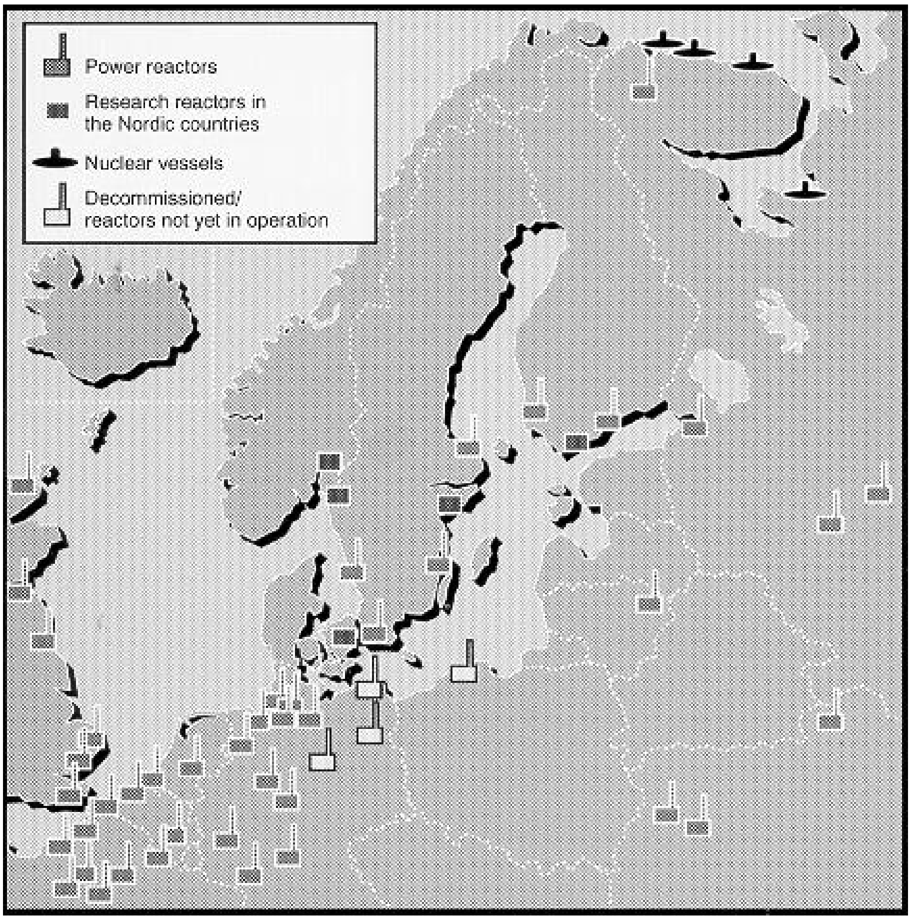
Preparedness Strategy and Procedures



nks

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 background material for decision makers and help achieve a better understanding of nuclear issues.

To that end, the results of the fifth four-year NKS program (1994 – 1997) are herewith presented in a series of final reports comprising reactor safety, waste management, radioecology, nuclear emergency preparedness and information issues. Each report summarizes one of the ten projects carried out during that period, including the administrative support and coordination project. A special Summary Report, with a brief résumé of all ten projects, is also published. Additional copies of the reports on the individual projects can be ordered free of charge from the NKS Secretariat.

The final reports – together with some technical reports and other material produced during the 1994 – 1997 period – have been collected on a CD-ROM, also available free of charge from the NKS Secretariat.

klæbel's offset tryk a-s 1998

NKS(97)FR6
ISBN 87-7893-027-8

The report is published by:
NKS Secretariat
Building 100
PO Box 49
DK-4000 Roskilde

Phone +45 4677 4045
Fax +45 4677 4046
E-mail annette.lemmens@risoe.dk
http://www.nks.org

NKS(97)FR6
ISBN 87-7893-027-8

Preparedness Strategy and Procedures

Final Report of the Nordic Nuclear Safety Research Project EKO-3

Anders Damkjær
Jens Hovgaard
Sigurður Emil Pálsson
Jan Preuthun
Anneli Salo

February 1998

This is NKS

NKS (Nordic Nuclear Safety Research) is a scientific cooperation program in nuclear safety, radiation protection and emergency preparedness. Its purpose is to carry out cost-effective Nordic projects, thus producing research results, exercises, information, manuals, recommendations, and other types of background material. This material is to serve decision-makers and other concerned staff members at authorities, research establishments and enterprises in the nuclear field.

The following major fields of research are presently dealt with: reactor safety, radioactive waste, radioecology, emergency preparedness and information issues. A total of nine projects have been carried out in the years 1994 - 1997.

Only projects that are of 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 RadiationProtection Institute

Additional financial support has been given by the following organizations:

In Finland: Ministry of the Interior; Imatran Voima Oy (IVO); Teollisuuden Voima Oy (TVO)
In Norway: Ministry of the Environment
In Sweden: Swedish Rescue Services Board; 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 several participating organizations.

NKS expresses its sincere thanks to all financing and participation organizations, the project managers and all participants for their support and dedicated work, 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

Within the framework of the Nordic Nuclear Safety Research (NKS) programme four subprojects were carried out in order to assist the Nordic authorities in improving emergency response. The present report is a summary of all four subprojects; full reports of each subproject are or will be published separately.

In the field of mobile measurements an exercise was carried out on Rapid Environmental Surveying using Mobile Equipment (RESUME95) in Finland in August 1995. The main purposes were to test the ability of existing airborne (10 teams), carborne (7 teams) and *in situ* instruments (from 8 countries) to map contaminated areas (due to the Chernobyl accident) and to establish the comparability of results obtained with different systems. Preliminary analysis showed that major features of the spatial distribution of the contaminants were identified by all teams, but that significant variations in absolute figures were observed. Quantitative analyses were undertaken to assess the comparability of the results, and the need for further development was identified.

Quality assurance in sampling and analysis mainly addressed quality assurance in various aspects of gamma-ray spectroscopy with accreditation as a goal. Several details were examined; e.g. the possibility of adopting some joint reference sample geometries in the Nordic countries, the need for improving software for processing gamma-ray spectra, comparability of whole-body measurements and problems in reporting, storing and exchange of electronic data.

The derivation and application of operational intervention levels (OILs) was examined to provide background material for decision makers contemplating the harmonisation of OILs. A new, probabilistic approach for deriving OILs is presented, and the method is illustrated by calculating OILs, expressed in dose rates, in a simplified setting. In contrast to the standard approach, the probabilistic approach allows for optimisation of OILs. It is argued that optimised OILs may be much higher than the presently adopted or suggested values. It is recommended that the probabilistic approach is further developed and employed in determining site- specific OILs and in optimising environmental measuring strategies.

A co-operative project between radiation protection experts and agricultural and food experts was established with the ultimate aim of producing a handbook on agricultural countermeasures to be deployed in a nuclear emergency. During this project period background information on regulations, preparedness organisations in the Nordic countries and basics in radiation protection were addressed, but with regard to countermeasures the work was limited to consequence-limiting measures in agriculture during the alert period as well as during and immediately after deposition, for time reasons. The agricultural measures are discussed in relation to other urgent countermeasures; animal husbandry in the case of evacuation is one example needing good co-ordination among authorities. The pros and cons of the countermeasure options are discussed.

Key words

Quality assurance, accreditation, mobile measurements, gamma-ray spectroscopy, software for gamma spectrometric analysis, whole-body counting, operational intervention levels (OILs), probabilistic approach to OILs, countermeasures in agriculture and food.

Summary conclusions and recommendations

The overall objective of the project was to assist Nordic authorities in improving their emergency response and international co-operation in selected issues. The project was divided into four subprojects, namely mobile measurements, quality assurance in sampling and analysis, operational intervention levels and intervention issues in agriculture and food chains.

The results from the RESUME95 exercise on mobile measurements demonstrated the excellent capability of the airborne teams. Of the ten airborne teams, eight were able to deliver caesium-137 maps very soon after the surveys were completed, in some cases within a few hours. In general, the caesium deposition maps from the airborne and carborne teams showed the same spatial features but with some variation in absolute levels. Most of the observed differences can be attributed to differences in calibration methodology and spatial attributes of the various measuring techniques. It was found that accurate flight-path navigation and software for presentation and analysis played an important role in the search for hidden sources. The lessons learned from RESUME95 indicate a need for further operational exercises in which a number of specific problems should be addressed. These include the calibration and repeatability of the equipment as well as the field of view of the various systems. Influence of positional errors is also an important aspect when comparing the results from a variety of systems. Problems such as these should be considered in design of the exercise and choice of the areas to be surveyed.

With regard to quality assurance in sampling and analysis, the project provided an up-to-date picture of the state-of-the-art in gamma-ray spectrometry in the Nordic countries. The problems were identified and solutions suggested. One of the improvements needed was to develop access to software for gamma spectrometric analysis, which is able to make efficiency corrections for variable heights and densities. A manual was produced for one such program, which has been available to laboratories free of charge. Software intercomparison showed that considerable differences occur among programs in their quality of peak area estimates. It also showed that the user can be a significant factor. Thus, it is important to continue quality assurance work.

It is important, however, to specify the requirements in accuracy and precision in analyses and measurements specifically for emergency situations. Sufficiently reliable information must be produced even if the likely shortage of time and capacity in emergency situations would not allow the highest possible standard.

A survey of measurement geometries in use in the Nordic countries revealed the wide variety of sample containers used. The differences in shape and size are incidental, and the requirements regarding the containers are basically the same for most laboratories. Several advantages were identified in having the same geometries; e.g. easier intercalibration, more reliable supply of sample containers and possibility of exchanging samples in emergency situations. It is therefore recommended that agreement be adopted on a few of these containers as reference containers. Another recommendation is that Nordic laboratories participate in ongoing international work on standardisation of sample containers.

An intercalibration exercise was also carried out for whole-body measurements, which has already led some laboratories to improve their calibrations. Such exercises are seen as particularly important for those laboratories doing part-time whole-body counting. An outline for a quality manual and a technical manual were also prepared.

With regard to the accreditation of gamma laboratories, the work resulted in clarifying the process of accreditation to the participants, but implementation of accreditation remains the task of the institutes, however, it is important to maintain Nordic contacts during the process, because this may save effort.

Since the problem of long-term data storage is not unique for radiological data, the conclusion was to recommend that trends in information technology be carefully monitored. Some recommendations are given for possible formatting and reporting of data by referring to an internationally used system.

Operational intervention levels were treated within a probabilistic framework in which only a few basic facts concerning the accident are known and any detail about the accident is treated as unknown information at the time of decision making. The probabilistic approach developed offers a method for characterising the uncertainties in the efficiency of early intervention measures. Such a probabilistic safety assessment is a prerequisite for optimisation, both with respect to the planning and the implementation of emergency countermeasures.

In order to investigate the consequences of the probabilistic approach, OILs for sheltering were determined for typical scenarios associated with severe reactor accidents. Values were found to be an order of magnitude larger than those adopted in present day emergency planing. However, the OILs were evaluated in a simplified setting and the results presented should primarily be considered an illustration of the probabilistic method.

The recommendation, based on the present study, is that operational intervention levels are defined within a probabilistic framework. In this framework, an optimised operational intervention level is given as the measurement value, for which the average avertable dose is equal to the (generic) intervention level. Furthermore, it is recommended that the probabilistic approach be developed as a tool for optimising existing and future measuring strategies. This may involve optimising the type and number of measurements and the time scheme for deployment of mobile measurement units.

