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Radiological and Environmental Consequences

Sigurður Emil Pálsson
Icelandic Radiation Protection Institute

November 2002

Nordic Nuclear Safety Research (NKS)

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

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

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

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

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Final Report of the Nordic Nuclear Safety Research Project BOK-2

Sigurður Emil Pálsson

Icelandic Radiation Protection Institute

November 2002

This is NKS

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

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

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

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

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

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

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

Abstract

Final report of the Nordic Nuclear Safety Research project BOK-2, *Radiological and Environmental Consequences*. The project was carried out 1998-2001 with participants from all the Nordic countries. Representatives from the Baltic States were also invited to some of the meetings and seminars. The project consisted of work on terrestrial and marine radioecology and had a broad scope in order to enable participation of research groups with various fields of interest. This report focuses on the project itself and gives a general summary of the studies undertaken. A separate technical report summarises the work done by each research group and gives references to papers published in scientific journals. The topics in BOK-2 included improving assessment of old and recent fallout, use of radionuclides as tracers in Nordic marine areas, improving assessment of internal doses and use of mass spectrometry in radioecology.

Key words

Radioecology, radioactive fallout, sheep, radiocaesium, radiostrontium, technetium, seaweed, oceanic tracers, mass spectrometry, internal doses, doses to man

Summary

The NKS/BOK-2 project, *Radiological and Environmental Consequences, 1998-2001*, focuses on radioecology in the Nordic countries and areas of interest to them. The NKS has in previous programme periods included work on radioecology, and many basic questions concerning assessment of risk due to environmental radioactivity have been answered. One may then ask, why should one continue work in this field? This question, by itself, reflects the problem. Why should talented young people enter a field where many important questions have already been answered and the interest of society in nuclear methods is decreasing? In fact modern society still has pressing questions. The questions have changed, but answers are still urgently required and it seems there are fewer competent persons able to provide the answers.

The changed nature of questions asked by society can be seen from more requirements for studies to prove that there are no significant health risks from environmental radioactivity and for tracer studies to help understand processes and predict development of very low environmental concentrations. Risk and health related assessments are, however, still important. They form the backbone of emergency response plans. The threat scenarios change from time to time and thus new assessments are called for.

An important aim of the BOK-2 project was thus to provide a stimulating environment and to encourage contacts and co-operation between young and experienced researchers, between scientists in different fields (within and outside traditional radioecology) and between scientists within the Nordic countries and neighbouring regions. This was done through meetings, seminars and dissemination of information, including the use of the Internet. The Nordic network within radioecology is important for national authorities and for new people in the field and for making it possible to start close co-operation quickly between countries, e.g. if needed because of a nuclear accident.

When organising the project work within BOK-2, a choice had to be made between having a project with a broad range of activities and many participants, and narrowing the focus, obtaining more depth in a few fields, at the expense of limiting the number of participants. No one ideal solution can be found, what might suit one country can be inappropriate for another. The conclusion was to have a broad range of activities, build on existing project work in each country as much as possible and try to build-up a large network with many participants.

In accordance with the suggestions of the NKS programme group, it was decided to structure the BOK-2 project as follows:

BOK-2.1 Important Nordic food chains
- BOK-2.1.1 Radioecological vulnerability
- BOK-2.1.2 Internal doses

BOK-2.2 Radioactive tracers in Nordic sea areas
- BOK-2.2.1 Sea water transport
- BOK-2.2.2 Biological and biogeochemical processes

BOK-2.3 Applications of ICP-MS for measuring radionuclides

BOK-2.4 Methodology for defining exemption levels of radionuclides in timber

In BOK-2.1.1 the main emphasis was on using old fallout data to improve methods of estimating the effects of radionuclide deposition. This was done by using traditional UNSCEAR models on a combined data set of fallout and Chernobyl data, and by using precipitation data to predict deposition. Each approach was used successfully by participants from three Nordic countries, combined they involved all five Nordic countries and the Faroe Islands.

The aim with BOK-2.1.2, Internal doses, was to improve methods for dose calculations based on dietary methods (indirect method) and whole-body counting (direct method). It has e.g. involved two courses with practical exercises, calibration and intercalibration of equipment and preparation of a handbook for use in emergency situations.

BOK-2.2.1 focused mainly on radioactive tracers in Nordic waters, Tc-99, Cs-137 and to a lesser degree, I-129. Particular use was made of the Tc-99 peak in release from Sellafield in 1995. This release has been followed through the Danish straits into the Baltic Sea (with Cs-137 moving in the opposite direction) and along the Norwegian coast into the Arctic Ocean. At the end of the project period, no significant increase of Tc-99 had been observed at the Faroe Islands, but indications of increased concentrations in seaweed were found at the northern coast of Iceland.

The BOK-2.2.2 part focused on processes in the Baltic Sea. Main emphasis was on evaluating existing sediment data, comparing it with recent data, improving the coverage of sampling in the Gulf of Bothnia and improving the knowledge on the role of sedimentation in losses of radionuclides from the water column to the seabed. The last part of this study was to investigate the role of river discharges from Finland into the Baltic Sea.

BOK-2.3 was introduced late in the project period in order to meet increasing interest in investigating the applications of mass spectrometry for measuring long-lived radionuclides. It involved a training course, opportunity for work on own samples and experimental work.

BOK-2.4 was also introduced late in the project period. It involved a study on methodology for defining exemption levels for radionuclides in timber.

The project was organised in an open manner so that scientists working for the co-operating organisations and institutes were contributing with additional studies, without financial support from NKS. This meant that the focus of the project had to be widened, but it enabled more scientists to participate in the network provided by the project.

The BOK-2 project has through the tasks mentioned provided a stimulating environment for co-operation in various fields of Nordic radioecology. Eight meetings and seminars were held during the project period and feedback obtained from participants indicates that the Nordic network is a highly valued part of the project work.

