-1
Author(s)	Bent Lauritzen
Affiliation(s)	Risø National Laboratory, Denmark
ISBN	87-7893-118-5
Date	February 2002
Project	NKS/BOK-1
No. of pages	72
No. of tables	6
No. of illustrations	13
No. of references	25
Abstract	Final report of the Nordic Nuclear Safety Research project BOK-1. The BOK-1 project, "Nuclear Emergency Preparedness", was carried out in 1998-2001 with participants from the Nordic and Baltic Sea regions. The project consists of six sub-projects: Laboratory measurements and quality assurance (BOK-1.1); Mobile measurements and measurement strategies (BOK-1.2); Field measurements and data assimilation (BOK-1.3); Countermeasures in agriculture and forestry (BOK-1.4); Emergency monitoring in the Nordic and Baltic Sea countries (BOK-1.5); and Nuclear exercises (BOK-1.6). For each sub-project, the project outline, objectives and organization are described and main results presented.
Key words	Data Analysis; Emergency Plans; Gamma Spectroscopy; Interlaboratory Comparisons; Mobile Measurements; Nuclear Exercises; Progress Report; Quality Assurance; Radiation Monitoring; Radioactivity; Reactor Accidents; Remedial Action; Research Programs

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