Agricultural measures during the alert phase, such as activities needed on farms because of deposition and activities needed in animal husbandry in case of evacuation of the population brought up many questions on the pros and cons that must be considered when deciding on agricultural countermeasures. Deliberations clearly showed that many differences are present among the Nordic countries regarding the agricultural situation, and that too hasty conclusions about harmonisation of countermeasures should be avoided.

Co-operation between the radiation protection community and the agricultural and food community was necessary and very fruitful. Creating a solid information base as well as education/training and preparation of a joint Nordic handbook are essential elements in the continuation of such co-operation and further development of preparedness. A satisfactory preparedness to act should already exist in the alert phase.

It is essential that agricultural and food authorities have the ambition to develop an adaptable preparedness organisation, that can implement the necessary measures in a quick and efficient manner. Knowledge of alternative measures and their consequences is a prerequisite for efficient and timely implementation of these measures.

A forum should exist in which agricultural and food experts, who are part of the preparedness organisation, have the opportunity to exchange views with radiation protection people on the problems that occur and the effect and applicability of various consequence-limiting countermeasures. A manual should be available in every country for the areas of agriculture and foodstuffs, that concentrates not only on alarm routines and measures that increase preparedness, but also sheds light on consequences and possible countermeasures and gives enough basic knowledge to adapt the countermeasures to the prevailing situation.

Resumé, konklusioner og anbefalinger

Projektets overordnede formål har været at assistere de Nordiske landes myndigheder i deres arbejde med at forbedre beredskabsplaner og internationalt samarbejde inden for udvalgte emner. Projektet er opdelt i fire underprojekter: mobile målinger, kvalitetssikring i prøvetagning og analyse, operationelle indgrebsniveauer samt interventionsniveauer og interventionsproblemer i landbruget og i fødevaresektoren.

Resultaterne fra øvelsen RESUME95 vedrørende mobile målinger demonstrerede de luftbårne måleholds fremragende ydeevne. Otte af de ti luftbårne målehold var i stand til at levere kort over cesium-137 fordelinger meget hurtigt efter målingernes afslutning, i nogle tilfælde i løbet af få timer. Generelt viste de opnåede cæsium depositionskort fra luftbårne og fra bil-baserede målinger de samme fordelinger, men med nogle variationer i de absolutte aktivitetsniveauer. De fleste af de observerede afvigelser kan tilskrives forskelle i kalibreringsmetoder og forskelle i de geometriske betingelser for de forskellige teknikker. Øvelsen viste at nøjagtig flynavigation og software for data-præsentation og analyse spillede en vigtig rolle i eftersøgningen af skjulte kilder.

Erfaringerne fra RESUME95 viste, at der er behov for yderligere operationelle øvelser med henblik på løsningen af en række specifikke problemer som f.eks. kalibrering af udstyret, reproducerbarheden af målingerne og en nøjere bestemmelse af de forskellige systemers geometriske synsvinkel. Betydningen af fejl i positionsbestemmelsen er også et vigtigt aspekt når resultaterne fra de forskellige målesystemer skal sammenlignes. Sådanne problemer bør tages i betragtning ved planlægningen af øvelser og ved valget af de områder, der skal opmåles.

Med hensyn til kvalitetssikring af prøvetagning og analyse har projektet givet et aktuelt billede af gammaspektrometriens stade i de nordiske lande. Problemerne er blevet kortlagt og løsningsforslag er fremlagt. Et af de områder, hvor der er påvist behov for forbedringer, er vigtigheden af at have adgang til software til gammaspektrumanalyse, som er i stand til at korrigere for variationer i prøvernes højde og tæthed. Som et led i arbejdet er der fremstillet en brugerhåndbog for et sådant analyseprogram, som har været stillet gratis til rådighed for de deltagende laboratorier.

Sammenligningerne af analyseprogrammer viste, at der er betydelige afvigelser mellem de forskellige programmers kvalitet med hensyn til bestemmelse af toparealer i gammaspektre og at brugeren selv er en betydelig faktor. Det er derfor vigtigt at fortsætte arbejdet med kvalitetssikring på dette område. Det er i den forbindelse vigtigt at specificere kravene til nøjagtighed og reproducerbarhed af de analyser og målinger, der skal anvendes i en beredskabssituation. Der er behov for at den information der genereres har et tilstrækkeligt troværdighedsniveau selv om manglen på tid og kapacitet i en beredskabssituation ikke tillader den højest mulige kvalitetsstandard.

Oversigten over de anvendte målegeometrier i de nordiske lande viste meget store variationer i udformningen af prøvebeholdere. Disse forskelle er tilfældige idet kravene til prøvebeholdere grundlæggende set er de samme for de fleste laboratorier. Der er i projektet påvist en række fordele ved at anvende ensartede målegeometrier: Simplere procedurer for interkalibreringer, større sikkerhed i forsyningen med prøvebeholdere og mulighed for at udveksle prøver i en beredskabssituation. En af projektets anbefalinger er derfor, at der bør tilstræbes enighed om at benytte nogle få af de anvendte prøvebeholdere som referencebeholdere. Herudover anbefales de nordiske laboratorier at deltage i det igangværende internationale arbejde med standardisering af prøvebeholdere.

En interkalibreringsøvelse for helkropsmålinger er også blevet gennemført med det resultat at nogle laboratorier allerede har forbedret deres kalibreringer. Sådanne interkalibreringer er specielt vigtige for de laboratorier, der ikke rutinemæssigt udfører helkropsmålinger. Der er udarbejdet en skitse til en håndbog i kvalitetssikring og til en teknisk håndbog.

Med hensyn til akkrediteringen af gamma-laboratorier har projektarbejdet bidraget til en tydeliggørelse af akkrediteringsprocessen for de deltagende laboratorier. Iværksættelsen af akkrediteringen er de enkelte institutioners eget ansvar, men der kan givetvis opnås arbejdsbesparelser ved at benytte de nordiske kontakter i denne proces.

Problemet med langtidsopbevaring af radiologiske data er et eksempel på et generelt problem vedrørende dataopbevaring. Projektarbejdets konklusion er derfor en anbefaling af nøje at følge udviklingen i informationsteknologien på dette område. Der gives enkelte anbefalinger med hensyn til mulige dataformater, idet der referes til et internationalt anvendt system.

Operationelle indgrebsniveauer er behandlet ved en probabilistisk model, hvori det antages at omfanget og varigheden af ulykken vil være ukendt på indgrebstidspunktet og at kun få detaljer om ulykken vil være tilgængelige til brug for en prognose. Metoden, som er udviklet under projektarbejdet, giver mulighed for at karakterisere de usikkerheder der vil være knyttet til virkningen af tidlig intervention i et forløb, hvor der spredes radioaktivt materiale i omgivelserne. Sådanne probabilistiske beregninger er en nødvendig forudsætning for at kunne optimere såvel planlægning som gennemførelse af modforholdsregler.

I en analyse af den probabilistiske metode, blev operationelle indgrebsniveauer af dosishastighedmåling bestemt for indgrebet “gå inden døre”, for nogle uheldsscenarier svarende til alvorlige reaktorhavarier. De fundne indgrebsniveauer er typisk en størrelsesorden højere end de indgrebsniveauer som anvendes i nordisk beredskabs-planlægning. Det bemærkes dog at indgrebsniveauerne er bestemt under forenklede antagelser, og de opnåede resultater skal først og fremmest ses som en illustration af konsekvenserne af den probabilistiske model.

På grundlag af dette metodestudium anbefales det, at operationelle indgrebsniveauer defineres i en probabilistisk sammenhæng. På denne måde kan et optimeret operationelt indgrebsniveau for en given beskyttelsesforanstaltning beregnes som den måleværdi, for hvilken den gennemsnitlige undgåede dosis er lig med det generiske indgrebsniveau.

Det anbefales herudover at udvikle den probabilistiske metode til brug for optimering af eksisterende og kommende målestrategier, f.eks med hensyn til type og antal af målinger samt tidsskemaet for indsættelsen af mobile målehold.

Arbejdet med modforholdsregler inden for landbruget i en alarmperiode, herunder de nødvendige indgreb på gårdene i forbindelse med spredningen af radioaktivt materiale samt de problemer, der vil være forbundet med evakuering af gårde med dyrehold, blotlagde mange spørgsmål som må tages i betragtning, hvis der skal træffes beslutning om modforholdregler. Overvejelserne viste klart, at der er mange indbyrdes forskelle mellem de nordiske lande med hensyn til den landbrugsmæssige situation og forhastede konklusioner vedrørende harmonisering af modforholdsregler bør derfor undgås.

Samarbejdet mellem faggrupperne inden for strålingsbeskyttelse og inden for landbrugs- og fødevaresektoren har været meget frugtbart og nødvendigt. Med hensyn til fortsættelsen af dette samarbejde og udviklingen af beredskabet, anbefales det at lægge vægt på den fortsatte videnopbygning og uddannelse samt fremstillingen af en fælles nordisk håndbog for området. Et tilfredsstillende indgrebsberedskab bør eksistere allerede i alarmperioden.

Det er nødvendigt at myndighederne på landbrugs- og fødevareområdet stræber mod at udvikle en fleksibel organisering af beredskabet, således at de nødvendige indgreb kan gennemføres hurtigt og effektivt. En forudsætning herfor er at den nødvendige viden er tilsted med hensyn til hvilke indgreb, der kan anvendes og hvilke konsekvenser indgrebene har.

Det ville være formålstjenligt med et forum, hvor de landbrugs- og fødevareeksperter, som indgår i beredskabsorganisationen, har mulighed for at udveksle synspunkter med eksperterne inden for strålingsbeskyttelse angående effekten og anvendeligheden af de forskellige modforholdsregler.

Det ville ligeledes være nyttigt i hvert land, at have en håndbog, der dækker beredskabsspørgsmålene for landbrugs- og fødevaresektoren. Håndbogen skulle behandle både beredskabsopbygning og alarmrutiner samt beskrive mulige indgreb og konsekvenser. Desuden kunne den indeholde den grundlæggende information, som vil gøre det muligt at tilpasse indgrebene til de foreliggende forhold.

Table of contents

Introduction

The following four independent subprojects were performed under the title ”Preparedness Strategy and Procedures”:

EKO-3.1 Mobile measurements
EKO-3.2 Quality assurance in sampling and analysis
EKO-3.3 Operational intervention levels
EKO-3.4 Measurement strategy, basis for decisions and interventions in agriculture

The overall aim of the sub-projects was to assist Nordic authorities in improving their emergency response and international co-operation in selected issues.

Reliable and comparable results of different types of measurements are an essential basis for decisions on protective measures. The first subproject focused on mobile measurements, which are vital in mapping deposition in the immediate aftermath of a nuclear accident. In previous Nordic Nuclear Safety Research (NKS) research projects and similar programmes elsewhere, it has been common to evaluate a single specific measuring technique. In an emergency situation after a major release of radioactive material, however, many different types of measuring systems will be used. These systems may operate on different principles for measuring the gamma radiation field and could include NaI spectrometers, HpGe detectors, ionisation chambers, simple GM counters or total-count scintillometers. Consequently, the results from such a wide variety of systems may not be directly comparable. In addition the individual detector systems could be mounted in a mobile vehicle such as a helicopter, fixed-wing aircraft or car. *In situ* gamma-ray measurements would also be made. With this wide variety of configurations, the field of view of the detector can vary from a few square metres to several thousands of square metres.

Sampling of various types of environmental materials and analysis of samples containing a multitude of radionuclides, including measurements of man, require a well-established quality assurance system to promote confidence in the results. After a major nuclear accident international compatibility of the results is vital both because assistance may be necessary from other countries and because public confidence in the emergency management must be maintained.