Sammenfatning

NKS/BOK-2 projektet, *Radiologiske og miljømæssige konsekvenser, 1998-2001*, har fokuseret på radioøkologi i de Nordiske lande og i områder af interesse for dem. NKS har i tidligere programperioder inkluderet radioøkologisk arbejde, og mange grundlæggende spørgsmål inden for radioøkologi er blevet besvaret. Man kan spørge, hvorfor skulle man så fortsætte arbejdet inden for dette område. Selve spørgsmålet afspejler problemet. Hvorfor skal talentfulde unge mennesker arbejde inden for et område hvor mange vigtige spørgsmål allerede er besvaret samtidig med, at samfundets interesse i brug af nuklear teknologi mindskes? Det moderne samfund har stadig vigtige spørgsmål som skal besvares. Der er tale om andre spørgsmål end før, men det er vigtigt at disse spørgsmål besvares, og det ser ud til, at der bliver færre kompetente personer til at besvare spørgsmålene.

Den ændrede natur af spørgsmålene som stilles af samfundet fremgår ved behov for undersøgelser til at belyse konsekvenser af miljøforurening samt behov for sporstofstudier, hvor man undersøger processer og vurderer udvikling af meget lave koncentrationer af radioaktive stoffer i miljøet. Vurdering af helbredsrisiko ved radioaktiv forurening er stadig vigtig. Det er grundlaget for beredskabet inden for området. Det aktuelle trusselsbillede ændres med tiden, og derfor må nye vurderinger kunne udføres.

Et af hovedmålerne med BOK-2 projektet har været at skabe et stimulerende miljø og at etablere kontakter og samarbejde mellem unge og etablerede forskere, mellem forskere i forskellige områder (inden for og uden for traditionel radioøkologi) og mellem forskere i og udenfor Norden. Dette er blevet opnået ved møder, seminarer og spredning af information, blandt andet ved brug af Internettet. Det nordiske netværk inden for radioøkologi er vigtigt for nationale myndigheder og nye medarbejdere inden for området, og netværket gør det muligt at starte et hurtigt konkret samarbejde, hvis det behøves på grund af et nukleart uheld.

Da arbejdet inden for BOK-2 projektet blev organiseret, måtte man vælge mellem et projekt med forholdsvis forskelligartede aktiviteter og mange deltagere, og et projekt med mere fokus og dybde i et begrænset område og færre deltagere. Der findes ingen ideal løsning. Hvad der er rigtigt for et land kan være en dårlig løsning for et andet. Resultatet blev et projekt med forskelligartede aktiviteter, som byggede på igangværende projektarbejde i hvert land så vidt som muligt, og som bidrog til et netværk med mange deltagere.

Ifølge anbefalinger fra NKS programgruppen blev det besluttet at strukturere BOK-2 projektet på følgende måde:

BOK-2.1 Vigtige nordiske fødekæder
- BOK-2.1.1 Radioøkologisk sensitivitet
- BOK-2.1.2 Interne doser

BOK-2.2 Radioaktive sporstoffer i nordiske havområder
- BOK-2.2.1 Transport med havstrømme
- BOK-2.2.2 Biologiske og biogeokemiske processer

BOK-2.3 Brug af ICP-MS til måling af radionuklider

BOK-2.4 Metodik til at definere "exemption levels" for radionuklider i tømmer

I BOK-2.1.1 var hovedvægten på at forbedre metoder til at estimere omfang og spredning af nedfald af radioaktive stoffer ved at benytte eksisterende data. Det blev gjort med traditionel UNSCEAR modellering på basis af data fra før og efter Tjernobylulykken og ved at bruge nedbørsdata til at estimere nedfaldet. Hver metode blev brugt med gode resultater af forskere fra tre nordiske lande og tilsammen blev de brugt af alle de fem nordiske lande og Færøerne.

Målet med BOK-2.1.2, interne doser, var at forbedre metoder til at beregne doser på basis af indtag via fødevarer (indirekte metode) og med helkropsmålinger (direkte metode). Der blev gennemført 2 kurser med praktiske øvelser, kalibrering og interkalibrering af måleinstrumenter, og der blev udarbejdet en håndbog til brug i beredskabssituationer.

BOK-2.1.1 lagde vægt på radioaktive sporstoffer i de nordiske havområder, Tc-99, Cs-137 og i mindre omfang I-129. Der blev lagt mest vægt på udslip af Tc-99 fra Sellafield. Udslippet kulminerede i 1995 og blev fulgt gennem de danske farvande ind i Østersøen (med Cs-137 i modsat retning) og langs den norske kyst til det Arktiske Hav. I projektperioden har man ikke set nogen stigning i koncentration af Tc-99 i færøske havområder, men en stigning er muligvis set i tangprøver fra Islands nordkyst.

BOK-2.2.2 handlede om processer i Østersøen. Der blev lagt mest vægt på evaluering af eksisterende sediment data, at sammenligne med nyere data, forbedre prøvetagningen i den Botniske Bugt og at forbedre viden om sedimentationens betydning for at fjerne radionuklider fra vandsøjlen. Endvidere blev der foretaget undersøgelser af transport af radioaktive stoffer med finske floder til Østersøen.

BOK-2.3 blev introduceret relativt sent i projektperioden for at imødekomme en voksende interesse i brug af massespektrometri til at måle radionuklider. Der blev afholdt et kursus med mulighed for at arbejde med egne prøver og eksperimentere med teknikken.

BOK-2.4 blev også introduceret relativt sent i projektperioden. Det drejede sig om en studie om metodik til at definere undtagelsesniveauer (exemption levels) for radioaktive stoffer i tømmer.