In recent years more and more emphasis is being placed on the ability to demonstrate the quality of measurements and data. This follows from increased international exchange of data and information between authorities and institutes. It is no longer enough to be able to produce good measurements; laboratories need to be able to demonstrate the quality of their measurements and the limitations of the results. One such example is the European Union´s requirement that laboratories conducting measurements on foodstuffs and issuing certificates should be accredited to the EN 45001 standard.

From the radiation protection point of view the key issue in emergency response and management is to be able to implement protective actions in a timely manner in order to avert radiation exposure and consequently minimise the health effects. The aim is to avoid deterministic effects and to keep the stochastic effects at a level as low as reasonably achievable under the prevailing circumstances. Due to the strong psychological implications in a radiation accident, it is considered desirable to harmonise at least the intervention levels (in terms of avertable dose) among the countries but also the action levels and operations intervention levels (OILs), i.e. quantities accessible for direct measurements, if possible.

For ten years various attempts have been made to this effect without much success. The Nordic authorities are presently examining the question of harmonising the intervention levels and one of the subprojects in the present programme investigated the technical background for the use of OILs in a nuclear emergency. A problem exists that stems from the requirement of radiation protection to optimise the intervention/action levels and the desire to harmonise the levels, in particular OILs that are accident- and site-specific. A probabilistic approach was adopted to study the conditions under which harmonisation of action levels would not unreasonably violate the radiation protection principles.

The subproject on measuring strategy, basis for decisions and intervention in agriculture was initiated because agricultural and food experts, who are part of the preparedness organisation in their respective Nordic countries, have much too seldom had opportunities to exchange viewpoints with radiation protection experts, especially on problems in agriculture, effects of consequence-limiting measures and applicability in the event of radioactive fall-out. It was also considered essential that these agricultural and food experts, who are part of the preparedness organisation in each country respectively, as advisers or authority representatives, form a ”network” with radiation protection experts engaged in agricultural and food issues, which would facilitate contacts in the event of an accident.

By disseminating the knowledge that exists in the Nordic countries, the preparatory work is made more efficient by avoiding double workload. A forum would thus also exists with the objective of justifying the differences existing among countries in the manner of taking action by basing them on facts. The latter is essential to maintain the public confidence in the authorities in the event of an accident.

Since all these subprojects have specific objectives and were organised differently, these will be described project by project in the following chapters. The timing of the projects also differed such that EKO-3.1 on mobile measurements was undertaken in the beginning of the NKS 1994-1997 project period, and it was not until the middle of the period that the EKO-3.2, EKO-3.3 and EKO-3.4 subprojects on quality assurance, on operational intervention levels and on food and agricultural issues were added to its activities.

Mobile measurements

Objectives

The RESUME95 exercise - Rapid Environmental Surveying Using Mobile Equipment - was conducted in Finland in August 1995. The objectives of the RESUME95 exercise were to compare different monitoring systems used under the same conditions as well as results from similar systems with different data analysis and presentation software. Another objective was to acquire basic knowledge on standardising and cross-calibrating the European air-born gamma-survey capability such that the results from various systems could be directly comparable. Finally, one of the objectives was to test potential mutual co-operation and assistance in the event of a nuclear emergency.

Project outline and organisation of the work

The exercise involved 10 airborn monitoring teams, 7 teams with vehicle-mounted monitoring systems as well as ground survey teams from 8 countries. Most systems incorporated GPS satellite navigational aids and computers for real-time display of the data, which was also recorded for postflight analysis. Most of the car- and airborne systems were based on NaI detectors, whereas most of the *in situ* systems and a few airborne systems were based on the use of HpGe detectors.

The exercise took place in an area near Asikkala and Padasjoki, 25 - 50 km north of Lahti. Three different areas were surveyed, which included:

1. An airfield near Vesivehmaa, which was intended as a calibration site. Soil samples had been taken previously and used to establish the caesium-137 activity of the soil as well as the activity of the natural radionuclides potassium-40, bismuth-214 and thallium-208.
2. An area contaminated by the Chernobyl nuclear accident. This area was intended for testing the capabilities of the car- and airborne teams for mapping caesium-137. A number of predetermined points in the area were used by *in situ* teams.
3. An area with a variety of hidden radioactive sources. These sources of cobalt-60, caesium-137, iridium-192 and technetium-99 ranged in activity from 0.6 mCi to 15 Ci and was used to test the capability of the various airborne teams for locating lost radioactive sources.

Immediately after all three areas were surveyed, it was required that the results of the search for hidden radioactive sources should be delivered to the organisers. During the week of the exercise, more detailed analyses were performed. Maps of the caesium distribution in the second area were also produced and presented on a common bulletin board during the course of the exercise. On the last day, each participating team presented their results at a seminar. A final report was prepared, including individual papers written by the various participating monitoring teams describing their own results, interpretation and experiences. In addition some selected papers were included that provided a general description of the exercise and a final summary of the results./Publ. 1 /

Main results

The results from the exercise demonstrated the excellent capability of the airborne teams. Eight of the ten airborne teams were able to deliver caesium-137 maps very soon after the surveys were completed, in some cases within a few hours. In general, the caesium-137 deposition maps from the airborne and carborne teams showed the same spatial features, but with some variation in absolute levels. Most of the observed differences could be attributed to differences in calibration methodology and spatial attributes of the various measuring techniques. It was found that accurate flight-path navigation and presentation and analysis software played an important role in the search for hidden sources.

Two line plots of a subset of the data sets are shown as examples of the measuring results in Figs. 1 and 2. They include only measurements situated less than 75 m from the predefined flight lines, while measurements taken at a greater distance are not shown. From the line plots it is clear that point-to-point comparison of the various measuring techniques is difficult, due to differences in field of view of the detectors and the different sampling times used by the teams, both of which factors also interact with the natural spatial heterogeneity of the caesium-137 deposition. A certain variation from the predefined flight lines can also be observed in the missing points and also in the small shifts in position of significant features. Nevertheless, among the airborne, carborne and to a lesser extent *in situ* measurements a remarkable degree of concordance still persists.

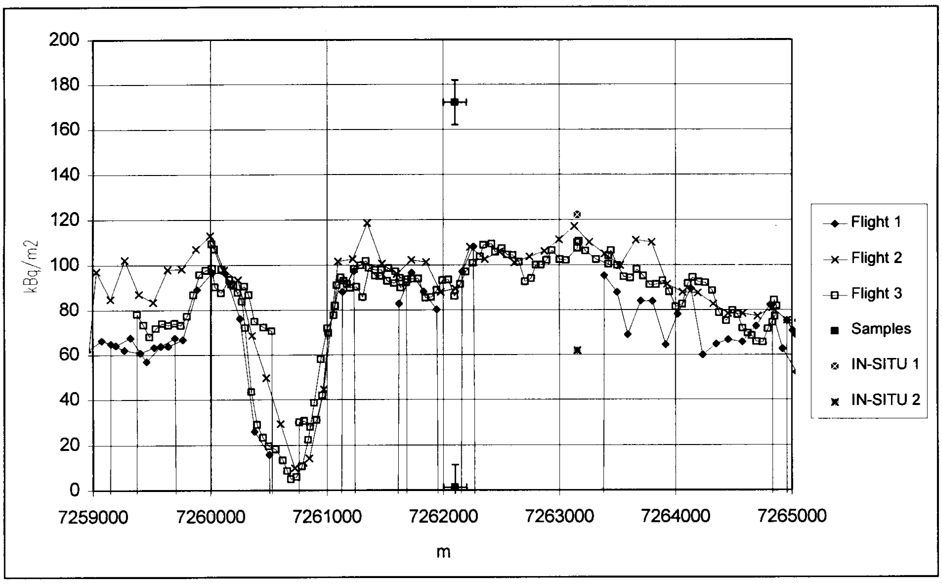


Figure 1 Line data (profile) for three airborne data sets and nearby in-situ measurements and soil samples (RESUME 95)

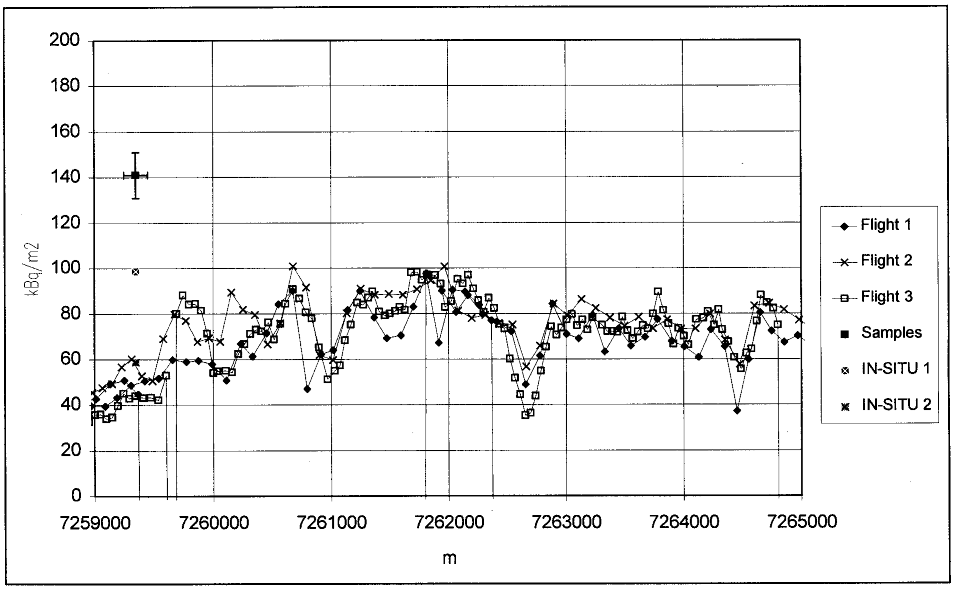


Figure 2 Line data (profile) for three airborne data sets and nearby in-situ measurements and soil samples (RESUME 95)

RESUME95 has demonstrated conclusively that it is possible to integrate different mobile teams within the framework of emergency response. Each airborne team over a 1.5-hour period, and each carborne team over 3-8 hours was able to make a detailed survey of an area roughly 3x6 km in size. Data delivered to the organisers indicate that data processing can be performed at the same rate as or faster than the data collection.

Remaining problems

Analysis of the results, however, indicated the existence of some general difficulties in comparing data sets with quite different spatial attributes, such that although the main features are identified by all the teams, some additional work remains to ensure full integration of different types of systems. Calibration of the equipment and repeatability as well as the field of view of the various systems needs to be studied. Influence of positional errors is also important when comparing results from a variety of systems. The relationship between *in situ*, soil samples and aerial results needs better understanding.

The remaining problems may be categorised into two groups. The first concerns the environmental radioactivity field and its spatial properties and hence its interaction with the sampling and positioning of the instruments. The second concerns the basic problem of measurement of radioactivity and includes aspects of calibration, background correction, spectral stripping etc.

Quality assurance in sampling and analysis

Objectives

Some of the laboratories in the Nordic countries have been measuring radionuclides and producing results of excellent quality for many years. First-class quality results for all radionuclides that are of concern and under all circumstances can, however, be difficult to achieve. Results from intercomparisons have also shown that many laboratories experience difficulty even with those radionuclides that are generally considered as easily measurable (e.g. caesium-137) and that the accuracy of the results is not within stated uncertainty.

The main objectives of the EKO-3.2 subproject were to assist Nordic laboratories in

1. assessing the quality of their current measurement techniques, e.g. through intercomparison exercises,
2. improving the quality of analytical techniques and
3. demonstrating in a formal manner the quality of measurements by introducing the writing of quality manuals and the process of accreditation.

Project outline and organisation of the work; main results

In the project work it was decided to put emphases on the following six topics:
1. Sampling and sample preparation during a state of emergency
2. Reporting, storing and exchange of electronic data
3. Reference sample geometries
4. Quality assurance in gamma spectroscopy with accreditation as a goal
5. Methods for processing gamma-ray spectra
6. Quality assurance in whole-body measurements

The six topics were addressed separately with one person in charge of each topic; the results are summarised in Publ. 2. To ensure sufficient cross-fertilisation among the topics and participation by the countries, the entire subproject was co-ordinated by a steering group with representatives from all the Nordic countries. Each topic area was handled differently and is described together with the results below.

Sampling and sample preparation during a state of emergency

Sampling and sample preparation are crucial factors in producing reliable and comparable results. The choice of sampling techniques is dependent on several things, such as the purpose of sampling, local conditions, techniques commonly used for similar sampling in the region, elsewhere or in related fields etc. Preparation of samples is highly dependent on the analytical technique and what will be measured. It may, therefore, be appropriate to use different sampling techniques and preparation methods for the same type of sample.

Harmonised Nordic procedures have been desired for sampling and sample preparation, but even when putting sampling traditions aside, it may still not be possible if the conditions and purposes vary. All the Nordic countries, however, would benefit from information on the procedures commonly used in other countries and on the bases for the differences among laboratories. The topic was only addressed by Sweden, which produced two reports: one on soil sampling and preparation and another on grass sampling, both in an emergency situation. Other countries did not comment on the reports, although requested.

These questions, however, were discussed shortly at an EKO-3.4 seminar with the authors of the two reports. The topic of soil sampling provoked a discussion on e.g. how the purpose of the sampling affects the choice of sampling methods, should vegetation be included and how, how local uncertainty should be estimated and what type of sampling grid (triangle or square) should be used. The sampling plan of grass was relatively well received. Such reports could be used as starting points in Nordic discussions.

If Nordic documents on sampling are desired, it is necessary to establish a contact group to define the purpose of sampling and other boundary conditions and to jointly outline the project. There are decennia long traditions in sampling for many purposes and under widely varying environmental conditions that need to be discussed if harmonisation is desired.

Reporting, storing, and exchange of electronic data

When exchanging data internationally the format of reporting requires special attention. All information necessary for correct interpretation of the data must be included. When data have been collected in various international fora the format is normally defined by the co-ordinating body, but generally accepted rules have yet to be created.

In recent years explosive growth has been seen in the amount of information produced and stored. Most of this new information is stored in digital format, which creates problems when it comes to long term storage. For long-term storage, the need exists for a suitable medium for the purpose, for future devices still able to read the information when it is to be retrieved and decoders (e.g. computer programs) capable of converting a string of binary digits into the information desired.

Some of today’s magnetic or optical storage media may not be able to store the recorded signal for long periods. In many cases the rapid development of data storage devices makes it difficult to find a device capable of reading information stored only a decade ago. Punched paper card readers are becoming difficult to find as well as diskette drives for some of the large older formats. Being able to read the digital information on the storage medium does not guarantee that the information can be retrieved. The stored information is only a string of binary numbers ”0” and ”1”. The decoding process then needs to convert it into text, a gamma spectrum file, video or any other end product. This encoding/decoding process can be sensitive to the development of the software used, as most users of word-processing or spreadsheet programs will have noticed. A new version of the software may not be able to properly retrieve information stored only a few years ago.

The problem of long-term data storage is, of course, not limited to those needing to store data on radionuclide measurements. This is a general problem and is of concern for many involved in information technology; therefore it would be wise to monitor the main trends and to continue the discussion among Nordic laboratories.

One possible format for reporting data is that adopted by the International Data Centre (IDC) of the Comprehensive Test Ban Treaty (CTBT)) for its Radionuclide Monitoring System (RMS). A description of the formats and protocols used in this

Global Atmospheric Radionuclide Detection System (GARDS) can currently be obtained in postscript format from the WWW location: http://www.cdidc.org:65120/web-gards/Documents/IDCDocs/

Reference sample geometries

The phrase ”measurement geometry” is here used to refer to a sample container and how its geometric shape affects the results of gamma spectrometric measurement. The shape of a sample container used for gamma spectrometric measurements can greatly affect the quality of results for several reasons. The counting efficiency is dependent on the average distance of the sample from the centre of the detector. A geometry that places most of the sample close to the detector will therefore result in higher counting efficiencies (e.g. Marinelli beakers). If all parts of the sample are at the same distance from the detector, less influence will be shown by possible sample inhomogeneity or even differences in sample volume. Coincidence summing effects increase as the distance to the detector decreases. When measuring radionuclides, with which these effects are a problem, one might desire to increase the distance of the sample from the detector, even though this would mean less counting efficiency. Regular geometries can facilitate the use of numerical methods to estimate counting efficiencies.

The choice of an optimal measurement geometry can thus be dependent on various factors, but it is important for the user to have a choice of suitable geometries and knowledge on how to choose.

As a first step in the study, a survey of the measurement geometries currently in use in Nordic laboratories was conducted to determine if any are in such widespread use that they could be adopted as reference geometries. Possible international efforts at standardising measurement geometries were also examined. At present an international standard exists for Marinelli-type beakers. This standard adopted by the IEC and ANSI describes two different beakers with volumes of 0.5 l and 1.0 l. In addition to these a 1.3 l Marinelli beaker of Swedish design is available that is widely used in the Nordic countries. With regard to Marinelli beakers, this suggests that Nordic standards exist, in fact even though they have not been formally adopted.

It was revealed that no national or international standards are available concerning the cylindrical beakers placed on top of the detectors. In the Nordic countries a number of different beakers for gamma spectrometry are currently used for environmental samples. It would be useful if laboratories could agree to adopt some models (one for each reference volume) as standards or rather as references. On the international level a proposal has been made for a standard of cylindrical beakers (Draft IEC 61428: Sample containers for gamma-ray spectrometry with Ge-detectors). Central Nordic laboratories performing radionuclide measurements have not been involved in this work. This is unfortunate, as some of them are in the forefront of research on optimal geometries.

Quality assurance in gamma spectroscopy with accreditation as a goal

In recent years increased need has been shown for laboratories to be able to demonstrate in a formal manner that they can produce measurements of high quality in a consistent manner. The European Union has added to this pressure by issuing a directive (93/99, October 23, 1993) on laboratories conducting measurements on foodstuffs. The directive requires that all laboratories performing such measurements must have accreditation according to the EN 45001 standard before November 1, 1998. Many laboratories have believed that they could demonstrate their ability through participation in international intercomparisons. The EU directive now places the laboratories in a different position, calling for a formal procedure to be followed, at least with reference to analysis of food products.

Nordic authorities have expressed their view on the need for accreditation based on the EU directive. After exploring what accreditation actually involves and producing material on the requirements, the project investigated the possibility of jointly writing a prototype Nordic quality manual for laboratory measurements of gamma emitting radionuclides. Work at the national level on writing a quality manual had already been initiated or was planned in all laboratories participating in a planning meeting, and therefore the suggested form of work was that each laboratory would submit a section of the prototype manual. Since most of the authorities have decided to integrate the quality assurance work of the gamma laboratory into the quality assurance policy of the institute as a whole, work on the prototype gamma manual has not progressed as initially planned and will not be available by the end of the project period. The project, however, resulted in clarifying the process of accreditation of gamma spectrometry laboratories and the relationship of accreditation to the quality of the measurements. Examples of the latter include the EN 45001 standard, which not only requires a process but also requires the laboratory to have the necessary technical competence to perform the measurements and that certain types of flexibility can be built into the quality manuals.

It is strongly recommended that authorities should maintain close contacts and that other Nordic laboratories interested in writing quality manuals should participate in the work as well. During the current project period confidential material was distributed, which cannot be published or directly quoted in the EKO- reports. Laboratories participating in the development of a Nordic prototype quality manual would, however, be able to benefit indirectly from this confidential material. Some of the participating laboratories have also invested in standards and specialised software for developing and maintaining quality manuals.

Methods for processing gamma-ray spectra

Some Nordic laboratories have a long tradition in producing excellent radionuclide measurements. Recent intercomparison exercises have nevertheless shown that many laboratories still have problems in measuring radionuclides that are commonly assumed to be easily measurable. A project was initiated to assist the laboratories in identifying where the main problems lie and to help them develop the means to correct them.

To begin with a survey on the use of software for gamma spectrometric analysis was conducted. Answers to a questionnaire were received from 9 out of 22 Nordic laboratories and from 5 out of 5 Baltic laboratories. The survey revealed that the programs used can be divided into two categories with rather different properties. The first group consists of commercial programs that are less flexible and require separate calibration for each geometry. Almost all also require a separate calibration for each sample density. The second group consists of ”home-made” programs that are more flexible and allow geometric variations such as varying the filling heights of sample containers. These programs also use theoretical or semiempirical methods to correct for variations in sample densities. The response to the questionnaire also showed that the most desired improvements for current software would be efficiency corrections for varying sample heights and density. This implies that commercial programs do not meet the needs of laboratories.

One of the ”home-made” programs in the survey is the GAMMA Program initially developed at the Radiation and Nuclear Safety Authority (STUK)/Finland and the National Radiation Protection Authority (NRPA)/Norway. The program has been the main program used in both institutes for a number of years. It has now been rewritten at STUK for the PC Windows program environment. STUK has distributed the program free of charge to several institutes showing interest in its use. The program is able to make efficiency corrections for varying heights and densities. Furthermore, the program has the unique property of being able to calculate coincidence summing corrections based on nuclear data. This enables the program to make efficiency corrections for nuclides never used in a calibration. The program can thus analyse a much wider range of radionuclides than would otherwise be possible. A manual in English for the GAMMA Program has been produced, with financial support by NKS, to make it easier for laboratories to use this alternative method of analysing gamma spectra /Publ. 4/.

A third component in this subsubproject was performance of a software intercomparison. It was organised using test spectra developed by the IAEA, which were distributed via the subproject´s WWW site and the results were collected using E-mail. The intercomparison exercise focused on the reliability of peak area measurements. The performance of a computer program that measures peak areas is also dependent on parameters that the user can adjust.

The test of precision revealed that only 8 of the 15 data sets received showed agreement between the calculated and observed variability of peak areas. Testing of accuracy showed that only 6 of the data sets showed agreement between the calculated peak area ratios and the true values given by the IAEA, accounting for the stated uncertainties. Only 4 of the 15 data sets showed both acceptable precision and accuracy, see Fig.3. The intercomparison showed that considerable differences occur among programs in their quality of peak area estimates and that the user can be a significant factor.