Projektet blev organiseret således, at forskere hos de medvirkende institutioner bidrog med ekstra arbejde uden økonomisk støtte fra NKS. Dette betød, at delprojektets formål måtte gøres bredere, men med flere deltagere i netværket.

BOK-2 projektet har skabt et stimulerende miljø med samarbejde indenfor en række områder af nordisk radioøkologi. Der blev gennemført 8 møder og seminarer i projektperioden. Ifølge deltagerne er det nordiske netværk et af de betydeligste resultater af projektarbejdet.

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Introduction

This report describes work done within the NKS/BOK-2 project, *Radiological and Environmental Consequences, 1998-2001*. It focused on radioecology in the Nordic countries and areas of interest to them. The NKS has in previous programme periods included work on radioecology, and many of the basic questions concerning estimating health effects of environmental radiation have already been answered. One may then ask, why should one continue work in this field? This question, by itself, reflects the problem. Why should competent young people enter a field where most of the important questions have already been answered and the interest of society in using radionuclides is decreasing? In fact modern society still has pressing questions as before. The questions have changed, but answers are still urgently required and it seems there are fewer and fewer competent persons able to provide the answers. One could thus argue that there is even a greater need for NKS work than before.

The background for the development of the project is described in this report and the report work is summarised. A more comprehensive description of the work done is available in a separate technical BOK-2 report. References to scientific papers produced within BOK-2 can be found in this technical report.

Background: Why this project?

The NKS has in previous project periods dealt with radioecology or some environmental consequences of the distribution of radionuclides to the environment, at times in different projects (e.g. EKO-1 *Marine Radioecology* and EKO-2 *Terrestrial Radioecology* in the previous period). In the current period it was decided to combine this work into one project, BOK-2, *Radiological and Environmental Consequences*.

Environmental studies are costly and the NKS is not a research fund. One must bear in mind the benefits of the supported work for nuclear safety and emergency preparedness. Scientific competence in radioecology is however essential for making the best possible assessments for authorities and industry.

The Nordic countries played a leading role in the beginning of the nuclear age, when assessments had to be made of the releases of radionuclides to the environment, especially as a consequence of the testing of nuclear weapons in the atmosphere in the late fifties and early sixties. Much of today's knowledge is still based on the studies done at that time. After the Chernobyl accident the Nordic countries were again in the forefront, both concerning initial detection of the accident and subsequent evaluation of the consequences. One may ask, why should the authorities then have interest in further research in this field? It is easy to point out two issues, no doubt there are more:

1. Need to be able to answer changing questions from the society
2. Maintaining competence in the field

New questions asked by society. The questions asked by society are changing and the authorities need competence in more areas than just estimating the health effects of radioactive fallout, as was experienced in the sixties and after the Chernobyl accident. Society is becoming less tolerant of various types of pollutants and measurable radioactive contamination can become a political issue, irrespective of the corresponding consequences to health. More effort is now needed to demonstrate that some human activity has not, does not or will not cause unacceptable health effects. In many cases the emphasis has thus shifted from looking at potential causes of health effects to study processes to demonstrate that unacceptable health effects will not occur. This may involve studies of other radionuclides than previously studied. As an example the assessment of the long term consequences of storage and disposal of radioactive waste requires understanding of the behaviour of many radionuclides, some with long half-lives. The best way to measure some of these radionuclides may be by using non-radiometric methods, e.g. mass spectrometry.

Need of building up and maintaining competence. In spite of the new questions asked by society, it still needs competent persons able to answer the old ones. Such a need could arise because of a nuclear (or radiological) accident, or even just because of a possible threat of such an event occurring. There are also many instances where the old answers are found to be wrong when applied to a type of environment not previously investigated. This can be especially relevant for the Nordic countries with their reliance on use of semi-natural ecosystems. Information is being processed and transmitted faster and faster in modern society. The authorities have to be able to react faster to accidents or rumours than before. This requires an efficient network of competent experts. Many of the pioneers from the sixties have retired and the experience from the Chernobyl accident is gradually becoming a thing of the past. A stimulating scientific environment is essential to keep competence in the field and to attract young scientists.

The NKS does not have the means to be the sole supporter of comprehensive environmental studies. But it can base its work on existing or planned studies, influence these and add a new joint Nordic element to them. A Nordic NKS forum can create a stimulating environment for exchange of ideas and co-operation, both for those established in the field as well as newcomers, for Nordic scientists as well as others invited to join in (e.g. Baltic scientists). Informal Nordic co-operation can also be a good preparation for co-operating in international projects and complement such work.

The gain for the authorities is that the focus of the Nordic research activities can be shifted to issues that they feel should be prioritised. The benefits are not only the actual results of the studies undertaken, perhaps the most important benefits is the maintained (and increased) competence to deal with issues of concern for the future, including emergency preparedness.

Development of project priorities, plans and organisation

The final report of the NKS Programme Group, NKS(98)1, and the NKS Directive for Pre-Project Work, NKS(98)4, were used as guidelines throughout the development of the project plan. The possible work that could be undertaken was discussed by a BOK-2 discussion group at the Saltsjöbaden NKS Final Seminar in 11-12 March 1998. The formal planning work began after the nomination of participants in the BOK-2 pre-project planning group. A BOK-2 World Wide Web (WWW) web site was set up and used to distribute information during the development stage. Those wanting to send in comments were asked to use the final report of the NKS programme group as a starting point. A compilation of submitted comments was put on the mini-web before the BOK-2 seminar was held at Sorø, Denmark, May 13th - 15th. The seminar was an open one where all those who wanted and had the possibility could attend. Subsequently a draft project plan was written based on the outcome of the seminar and additional material submitted afterwards by members of the pre-project planning group and participants at the seminar. This draft project plan was presented to the NKS Reference Group at its meeting in Stockholm, June 4-5, 1998. The plan was approved by the NKS Board in September 1998 and it can be found in the publication NKS-5 *"Planer for NKS-programmet 1998-2001"*. Much of the description given here on the plans for the BOK-2 project is based on the text found there, since during the course of the project no significant changes were made to the plans.