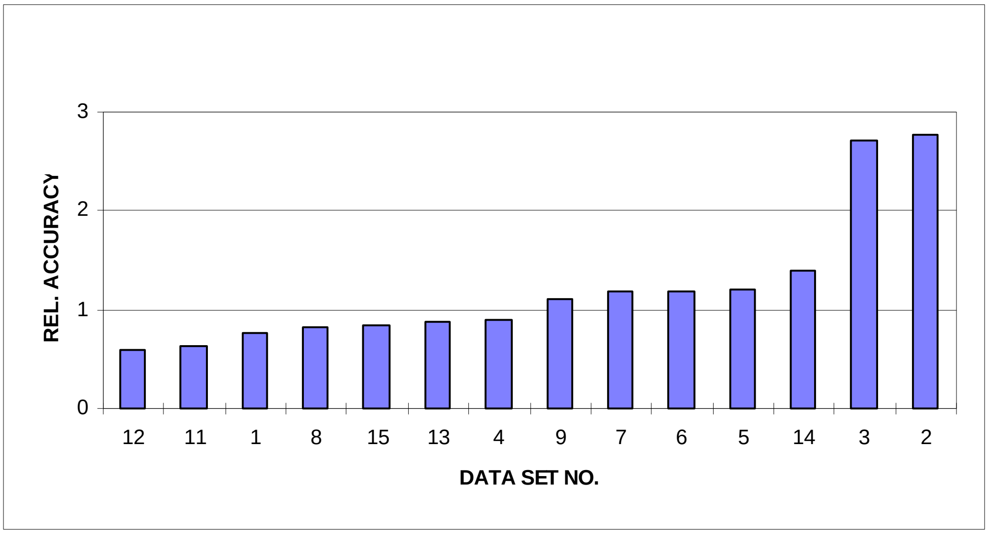


Figure 3 Plot of relative average accuracies of peak-area ratios for the data sets (S.P. Nielsen and S.E. Palsson, An intercomparison of software for processing Ge gamma spectra).

It is obvious from the results that considerable room for improvement exists in the quality of gamma spectrometric measurements carried out by Nordic laboratories, and thus quality assurance work will also be necessary in the future. Participation of laboratories of the Baltic countries in such work is highly recommended. It is also beneficial for the Nordic countries in the event of a nuclear accident to know the quality of measurements in Baltic laboratories.

Quality assurance in whole-body measurements

In previous NKS programmes intercalibration of whole-body measurements has proved to be a useful tool for promoting the comparability of results. This technique has the same problems as discussed above regarding the other gammaspectrometric measurements. Additional problems arise because of the complex geometry of the human body.

It is vital to obtain reliable results in whole-body measurements, because they constitute the basis for dose calculations both in the surveillance of radiation workers and the population in the event of an accident. Nordic radiation protection authorities, therefore, purchased a special phantom for quality assurance purposes in whole-body measurements. The present project then organised the circulation among those Nordic laboratories willing to participate, and assessed the results of the measurements performed by the laboratories.

The phantom version used in this project corresponds to a 62- kg person, and consists of rectangular blocks 165x110x55 mm in size and half-size blocks of 165x110x25 mm of tissue-equivalent plastic material. The maximum weight is 110 kg, and weights down to those of a small baby can be used.
Seventeen laboratories participated in the exercise and reported their results. Several of the laboratories also used the opportunity to calibrate their measuring systems with iodine in the thyroid. A thyroid phantom is an annex to the main phantom and can be used separately or as part of the main phantom.

The results of the intercalibration exercise are presented in Fig. 4 and compared with the reference activity. Measurements in Figs.4a-c were taken separately for each of the nuclides (cobalt-60, caesium-137, potassium-40) and in Figs. 4d and 4e the two nuclides (cobalt-60 and caesium-137) simultaneously in the phantom. The open symbols represent semiconductor detectors and the filled symbols NaI detectors. The thyroid phantom was not yet fully used in the exercise; however, it would be important to have wide participation in iodine intercalibrations, since iodine measurements could need the full capacity of whole-body counters in the country to assist after an accident.

The project also contained drafting of an outline for quality and technical manuals for whole-body counting. Quality assurance as part of the task thus includes all the aspects needed for ensuring and maintaining good quality of whole-body measurements where the final product constitutes an assessment of the internal radiation dose. The task was performed as part of a European harmonisation exercise, which is important because the same nuclear workers may need to be measured in different countries, as is presently the case between Sweden and Finland.

Fig. 4. Results obtained from the intercomparison measurements of a phantom containing unknown activity. The phantom circulated among the whole-body counting laboratories in the Nordic countries during 1997 as a part of the NKS/EKO 3.2.6 project : Quality assurance of whole body counters by Tua Rahola and Rolf Falk

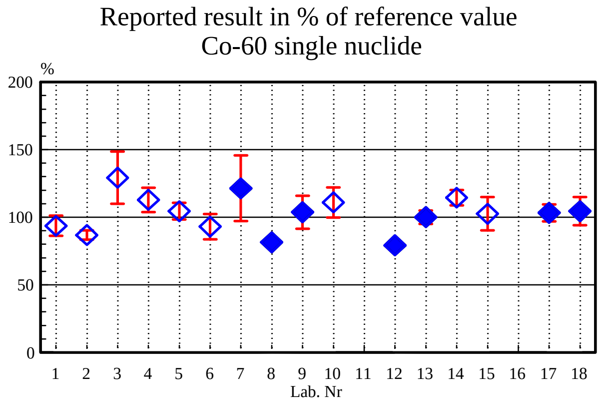


Figure 4a

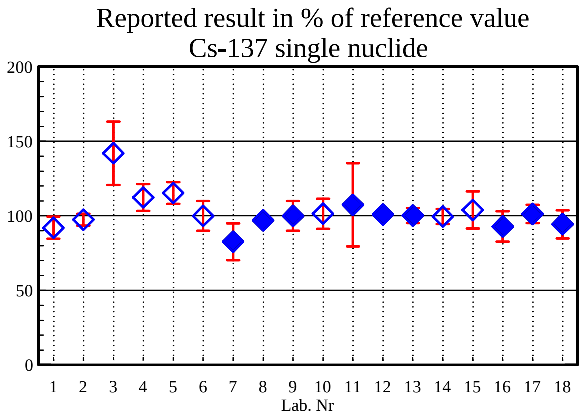


Figure 4b

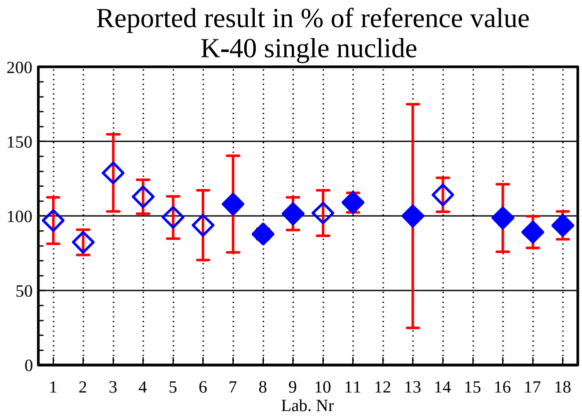


Figure 4c

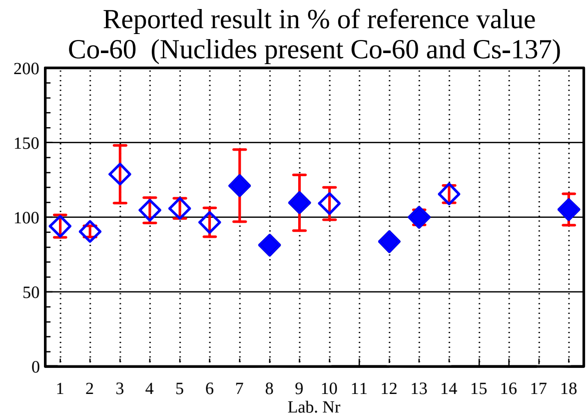


Figure 4d

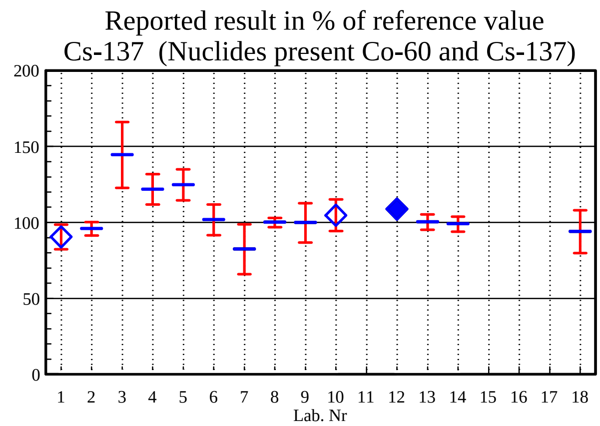


Figure 4e

Operational intervention levels

Objectives

The project deals with operational intervention levels (OILs), pertinent to early phases of a nuclear or radiation emergency. OILs are defined as the values of environmental measurements above which protective actions should be undertaken in emergency situations. Of particular interest are dose rate measurements carried out as part of a nuclear emergency preparedness programme, since they are commonly accessible and may provide for a preliminary estimate of the radiological consequences of an ongoing nuclear accident.

In accident management, the main focus of radiation protection is to reduce the adverse health effects of the accident by reducing radiation exposure to radiation workers and to the public to a level where deterministic effects can be avoided and where stochastic effects are limited ”as much as reasonably achievable”. For effective protection of the public, timing of countermeasures is important, since normally the earlier they are implemented, the more effective they will be. In this context, the OILs are introduced as decision-aiding tools, i.e. environmental (dose rate) measurements will facilitate a rapid emergency response by invoking predetermined OILs as observable thresholds for specific intervention measures.

Intervention is usually considered to be justified when the avertable dose exceeds an intervention level (IL), defined in the same units of avertable dose. At the time of implementation of urgent countermeasures, however, information on the scale and severity of the accident may be very limited, and assessment of the avertable dose will be very uncertain. If this uncertainty is not addressed explicitly, decisions on intervention will, to a large extent, be arbitrary.

For purposes of accident management OILs will, for urgent countermeasures, replace the less practical ILs. An OIL can be defined based on the same general principles as the IL, namely that the expected benefit of dose reduction just offsets the negative effects inevitably associated with the intervention measure. It is emphasised, with this definition of OILs, there is no *a priori* need for the introduction of an IL in the process of deriving the OIL. On the other hand, since ILs have already been optimised, they may play a role as a calculation tool in the derivation of OILs.

The aim of this subproject has been to provide the technical background for the determination of OILs in Nordic nuclear emergency preparedness programmes. The calculations performed in the present study are not intended to cover all possible accident scenarios and meteorological conditions. Rather, the focus has been to investigate the consequences of a probabilistic approach in determining OILs and to derive OILs in typical scenarios associated with severe reactor accidents. OILs are derived separately for different intervention measures, however, in the present study only dose rate measurements and the sheltering intervention option were investigated in detail.

The urgent countermeasures of evacuation and iodine prophylaxis have not been investigated in detail. Evacuation is a much more costly intervention measure than sheltering, and the prospect of evacuating a population is extremely sensitive to local conditions, therefore making general treatment less meaningful. When decisions on iodine prophylaxis are to be based on environmental monitoring, the data should include spectroscopic information, making assessment of the iodine concentrations possible. Such information is not widely accessible in the Nordic countries, and calculations must be based on the actual equipment available and on the measuring strategies envisioned.

Project outline and methods applied

Accident management has traditionally been considered a real-time problem in which the situation is to be assessed and response optimised in real time. The consequences of an accident are calculated deterministically, based on a specified source term, meteorological conditions and the effect of the countermeasures in question. In a realistic situation the information available will be less than complete, especially during the early phases of an accident, thereby rendering deterministic calculations unfeasible. The approach taken here is to evaluate OILs for early countermeasures in a probabilistic setting, in which only a few basic facts concerning the accident are known and any detail about the accident is treated as unknown information at the time of decision making. This is consistent with the requirements that OILs should be predetermined and that decisions must be based solely on the measurements (e.g. dose rate measurements) in the event that no other information on the accident is available.