The BOK-2 steering group

Although the work in the project was organised in an open and transparent manner, there was nevertheless a need for making sure that it would be run in accordance with the priorities of the Nordic authorities sponsoring the work. This was done by establishing an informal *steering group*. The steering group was a part of the planning/project group, with key contact persons in each country suggested by authorities involved in NKS work.

The establishment of the steering group was done to ensure that the work done would be based on the needs of the authorities.

Main aim with project work

The BOK-2 project attempted to respond to the needs described above by attempting to create and maintaining a stimulating forum in radioecology, e.g. strengthening the Nordic network by encouraging contacts between:

- newcomers and experienced scientists
- scientists in different fields, both within and outside traditional radioecology
- scientists within the Nordic countries and neighbouring regions

The funding available within the project is limited and cannot be used to support a comprehensive research programme. NKS can only fund a part of the actual cost of studies, since sampling and analysis in radioecology can be very expensive. Nowadays it is also difficult to find one research topic which is of major relevance for all participating countries. When planning the project a decision had to be made whether the project was to have a broad focus and enable many to participate or if the focus was to be narrowed, enabling more support for some specific studies but at the expense of fewer participants. The conclusion was to have a broad focus and try to give as many as possible a chance to participate. This was done by basing the project work on ongoing research in the participating countries and to use the funds available to stimulate contacts between the researchers, and where appropriate, co-operation.

Organisation of work as *core activities* and *additional activities*

In order to enable broad participation and the same time to have some focus in the work, it was decided to

- Build project work on ongoing or planned studies, with relevance for authorities in each country
- Define activities with joint Nordic relevance (or at least relevance for 3 countries), these should form the *core activities* of the project

Additional activities

During the project period individuals and groups enquired if their work could be included under the BOK-2 framework, these were e.g.

- young scientists
- established researchers

In either case, this extra contribution to the BOK-2 project was not done for financial gain, since it did not increase funding to them or their institutes/authorities. It was rather that they wanted to become a part of the Nordic network of Nordic radioecologists and have their work presented and discussed there. This was considered an important part of the project's role and it was decided to include this work and thus support the Nordic network in radioecology, even though this would result in a more heterogeneous project structure.

Organisation of BOK-2 work

Studies, seminars and reporting

The main elements of the work in BOK-2 were

Studies

Encouraging Nordic co-operation on environmental radiation, with relevance for Nordic authorities

Seminars

Strengthening the Nordic network and co-operation
encouraging participation of young scientists

Reporting

Encouraging publishing in scientific publications.
Regularly updated informal reporting on Web
Final reporting as a technical report
+ BOK-2 Project final report

Studies: form of co-operation, policy on use of data

The steering group decided (especially with respect to studies on the terrestrial ecosystem) that interpretation of data, research and publishing should be done by each group, not jointly. Co-operation should focus on methods and expertise, not results.

The argument given was that the use and interpretation of data (e.g. with respect to studies on radioecological vulnerability) was best done by the researchers and authorities in each country, co-operation and interaction would however be valuable.

Networking through seminars and meetings; courses

Combined meetings and seminars were held 2 times per year, with typically 20-30 persons attending. In addition the following courses were held:

- Nordic-Baltic course on radioecology
- Internal dosimetry (Nov. '99 + March '02)
- Mass spectrometry

The *8th Nordic Seminar on Radioecology* was held during the project period, in Rovaniemi, Finland, 25-28 February 2001. The seminar was supported financially by NKS and many of the BOK-2 studies were presented, then nearing their final phase. Proceedings of the seminar have been published as the report NKS-70.

International contacts

Making formal connections with other international research programmes (such as EU projects) on behalf of BOK-2 was not considered as feasible. This was e.g. due to the difference in framework. But many of the BOK-2 participants had

nevertheless international contacts through their own work on NKS supported studies. Indirect contacts were also encouraged by inviting international experts (often playing a leading role in international programmes) to participate in seminars or to give lectures at BOK-2 courses.

Baltic participation in BOK-2

Representatives from the Baltic States were invited to join BOK-2 seminars, courses and meetings. Invitations were sent to those who where known to have been active in NKS or other Nordic supported work. No commitment or contributed work was requested in return, since the funding to support Baltic attendance in BOK-2 meetings had to be obtained on a meeting-by-meeting basis from various sources. Presentations given by Baltic representatives at various meetings showed often a high degree of enthusiasm, commitment and expertise. Some of the Baltic scientists have also become actively involved in international co-operation and been publishing their work in scientific journals. Being able to give them the opportunity of contacts with the Nordic network of scientists was viewed as a valuable supplement to Nordic co-operation programmes in the area

Reporting: presentations, papers and the BOK-2 Technical Report, *Summaries of studies carried out in the NKS/BOK-2 project*, NKS-35

Participants were encouraged to publish findings of their studies in scientific journals and to present them at conferences. The BOK-2 technical report, *Summaries of studies carried out in the NKS/BOK-2 project*, NKS-35, contains a collection of short papers, 32 in all, each with a list of references where more detailed information can be found, e.g. published articles in scientific journals and proceedings. In addition to this, some of the activities contributed to BOK-2 were presented at the mini-seminars and summary information distributed, e.g. as copies of overheads used. Interim progress reports, updated by participants, were available while the project was ongoing at the project's closed web site.

The BOK-2 studies – An overview

Framework for studies

The project was originally divided into 2 main parts, BOK-2.1 and BOK-2.2, later two new parts, BOK-2.3 and BOK-2.4, were added after suggestions for additional work had been approved by the NKS Board.