At a later stage when detailed information is available, doses avertable by means of a protective action may be calculated deterministically and directly compared with the ILs expressed in avertable dose. In this case OILs will be less important as decision-aiding tools for accident management.

The reason for considering emergency management as a probabilistic problem is twofold. Firstly, even in the unlikely event that detailed information on the accident is available, allowing in principle for an accurate estimate of the off-site consequences, the demand for rapid emergency response may effectively preclude the data administration and processing needed to perform the estimate and to optimise the response. Secondly, by assessing in advance the uncertainty of the forecasting process in terms of the probability distribution of the off-site consequences, decision making is aided since the uncertainty will be a measure of the level of confidence that there is in the forecasting.

The variability of forecasted exposures originates partly in incomplete knowledge of the source term and local meteorology (accident-specific variability) and partly in the variability in efficiency of dose-reducing measures (site-specific variability). Even if the accident history were fully specified and the uncertainty associated with the stochastic nature of atmospheric dispersion and deposition processes could be neglected, radiation doses to the public would still display a distribution stemming from variations in the behaviour of individuals and their access to adequate protective arrangements.

In modelling accident scenarios, the model parameters may correspondingly be separated into those that are site-specific and those that are accident-specific. While the accident-specific parameters such as nuclide release fractions and parameters governing the meteorology are unknown parameters at the outset of an accident, the site-specific parameters, such as shielding factors or transport facilities for evacuation, are quantities that at least in principle could be assessed prior to the accident.

The results of forecasting may be expressed in terms of probability densities of averting a dose by means of protective action. The general appearance of the probability density as a single-humped function is the same, whether or not some prior knowledge exists about the situation, provided that a severe accident has occurred. The details of the distribution (e.g. width and mean value) are dependent on the information available, with any added piece of information in principle constraining the range of possible avertable doses. Data acquisition either from the plant or from environmental monitoring may be utilised to improve precision in forecasting.

The conditional probability distribution p_a of avertable doses due to the protective action "a" may be estimated by running a series of atmospheric dispersion model calculations, using an accident consequence assessment code. For probabilistic assessment, the important parameters describing both the accident scenario and atmospheric transport and deposition of radionuclides must be treated as stochastic variables and as such be ascribed a multivariate probability distribution function.

A Monte Carlo calculation of the atmospheric dispersion and deposition yields a joint probability distribution $p_a(\Delta E,d)$ from which the conditional probability is derived as

$$p_a(\Delta E \mid d) = p_a(\Delta E,d) / \int d(\Delta E) p_a(\Delta E,d).$$

The dose rate d is the dose rate measured outdoors due to external radiation from the plume and the ground. The avertable dose ΔE is the effective dose averted by means of the protective action a. In practice, only doses from external radiation and effective, committed dose from inhalation are important for short-term intervention measures. Doses from the ingestion pathway and from inhalation of resuspended material need not be included. The dose rates are evaluated for a limited number of positions mimicking the locations of measurement points. The number of measuring points and their positioning is dictated by the contingency plans of the emergency preparedness authorities. Since the emergency response, if any, will be triggered by the largest measurement value, this largest value of the dose rates (d) is utilised in the distribution $p_a(\Delta E \mid d)$. The avertable doses, on the other hand, are evaluated for all positions of the same distance to the release site. The value ΔE that is used in the distribution is taken to be the largest avertable dose so found.

The joint probability distribution $p_a(\Delta E,d)$ has been evaluated by using a modified version of the atmospheric dispersion model LENA 3.0, developed by the Swedish Radiation Protection Institute (SSI) . The atmospheric dispersion model LENA 3.0 is a straight-line Gaussian plume model in which a continuous release of activity is dispersed downwind, forming a Gaussian-shaped plume. Modifications allow the meteorology (e.g. wind direction and speed) to change every hour, such that the total release is segmented into hourly releases, each forming a straight-line Gaussian plume.

The reactor undergoing the accident is taken to be the Barsebäck nuclear power plant. Two accident scenarios were selected that could result from a severe core meltdown with loss of coolant, and the joint probability density was evaluated independently for each of the two scenarios. In accident scenario 1 (small releases), the containment is assumed to be functioning and the activity is released only through the filter system, causing a delay before release. In accident scenario 2 (large releases), the containment is malfunctioning and a substantial amount of activity bypasses the filter and is released to the atmosphere. The accident scenarios are chosen mainly for illustration purposes and do not result from a PSA Level-2 calculation. The accident parameters used and other detailed information are given in the main report /Publ. 5 and Publ. 6/.

Main results

In Fig. 5, the joint probability density for sheltering is shown for the two accident scenarios and for three selected distances. The probability densities are evaluated by the Monte Carlo technique; each dot in the figure results from a definite choice of parameters describing all processes from release to radiation exposure and the density of the dots indicates the joint probability distribution of dose rates and avertable doses. The large variability in avertable doses is evident from the figure, and in particular it is clear that there is no one-to-one correspondence between the dose rates and avertable doses.

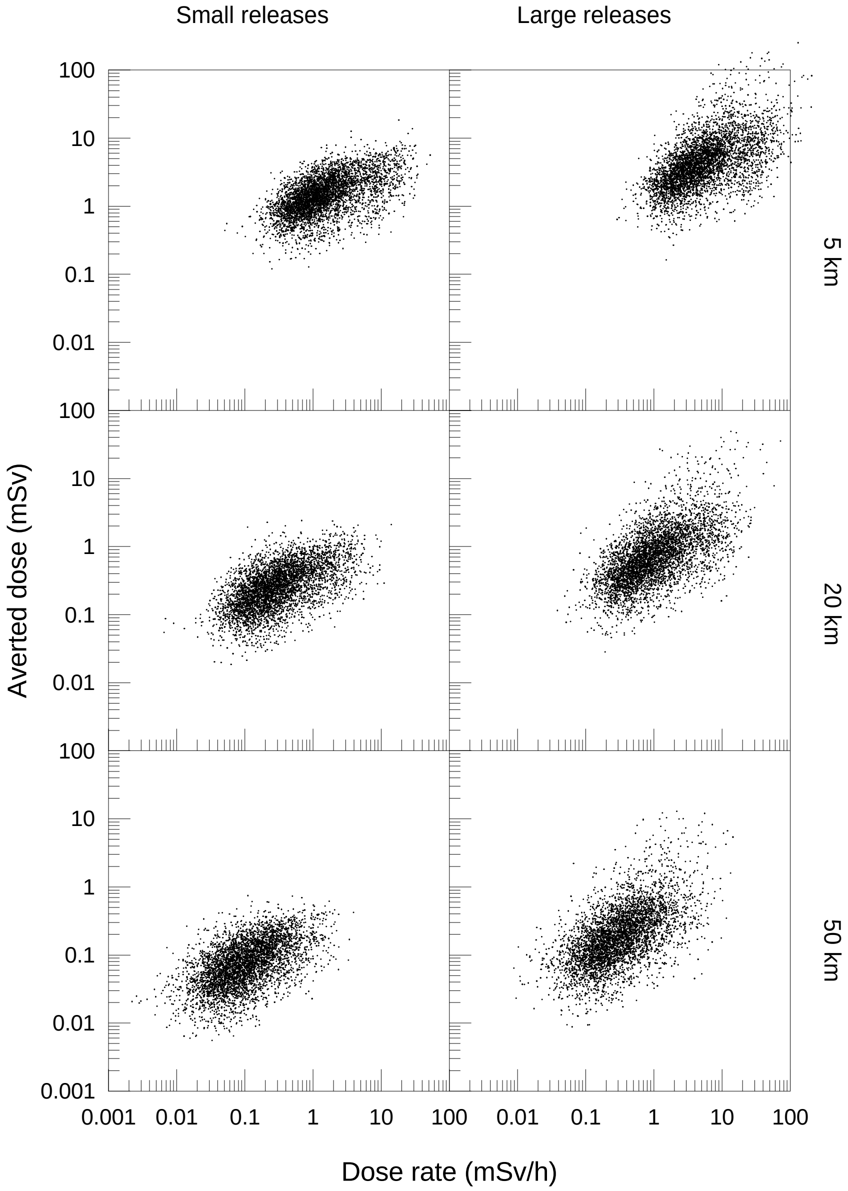


Figure 5 Joint probability distributions $p_a(\Delta E, d)$ for sheltering. In the two accident scenarios, “small releases” and “large releases”, all of the noble gases as well as a small and large fraction, respectively, of particulates are released from the plant.

The probability distributions comprise the information for decision making. OILs may be derived from the distributions. The probabilistic analysis shows that environmental dose rates and doses averted by sheltering are to some extent correlated; hence, OILs for sheltering may be defined in terms of the measurable dose rates. Optimised values of the dose rate OIL are defined by requiring that the expectation value of avertable dose is equal to the IL,

$$\Delta E_{IL} = \int d(\Delta E) p(\Delta E \mid d_{0IL}) \Delta E.$$

The optimised OILs are not proportional to the ILs. The analysis shows that due to the inevitable fluctuations, the OIL and IL have a nonlinear relationship that is approximately a power-law dependency. Furthermore, the analysis shows that the optimised OILs are dependent both on the source term and on the distance from the source.

Typical OILs for sheltering are found to be in the range of $d_{0IL} > 1$ mSv/h for distances larger than 5 km, i.e. values that are an order of magnitude larger than those adopted in Nordic and international emergency preparedness planning. This indicates that, the OILs previously have been defined very conservatively, ignoring that optimisation was already done in defining the ILs. Part of the explanation is likely to be found in the principal difference between the deterministic and the probabilistic approaches. In the former, there is an underlying hypothesis of a linear one-to-one relation between dose rate and averted dose. This hypothesis is unsustained; the inevitable fluctuations preclude a simple relationship between avertable dose and the measured dose rate.

The OILs are dependent both on the accident scenario and the distance from the site of the accident to the site where the countermeasure is taken. The implication is that a single OIL cannot be optimal, except at one distance and for a specified source term. Site-specific calculations will be needed to account for local differences in assumed source terms, effectiveness of countermeasures as well as differences in measurement strategies.

Remaining problems

The present work, in which the dose rate OILs for sheltering are calculated within the probabilistic approach, must be seen more as expanding on the idea of employing a probabilistic approach than giving an exclusive account of what OILs to use in an emergency. Proper OILs need to be optimised locally, depending on the radiation source and the local conditions. Such investigations remain to be done, and the calculations performed in this study do not represent the final work on the topic. Rather, the present results suggest that calculations of optimised OILs be performed independently for each major potential source of radionuclide contaminants. The numbers may all change in a more detailed study, e.g. in a study that is tailored to a specific nuclear reactor; for instance, the two years of meteorological data employed in the present study may not be representative of the meteorological sequences encountered over a longer time period.

Measurement strategy, basis for decisions and intervention in agriculture

Objectives

The objective of the work was to improve mutual understanding on one hand between the agricultural and radiation protection communities in the Nordic countries and on the other hand among the Nordic countries on possible countermeasures in agriculture. Eventually the work aims at a joint Nordic manual on agricultural and food chain countermeasures with background information.

Project outline and organisation of the work

Possible agricultural measures were analysed by the project. Because of time constraints, it was necessary to restrict the work on consequence-limiting measures to agriculture and within this to the alert period and immediately after the deposition. Since evacuation can be necessary at different time stages and animal husbandry can thereby cause problems, this was dealt with in the project. Some problems of weighing pros and cons in the long run were also identified. Dealing with measurements was limited to those occurring within the agriculture and food sectors.

A national group of 3 - 7 members was appointed within each country who, at least, represented agriculture (partly arable farming and partly animal husbandry, when necessary), and food and radiation protection - persons who, in the case of a nuclear accident, would be part of or closely related to the preparedness organisation in each country. A so-called co-ordinator was appointed for each country, who was responsible for documentation from and activity within the country.

As a first step (Publ. 8), in producing a Nordic manual on measures limiting the consequences of a nuclear accident in food chains, a report was prepared on necessary background information and measures during the early phase of an accident. The background information on radiation protection, food regulations and preparedness organisations was necessary for improving the mutual basis for the planning of countermeasures. The present main report (Publ. 8) serves rather as a discussion paper for further development than as a final part of the manual.

Main results

Some general aspects are pointed out in the report:

Within agriculture, not only the consequences of the contamination of the product should be considered, but also the requirements for limiting the radiation dose to farmers in their work and to avoid treating animals in a manner violating the legislation on animal welfare.

In the event of an accident the European Union plays a significant role within the area of agriculture and food, since it will determine the maximum permitted levels of radioactive contamination of food and feeding stuffs. The validity of the EU´s maximum permitted levels for import from a third country after the Chernobyl accident thereby expires as well as the existing national limiting values. The EU´s maximum permitted levels will probably also be followed by Iceland and Norway.

The preparedness organisations in each of the Nordic countries primarily has a co-ordinating role, and decisions are made by each competent authority in their area of responsibility. Some exceptions, however, exist; e.g. in Norway the Crisis Committee for Nuclear Accidents has the authority to introduce some restrictions during an acute phase. In the event of a nuclear accident it is therefore vital for the agricultural and food authorities in the Nordic countries to have good contacts with each other over the need and choice of consequence-limiting measures. Contacts need to be established with the corresponding authority or its representative in the co-ordinating preparedness organisation. It should also be noted that the food industry and traders are responsible for control of their products.

The present report focuses on measures within agriculture to be implemented during the alert period. The alert period means here the entire period from the time the alarm is given for a possible accident (a leak of radioactive material has occurred or may occur) until deposition begins. The following views are presented in the report:
In the first place, steps must be taken to limit the presence of radionuclides in milk through the inhalation and rapid transport in the food chain grass-cow-milk-humans. If cows are allowed to be out grazing radioactive iodine can be detected in the milk within 24 hours of the deposition and caesium and strontium after a few days.

During the alert period there is great uncertainty concerning both the extent of deposition and the way the country may be affected. Housing of animals etc. must therefore be recommended over a wide geographic area and, presumably, be recommended long before it becomes necessary to advise humans to stay indoors. This may negatively influence confidence in the radiation protection authorities if the public gains the impression that the authorities care more about cows and agricultural production than about people, and may partly lead to an unfounded fear caused by the event suddenly appearing very serious.

Notice of housing for animals must, however, be given sufficiently early that farmers who bring their cows in to be milked can keep them inside after milking. Bringing animals in when they do not expect to be milked can be both time- consuming and difficult to carry through, and the time could be usefully spent on other measures. In addition to recommendations for housing of animals, further recommendations are given to guarantee the supply of feeding stuffs and water as protection for investment goods and products. Recommendations to farmers must be especially accompanied by explanations of the motives behind them.

While comprehensive steps are quickly taken during the alert period despite the uncertainty, it is likely be the opposite during the first period after the deposition. With incomplete knowledge of the extent and character of land coverage that is available during the first period after the deposition, it is essential to act carefully while waiting for measuring results, e.g. for withdrawing recommendations on the housing of animals. To be forced to reintroduce restrictions after more accurate measurements have become available, could be detrimental to the credibility of the decisions and recommendations of the authorities.

Farmers may temporarily be requested to postpone any planned activities in crop production (e.g. soil preparation, sowing and harvesting) and carry out animal husbandry work only if absolutely necessary (e.g. feeding and milking). If it is recommended to stay indoors for more than a couple of hours, particular instructions should be given to various occupational groups. It should be stated, among other things, that farmers can move between their residential properties and their barns for milking, feeding and other necessary attendance to the animals.

In addition, farmers may also be temporarily requested not to use material that has been stored outdoors during fall-out as well as permitting those animals, which were outdoors during the fall-out to remain outdoors and avoid permitting these animals to drink from small pools of water.

Whilst there is uncertainty about whether the extent of the fall-out has led to exceeding the intervention criteria, an embargo should be placed on selling newly produced products and advice should be given against consumption until better knowledge of the fall-out situation is available.

Instructions on the discarding of products should not be given too hastily, but the limited cooling facilities on farms may make it necessary to discard milk after only a day or two. This should not be done by dumping the milk into lakes, watercourses, the sea or the local drainage system. Firstly, the best solution would be to pour the milk into a dung well, and secondly to spread it on cultivated fields.

When deciding upon evacuation, consideration must be given to the necessity for milking and the fact that livestock should not be evacuated. Dairy cows should remain indoors, while beef production animals can be left outdoors if there is not enough room in the sheds. If housed animals are left indoors, suckling calves should be let loose so that they have the opportunity to suckle, the ventilation should perhaps be increased somewhat and the animals given access to enough water to last them several days and food for at least 24 hours. Personnel with protective outfits should make brief visits to feed, water and milk the animals.

Extensive slaughtering in a short period of time is not realistic due to the lack of cooling facilities. When considering aspects of animal welfare, the alternative of putting animals to death must be weighed against reduced attendance and the length of time the animals are expected to remain in the area.

More generally pros and cons should be weighed against each other, not only for alternative consequence-limiting measures but, above all, as to whether or not any measures need actually be taken.

Contamination of several foodstuffs can be at least halved through treatment during the processing stage or at the consumer level, but the contamination should already be reduced at the agricultural stage, if the treatment can be carried out at reasonable cost.

When selecting certain measures for reducing the dose, consideration must, among other things, be given to the ”cost” one is prepared to pay for a certain dose reduction in the prevailing situation, to whether or not the measures limit freedom of action, and whether the measures will affect that year's harvest or future production potential thereby jeopardising the food supply.

With regard to measurement strategies, the measurements must first be concentrated after the deposition of radionuclides on checking whether applicable operational intervention levels have been exceeded, on obtaining information on whether the countermeasures previously implemented can be cancelled or whether additional measures or advice are necessary. Measurements should also be implemented to determine the efficiency of the countermeasures, improve the prognosis of the developing radiation situation in agriculture and to assess the actual intake of radionuclides by the population as a whole and by special subgroups likely to be exposed more than the average population.

Remaining problems

During the present work several issues were identified, which need to be addressed to improve emergency preparedness in agriculture and food-chain management. The present report should be deepened and extended into a Nordic manual, that addresses the countermeasures in relation to the time factors. The season, in which deposition occurs, the first year after deposition, measures before and during the next grazing and cultivating season etc. need separate consideration. The manual should also cover food production in (semi)natural environments, the food industry and trading.

The subproject also revealed the need for an other type of work, namely that information exchange between the two expert communities should be established. Emergency exercises also need to cover better the problems in agricultural and food sectors from the threat phase to the long term.

Concluding remarks

The project consists of differing types of subprojects within the emergency preparedness framework, from development of procedures for intervention criteria, through improving the quality and comparability of measurements, to planning for countermeasures. The lessons learned and conclusions drawn are therefore many and varied.

The lessons learned from RESUME95 indicate a need for further operational exercises in which a number of specific problems should be addressed in mobile measurements. These include the calibration and repeatability of the equipment as well as the fields of view of the various systems. Influence of positional errors is also an important aspect when comparing the results from a variety of systems. Problems such as these should be considered in the design of the exercise and the choice of areas to be surveyed. These aspects have in fact already been considered during the programme period, in planning for a similar exercise in a broader European context.

The lessons learned from RESUME95 in this respect include the following:
*Some aspects of spatial problems could be examined by surveying the same line a number of times to examine variations.
*Accurate and precise positioning could also be improved by introducing checkpoints (e.g. known radioactive sources at set locations).
*To investigate the unresolved question of systematic offsets, it may be possible to identify an area where the radioactivity field has homogenous properties on a scale of finest to coarsest spatial resolution of the monitoring systems in question.
*For trials under operational conditions, it would be useful to identify areas with a wider range of activity concentrations than those in Area II in the present exercise and include nuclides other than caesium-137.
*Technical questions including calibration, background corrections, effects of depth distribution and the uncertainties of the estimated distributions should also be addressed.

With regard to sampling and laboratory analysis, there are reasons for believing that considerable improvements could be made throughout the entire chain from sampling strategy through measurements to reporting of results. This is actually a continuous task, since both personnel and facilities change, and without continuous efforts to assess quality it tends to degrade rapidly. International co-operation is a necessary stimulus to such efforts, particularly, in small countries with few laboratories in the field. International programmes on improving the quality of results, introduction of new techniques to laboratories and demonstration of the quality of measurements/analyses in a formal manner are therefore necessary.

E.g. the outline for a quality assurance system for whole-body counting has been substantiated. In the participating Nordic countries better provisions now exist, especially in accident situations, for making comparable dose assessments based on whole-body counting.

The benefit for the Nordic countries of such projects should not be overlooked. In particular, in the event of a nuclear emergency, it is vital to be well aware of the quality of the measurements in neighbouring countries and to have a joint reporting system to avoid misinterpretations and misunderstandings. Comparable results are particularly important if assistance is needed from neighbouring countries.

Planning for intervention in an emergency situation should be done in advance to be efficient. The probabilistic approach developed offers a method for characterising the uncertainties in the effects of early intervention measures. Such a probabilistic safety assessment is a prerequisite for optimisation, both with respect to the planning and the implementation of emergency countermeasures.

It is recommended that operational intervention levels be defined within the probabilistic framework. In this framework, an optimised OIL is given as the measurement value for which the average avertable dose is equal to the (generic) intervention level. Furthermore, it is recommended that the probabilistic approach be developed as a tool for optimising existing and future measuring strategies. This may involve optimising the type and number of measurements and the time scheme for deployment of mobile measurement units.

During the course of the subproject dealing with agricultural countermeasures it became clear how important the exchange of information was, among representatives from the two communities of food-chain management and radiation protection. It also became clear that if the planned manual concerning consequence- limiting measures can be completed during the next NKS programme period, it can only state the possibilities, i.e. which actions could be taken - not which actions will be taken. This is not only due to the fact that every incident is unique, but also that the conditions in each country differ to a certain extent and, furthermore, that they are not completely known in advance. The financial situation and composition of agricultural production will, for instance, have a great impact on the choice of consequence-limiting measures. The important thing is not that the choice of measures are the same in the various countries, but that the differences can be justified and understood. With such a Nordic manual as a basis, each country can then supplement it with alarm routines and preparedness-increasing measures to establish a national manual.

Acknowledgements

We want to express our sincere thanks to all the laboratories in the Nordic countries, the Baltic countries and elsewhere that participated in the EKO-3 subprojects, as well as to all those numerous individuals who contributed in various ways to the implementation of the subprojects.

Appendix 1

Publications

1. RESUME95, Rapid Environmental Surveying Using Mobile Equipment, 1997, NKS, Copenhagen, Denmark; consists of 8 country reports and a comparison of results.

2. Pálsson, S.E., Nielsen, S.P., Klemola, S., Rahola, T., Jónsson, þ.V., Ugletveit, F., Finck, R. and Ennow, K., Quality Assurance in Sampling and Analysis, 1998; final report of EKO-3.2 to be published as a NKS report.

3. Klemola, S. and Leppänen, A., 1997, GAMMA97 - Gamma-Ray Spectrum Analysis Program, Documentation and User´s Manual, STUK, Helsinki.