BOK-2.1 Important Nordic food chains

The main objective of the BOK-2.1 project part was to attempt to present an overall view of the experience concerning fallout nuclides gained during the last decades in the Nordic countries and to undertake limited additional studies so that past experience can be best utilised for assessing the possible future impact of fallout on Nordic food chains. This was to be achieved by concentrating the research on two main topics:

BOK-2.1.1: Radioecologcal vulnerability
with objective:

> to improve understanding of the radioecological vulnerability of various types of Nordic areas, e.g. through synthesis of old and recent radioecological data and use of traditional as well as modern radioecological models. Other studies involving comprehensive assessments were also included, such as comparing measured deposition with predictions based on precipitation data.

and

BOK-2.1.2: Internal doses
with objective:

> to improve methods for dose calculations based on dietary surveys (indirect method) and whole-body counting (direct method)

BOK-2.2 Radioactive tracers in Nordic Sea areas

Two fields of interest were defined for marine research in BOK-2.2:

BOK-2.2.1 Sea water transport
with objectives:

> To gain better understanding of radionuclide transfer from European reprocessing plants to Nordic marine areas and subsequent uptake and concentration factors. In this study the recent increased release of Tc-99 from the Sellafield reprocessing plant was to be used for the study.

and

BOK-2.2.2 Biological and biogeochemical processes
with objectives:

> To make a comprehensive assessment of processes in the Baltic Sea and its catchment and adjacent areas, synthesising old data with new data acquired in the project.

During the project period there was steadily growing interest in possible uses of mass spectrometry for measuring radionuclides. The longer the half-life a radionuclide has, the more promising mass spectrometry can be with respect to traditional radiometric methods. At the NKS Board meeting 3 May 2000 it was decided to add the following to the BOK-2 project:

BOK-2.3 Applications of ICP-MS for measuring radionuclides

> The objective of this work was to introduce the possibilities (and limitations) of inductively coupled plasma mass spectrometry (ICP-MS) to Nordic participants by arranging a course in using ICP-MS, giving participants a chance to use the technique at home or by visiting another Nordic facility and by supporting some experimental work exploring the possibilities of this rapidly developing technique.

Authorities have to be able to define criteria for when various practices can be considered safe, even in cases when it might seem obvious that radiation would not be the dominating risk factor. One such example of economical importance for the Nordic countries was brought to the attention of the NKS and it was decided at the Board meeting on 8 November 2000 to make the following addition to the BOK-2 project:

BOK-2.4 Methodology for defining exemption levels of radionuclides in timber

> The objective of this study was to develop a methodology for defining exemption levels of radionuclides in timber by calculating doses in industry and from forest products at different scenarios, especially using imported timber.

Summary of conclusions

This chapter summarises the main results from the studies. More extensive summaries written by the different research groups are published in a separate report, *Summaries of studies carried out in the NKS/BOK-2 project*, NKS-35. The papers there are in most cases based upon papers published in or submitted to scientific journals. Some of the text in this chapter is taken directly from the summary paper being discussed.

BOK-2.1.1 core project work: Radioecological vulnerability
Radioecological vulnerability or sensitivity to radioactive fallout was one of the core themes in the BOK-2 project. This was dealt with in the following six papers, which can be found in the BOK-2 technical report, all which also were extracting new information from old data sets.

- **Re-evaluation of Danish Fallout Data**
  Sven P. Nielsen and Mette Øhlenschlæger
- **Dietary Cs-137 and Sr-90 in Finland in 1960-2000**
  Aino Rantavaara, Ritva Saxén and Eila Kostiainen
- **Modelling long-term variation of radioactivity in foodstuffs in the Faroe Islands**
  Hans Pauli Joensen
- **Radioactive fallout in Norway from atmospheric nuclear weapons tests**
  Tone D. Bergan
- **Estimating Cs-137 fallout inventories in Iceland from precipitation data**
  Sigurður Emil Pálsson, Ólafur Arnalds, Magnús Á. Sigurgeirsson, Kjartan Guðnason Brenda J. Howard, Simon M. Wright, Þóranna Pálsdóttir
- **Radiocaesium (Cs-137) fallout in Iceland and its behaviour in Sub-Arctic volcanic soils**
  Magnús Á Sigurgeirsson, Ólafur Arnalds, Sigurður Emil Pálsson and Kjartan Guðnason

BOK-2.1.1, Radioecological Vulnerability

Radioecological vulnerability can be defined using different criteria. In some semi-natural ecosystems with highly organic soil the transfer rates to a wide range of foodstuffs can be very high. Some food products are vulnerable if they can easily get contaminated by radionuclides and they play a large role in the human diet.

Synthesis of recent and old fallout data

This was one of the two major components of the study. The Nordic countries span a considerable latitude interval compared to their area and contain different types of ecosystems. Emergency preparedness often uses sophisticated dynamic

radioecological models. It requires considerable knowledge to judge how well they describe the behaviour of radionuclides in the varied Nordic ecosystems. It is however relatively simple to apply the basic traditional UNSCEAR type of models. They require time series, which are available from many Nordic sites. Applying the traditional type of models is a good educational exercise and can help to identify possible need for further studies required for modelling work.

- In Denmark fallout data on radioactivity in Danish food covering time periods before and after the Chernobyl accident in 1986 were analysed with different types of radioecological models in order to compare model performances.
- In Finland the study involved compilation of long-term surveillance data for deposited radionuclides and their contents in foodstuffs. There were regional comparisons of radionuclide transfer, with an attempt to identify vulnerable areas. The UNSCEAR models applicability for pre- and post-Chernobyl situations was investigated and used for optimising future surveillance.
- In Faroe Islands the modelling study related the concentration of a radionuclide in a sample from a given year to the deposition rate of the nuclide from precipitation in the given year and in the year before, and to the accumulated deposition two years before. It focused on Cs-137 and Sr-90 data from the last four decades.

Study in the Faroe Islands

In some cases UNSCEAR models were used to reinterpret the data, in other cases precipitation data was used to estimate radionuclide deposition. An example of UNSCEAR regression analysis, as used in a study in the Faroe Islands, is given below:

$$C_i = b_1 \cdot d_i + b_2 \cdot d_{i-1} + b_3 \cdot \sum_{k=1}^{k=\infty} d_{i-k} \cdot e^{-\lambda \cdot k}$$

where C_i is the concentration of a given radionuclide in a sample from year (i), and d_i and d_{i-1} are the deposition rates (kBq/m^2) in the years (i) and (i-1). The regression coefficents can then be used to estimate the radioecological sensitivity, as defined by A. Aarkrog.

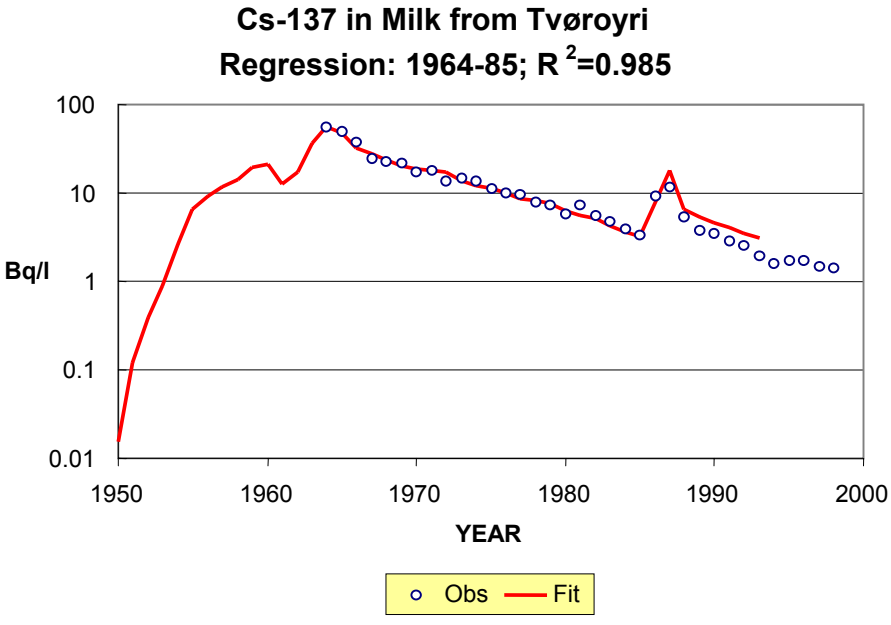

Figure 1. An example of use of the UNSCEAR approach, using data from the Faroe Islands (adapted from H.P. Joensen, *Modelling long-term variation of radioactivity in foodstuffs in the Faroe Islands*)

Study in Denmark

The traditional radioecological models of the UNSCEAR type were applied to time series of Danish data on Sr-90 and Cs-137 in grass, milk, beef and diet covering four decades. The models fit the data well for Sr-90 for the entire period, but for Cs-137 the models generally perform somewhat poorer from 1986 and onwards. The reason for this is the different transfer through the environment particularly in 1986 and 1987 of Chernobyl radiocaesium compared to that from atmospheric nuclear weapons testing. This difference is caused mainly by different seasonal modes of deposition. But overall, the models reproduce the data quite well. The radioecological sensitivity of the Danish diet for the transfer of Sr-90 and Cs-137 through Danish foodchains is found to represent an average individual intake of 3 Bq Sr-90 and 5 Bq Cs-137 for a ground deposition of 1 Bq m^{-2} when no countermeasures are applied.

Also more recent dynamic radioecological models were applied to the fallout data, but they do not reproduce the data better than the traditional models. However, the general features of the dynamic models make them suited for prediction of radiological consequences of routine and accidental releases in areas where limited radioecological data are available.

Study in Finland

Domestic animal products dominated dietary intake of Cs-137 in 1960 – 2000. Freshwater fish and vegetable products of agricultural origin were almost equal contributors of Cs-137 to the diet. Wild foods received from forests, assessed using a simple approach, were also non-negligible sources of Cs-137. Marine and brackish-water fishes, although of low activity concentration of Cs-137 compared to freshwater fishes, added to the ingestion dose through a higher consumption rate.

Sources of dietary Cs-137 during the period of atmospheric nuclear fallout from weapon tests differed from the post-Chernobyl time. Agricultural produce then seemed to dominate the Cs-137 received via the Finnish diet more than after the Chernobyl accident. Subsequent growth periods of considerable stratospheric fallout made the pathways from vegetation to human diet important in the 1960's.

Strontium 90 is mobile in soils for long periods of time. However, it has not been a significant dietary nuclide for Finns during the history of environmental radioactive contamination. In the years of maximum deposition rates in early 1960´s the doses exceeded more than tenfold the doses in the following decades, and also the doses received after the Chernobyl accident. The wild foods from forests are not likely to contribute to ingestion of Sr-90 essentially more than similar types of agricultural and garden products replacing wild foods in the diets of non-pickers and non-hunters.