4. Nielsen, S.P. and Pálsson, S.E., An Intercomparison of Software for Processing Ge Gamma Spectra; to be published

5. Lauritzen, B,, Bäverstam, U., Damkjær, A., Naadland Holo, Eldri and Sinkko, K., 1998, Operational Intervention Levels in a Nuclear Emergency, General Concepts and a Probabilistic Approach; to be published as an NKS report.

6. Lauritzen, B. and Bäverstam, U., 1997, Dose rate Measurements and Action levels in the Event of a Nuclear Accident, Variational Analysis, in Proc. of IAEA TCM on Special Topics Related to Level-3 PSA/Dose Calculations, Vienna, (Risø-I-1121(EN), Risø National Laboratory, Denmark, March 1997).

7. Jensen, Per Hedemann, 1996, Basis for Nordic Operational Intervention Levels, Methodology for deriving Operational Intervention Levels, Risø National Laboratory, Roskilde, Denmark

8. EKO-3.4 Rapport 1997, Preuthun, J., Brink, M., Rantavaara, A., Runólfsson, H., and Salbu, B., to be published in Swedish as an NKS-report.

Appendix 2

List of participants

EKO-3:

Project Leaders
Hovgaard, Jens, Ministry of the Interior, Danish Emergency Management Agency, Denmark
Salo, Anneli, Finland

EKO-3.1:

Sub-project Leader
Hovgaard, Jens, Ministry of the Interior, Danish Emergency Management Agency, Denmark

Participants
Grasty, Bob, Canada
Cox, John R., Exploranium, Canada

Jensen, Johs., Jensen, Consult, Denmark
Lund, Birger, Kanal 2, Forsvarets TV, Denmark
Olsen, René, Kanal 2, Forsvarets TV, Denmark
Benthin, Søren, Danish Emergency Management Agency, Denmark
Hein, Vibeke, Danish Emergency Management Agency, Denmark
Hovgaard, Jens, Danish Emergency Management Agency, Denmark
Juul, Kirsten B., Danish Emergency Management Agency, Denmark
Andersen, Frank, Technical University of Denmark, Denmark
Barghoiz, Kim, Technical University of Denmark, Denmark
Korsbech, Uffe, Technical University of Denmark, Denmark
Paulsen, Dorte Eide, Technical University of Denmark, Denmark

Pulakka, M., Finnish Air Force Depot, Finland
Honkamaa, Tapani, Finnish Centre for Radiation and Nuclear Safety, Finland
Huotari, Tuija, Finnish Centre for Radiation and Nuclear Safety, Finland
llander, Tarja, Finnish Centre for Radiation and Nuclear Safety, Finland
Karvinen, Ali, Finnish Centre for Radiation and Nuclear Safety, Finland
Karvonen, Jari, Finnish Centre for Radiation and Nuclear Safety, Finland
Lahtinen, Juhani, Finnish Centre for Radiation and Nuclear Safety, Finland
Lemmelä, Heikki, Finnish Centre for Radiation and Nuclear Safety, Finland
Markkanen, M., Finnish Centre for Radiation and Nuclear Safety, Finland
Niskala, P., Finnish Centre for Radiation and Nuclear Safety, Finland
Pöllänen, Roy, Finnish Centre for Radiation and Nuclear Safety, Finland

Tiilikainen, Hannu, Finnish Centre for Radiation and Nuclear Safety, Finland
Toivonen, Harri, Finnish Centre for Radiation and Nuclear Safety, Finland
Heininen, Tapio, Finnish Centre for Radiation and Nuclear Safety, Finland
Jappinen, Arto, Finnish Centre for Radiation and Nuclear Safety, Finland
Keskitaio, Kari, Finnish Centre for Radiation and Nuclear Safety, Finland
Kettunen, Markku, Finnish Centre for Radiation and Nuclear Safety, Finland
Kortesoja, Kari, Finnish Centre for Radiation and Nuclear Safety, Finland
Laine, Ilkka, Finnish Centre for Radiation and Nuclear Safety, Finland
Puputti, Margit, Finnish Centre for Radiation and Nuclear Safety, Finland
Hautaniemi, H., Geological Survey of Finland, Finland
Multala, Jukka, Geological Survey of Finland, Finland
Aarnio, Pertti, Helsinki University of Technology, Finland
Mäkinen, Susanna, Helsinki University of Technology, Finland
Nikkinen, Mika, Helsinki University of Technology, Finland
Koivukoski, Janne, Ministry of the Interior, Rescue Department, Finland
Peltola-Lampi, Tiina, Ministry of the Interior, Rescue Department, Finland
Lehtonen, Erik, RADOS Technology Oy, Finland

Bourgeois, Christian, Commissariat à L'Energie Atomique, France
Bresson, Jean, Commissariat à L'Energie Atomique, France
Chiffot, Thierry, Commissariat à L'Energie Atomique, France
Guillot, Ludovic, Commissariat à L'Energie Atomique, France
Tresamini, Eric, Commissariat à L'Energie Atomique, France

Barke, Holger, Federal Border Police, Germany
Carloff, Gunter, Federal Border Police, Germany
Mönch, Thomas, Federal Border Police, Germany
Scharmacher, Volkmar, Federal Border Police, Germany
Wetzlar, Peter, Federal Border Police, Germany
Wilkendorf, Dieter, Federal Border Police, Germany
Brummer, Ch., Federal Office for Radiation Protection, Germany
Buchröder, Helmut, Federal Office for Radiation Protection, Germany
Thomas, Michael, Federal Office for Radiation Protection, Germany
Winkelmann, Ingolf, Federal Office for Radiation Protection, Germany

Håbrekke, Henrik, Geological Survey of Norway, Norway
Mogaard, John Olav, Geological Survey of Norway, Norway
Willoch, Harald, NILU, Norway
Berg, Thor Ch., Norwegian Institute for Air Research, Norway
Henriksen, Ole, Norwegian Institute for Air Research, Norway
Larsen, Sven, Norwegian Institute for Air Research, Norway
Larsen, Erlend, Norwegian Radiation Protection Authority, Norway
Rønning, Stig, Geological Survey of Norway, Norway
Smethurst, Mark A, Geological Survey of Norway, Norway

Flø, Lise, Norwegian Radiation Protection Authority, Norway
Mikkelborg, O., Norwegian Radiation Protection Authority, Norway
Ugletveit, Finn, Norwegian Radiation Protection Authority, Norway

Rääf, Christopher, Lund University, Department of Radiation Physics, Sweden
Byström, Sören, Geological Survey of Sweden, Sweden
Lindén, Anders, Geological Survey of Sweden, Sweden
Lindgren, Jonas, Geological Survey of Sweden, Sweden
Almén, Anja, Lund University, Sweden
Eberhardt, Jacob, Lund University, Sweden
Samuelson, Christer, Lund University, Sweden
Arnising, Rune, National Defence Research Establishment, Sweden
De Geer, Lars Erik, National Defence Research Establishment, Sweden
Lidström, Kenneth, National Defence Research Establishment, Sweden
Ulvsand, Thomas, National Defence Research Establishment, Sweden
Ågren, Göran, National Defence Research Establishment, Sweden
Vintersved, Ingemar, National Defence Research Establishment, Sweden
Finck, Robert, Swedish Radiation Protection Institute, Sweden
Hagberg, Nils, Swedish Radiation Protection Institute, Sweden
Mellander, Hans, Swedish Radiation Protection Institute, Sweden
Samuelsson, Göran, Swedish Radiation Protection Institute, Sweden
Åkerblom, Gustav, Swedish Radiation Protection Institute, Sweden
Vesanen, Raine, University of Göteborg, Sweden
Isaksson, Mats, University of Göteborg, Sweden

Scott, Marian, University of Glasgow, Scotland
Allyson, David, Scottish Universities Research & Reactor Centre, Scotland
Heathcote, Paul, Scottish Universities Research & Reactor Centre, Scotland
McConville, Paul, Scottish Universities Research & Reactor Centre, Scotland
Murphy, Simon, Scottish Universities Research & Reactor Centre, Scotland
Sanderson, David, Scottish Universities Research & Reactor Centre, Scotland

Hendriks, Thane, EG&G/EM, USA

EKO-3.2:

Sub-project Leader
Pálsson, Sigurður Emil, Icelandic Radiation Protection Institute, Iceland

Steering group
Ennow, Klaus, National Institute of Radiation Hygiene, Denmark
Nielsen, Sven P., Risø National Laboratory, Denmark
Klemola Seppo, Radiation and Nuclear Safety Authority, Finland
Rahola, Tua, Radiation and Nuclear Safety Authority, Finland

Ugletveit, Finn, Norwegian Radiation Protection Authority, Norway
Finck, Robert, Swedish Radiation Protection Institute, Sweden

Other participants
Jónsson, þorsteinn V., Icelandic Radiation Protection Institute, Iceland
Leppänen, Arto, Radiation and Nuclear Safety Authority, Finland
Falk, Rolf, Swedish Radiation Protection Institute, Sweden
many others participating in the sub-sub-projects from various laboratories

EKO-3.3

Sub-project leader
Damkjær, Anders, Risø National Laboratory, Denmark

Participants
Lauritzen, Bent, Risø National Laboratory, Denmark
Sinkko, Kari, Radiation and Nuclear Safety Authority, Finland
Naadland Holo, Eldri, Norwegian Radiation Protection Authority, Norway
Bäverstam, Ulf, Swedish Radiation Protection Institute, Sweden

Other contributors
Hedeman Jensen, Per, Risø National Laboratory, Denmark
Nielsen, Flemming, Risø National Laboratory, Denmark
Thykier-Nielsen, Søren, Risø National Laboratory, Denmark
Salo, Anneli, Finland

EKO-3.4:

Sub-project Leader
Preuthun, Jan, Swedish Board of Agriculture, Sweden

Participants
Brink, Magnus, Plant Directorate, Denmark, Co-ordinator
Andreasen, Kaj, Directorate of Veterinary and Food Affairs, Denmark
Sporon-Fiedner, Charlotte, Directorate of Veterinary and Food Affairs, Denmark
Öhlenschläger, Mette, National Institute of Radiation Hygiene, Denmark

Rantavaara, Aino, Radiation and Nuclear Safety Authority, Finland, Co-ordinator
Latvio, Esa, Food Pool, Finland
Liskola, Kari, Ministry of Agriculture and Forestry, Finland
Mustonen, Irmeli, Food Pool, Finland
Mäkelä, Pia, Ministry of Agriculture and Forestry, Finland
Salminen, Kalevi, National Food Administration, Finland
Seppänen, Hannu, Association of Agricultural Centres, Finland

Runólfsson, Halldór, Ministry of Agriculture, Iceland, Co-ordinator
Sigurbjörnsson, Björn, Ministry of Agriculture, Iceland
Ólafsðóttir, Elisabet, Icelandic Radiation Protection Institute, Iceland

Salbu, Brit, Agricultural University of Norway, Norway, Co-ordinator
Hove, Knut, Agricultural University of Norway, Norway
Sannerholt Melbostad, Kari, Norwegian Food Control Authority, Norway
Strand, Per, Norwegian Radiation Protection Authority, Norway

Brasch, Agneta / Jeppsson, Sven, Swedish Board of Agriculture, Sweden
Jonsson, Evert / Areskoug, Göran, Swedish Board of Agriculture, Sweden
Finck, Robert, Swedish Radiation Protection Institute, Sweden
Svensson, Kettil, National Food Administration, Sweden