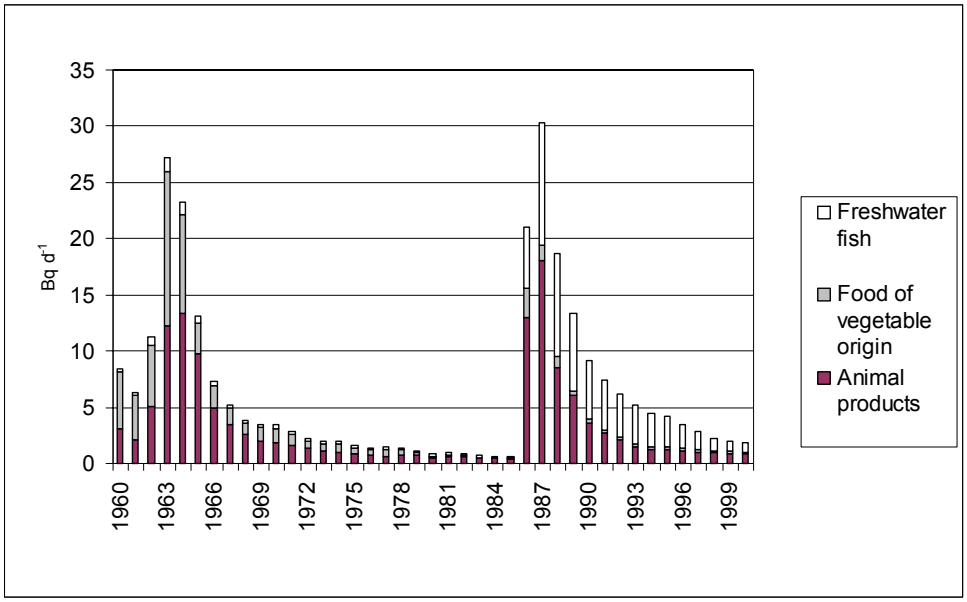

Fig. 2. Dietary ^{137}Cs from agricultural products and freshwater fish in Finland since 1960 (From A. Rantavaara *et al.*, *Dietary Cs-137 and Sr-90 in Finland in 1960-2000*)

Educational value for young scientists
Where good time series were available, the UNSCEAR models provided good results. Dynamic radioecological models did not reproduce the fallout data better, although they are better suited for predicting radiological consequences of releases where limited radioecological data are available. The work on the old data using the UNSCEAR approach also provided a good opportunity for young researchers to use old data and get better acquainted with previous data sets and their relationship with more recent ones.

Predicting radionuclide deposition, e.g. using precipitation data

This was the other main components of the study. UNSCEAR has published models for estimating deposition from nuclear weapons tests in the early sixties. In recent years there has been increased interest in the use of precipitation data for predicting radionuclide deposition, e.g. for predicting Cs-137 deposition from the nuclear weapons tests. If a relation between precipitation and deposition can be established for an area and precipitation data is available, then modern geographical information systems (GIS) make it possible to make deposition maps. Furthermore, if soil, vegetation and agricultural data are also available, then this can be used for identifying and mapping areas of greatest vulnerability. Use of precipitation data to predict radionuclide deposition is especially valuable in regions where deposition measurements are scarce, difficult to obtain or there are great variation in results. This type study was undertaken in Norway and Iceland as a part of the BOK-2 project. Similar studies have been undertaken and reported by Mats Isaksson, University of Göteborg, (e.g. at the eighth Nordic seminar on radioecology in Rovaniemi, 2001, which was supported by NKS), but his work was not a formal part of this project.

In Norway the aim with the study was to

- To collect old data on radioactive fallout, in order to obtain a better basis for dose assessments and radioecological modeling.
- Use measurements of radioactivity in air, precipitation and drinking water, total beta, Cs-137 and Sr-90.
- Compare with UNSCEAR models and data from other Nordic countries
- Improve transfer models

In Iceland deposition had been measured in soil at different locations, but no overall estimate existed of the Cs-137 fallout in Iceland following the atmospheric nuclear weapons tests. This was partly due to very uneven terrain and very variable precipitation pattern. The aim of the study was to:

- Make an overall estimate of the Cs-137 fallout in Iceland following the atmospheric nuclear weapons tests, using a similar approach as has been done in the AMAP project, where deposition has been estimated using precipitation data and GIS technology.

- Test the deposition predictions by measuring deposition in soil at locations with good precipitation data.

Results

In the Norwegian study, the main results were:

- Indication of a close range radioactive fallout in Northern Norway (from Novaja Semlja), not documented.
- Norway as a whole has been subject to "close range radioactive fallout", especially in the period 1957-58, i.e. considerably more than global models predict.
- Precipitation (mm/year) has dominating influence on the radionuclide deposition.

The study in Iceland has developed into an ongoing collaboration with the Centre for Ecology and Hydrology, UK, and received additional support from the International Union of Radioecology Arctic task force. The following results have been obtained:

- Deposition was measured in soil at 26 different locations, representing different precipitation rates, geographical areas and soil types. Agreement with predicted values was very good ($r^2 = 0,95$ for a line through the origin). This is better agreement than commonly seen in studies of this type, e.g. the AMAP study. It must be born in mind, however, that better correlation can be expected when the data are collected by the same team in a limited time interval than when data are compiled from various sources using.
- Total concentration of Cs-137 per unit area was found to be 900 - 4700 Bq/m^2

Both studies showed that precipitation has a dominating influence on radionuclide deposition and can be successfully used for prediction, if consistent data is available for the region of interest. Both studies gave similar estimates for the relationship between deposition and precipitation and are in agreement with studies conducted previously in other areas. The same can be said concerning the studies conducted in Sweden by Mats Isaksson and there is interest amongst all three parties to continue studies in this field and compare findings.

There was also a special study on properties of the Icelandic soils. They are young and volcanic, and they lack the clay minerals that usually bind caesium in soil. This can mean that the radiocaesium stays available for uptake for a long time, and that seems to be the case in Iceland. The study showed good correlation between soil textures and Cs retention at various depth intervals.

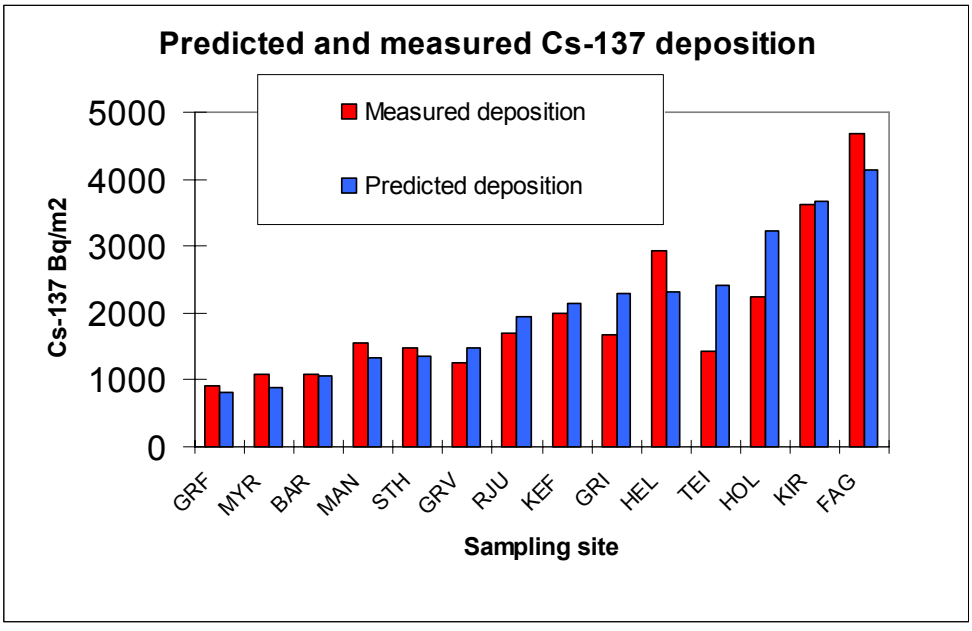

Figure 3. An example of the use of precipitation data to predict Cs-137 deposition in Iceland. The estimated deposition values are compared with measured ones, giving a measured to estimated ratio of 0.98 with 6 % standard error for 14 sites.
(S.E. Pálsson et al., *Estimating Cs-137 fallout inventories in Iceland from precipitation data*).

Long term trends and roots of variability in semi-natural ecosystems, Cs-137 in lamb meat

Previous NKS projects on radioecology have illustrated the importance of time series of data on environmental radioactivity. These time series illustrate the temporal development of levels of radioactivity in different environmental compartments, which are very different between the various ecosystems found in the Nordic countries. One such example is the so-called lamb project (RAD-3 and EKO-2.1) which illustrates the transfer of radiocaesium through the soil-grass-lamb food chain from 1990 to 1997 and shows very different rates of transfer for the different study sites. These differences contribute to the variabilities of the radiological sensitivities across the Nordic countries, and once quantified they may be incorporated into radioecological models and used for predictive purposes.

The aim with this task was to continue the time series obtained from 1990 to 1997 on a very limited scale. The proposed project work involves keeping a limited number of sheep at the same experimental farms as has been done before and to collect samples of vegetation and soil in autumn before slaughter along with lamb meat. The data required are the same as were requested for the EKO-2.1 model work on transfer of radionuclides from soil and vegetation to lamb meat.

Interest was shown in Denmark, Iceland, Norway, Sweden and the Faroe Islands to participate in this study and work plans have been submitted. All these institutes participated in the corresponding work during the previous two periods. Due to financial restraints the study in Sweden could however not be undertaken and the study in Norway was concluded in the middle of the project period.

The Danish study focused on the long-term evolution of the transfer of Cs-137 from soil to lamb at a location near Ribe, Denmark. The Norwegian study was conducted at Tjøtta, in Nordland county (66.6 °N) and was a continuation of a study started in 1988. The study in the Faroe Islands was done using sites spread over the islands and the study in Iceland was conducted at two sites, but comparison was made with monitoring samples obtained from slaughterhouses in autumns. Both studies were continuations of studies begun in 1990.

Even though the importance of lamb meat in the Icelandic diet is decreasing, it is still the main source of Cs-137 in the diet. The studies on the transfer of Cs-137 to lamb are described in the following 4 papers in the BOK-2 Technical Report. There is also one additional paper on the same topic in the appendix of the report. That paper was to have been included in the EKO-2 report from the previous period, but was left out by mistake in the printing process.

- **Transfer of Cs-137 from soil to plants and lamb meat in Iceland**
  Sigurður Emil Pálsson, Eiríkur Þorkelsson, Magnús Á. Sigurgeirsson and Kjartan Guðnason
- **Radiocaesium in Soil, Grass and Lamb at Ribe**
  Sven P. Nielsen
- **Cs-137 in the food-chain of lamb in the Faroe Islands. Measurements in the period 1990-2000**
  Hans Pauli Joensen
- **Transfer of Cs-137 from soil to plants and sheep at Tjøtta, Norway, 1988-1998**
  Ingar Amundsen

Main results
The results provide improved estimates of ecological half-lives and time series of data (1990-2000) used for radioecological modelling.

The observed concentrations of Cs-137 in grass and lamb collected from Ribe, Denmark, during the present BOK-2 project agree reasonably well with the concentrations predicted from the modelling work. This means that the transfer of Chernobyl Cs-137 from soil to lamb at the Ribe site is adequately described by the model during 4-14 y after the time of contamination.

The main results of the Norwegian study at Tjøtta, Norway, during the period 1988-1998 were:

- The ecological half-life for transfer to sheep was in the range of 8 - 11 years.
- Large variations in transfer from soil to vegetation were observed.
- Climate, biomass production and mushrooms did not influence the transfer to vegetation at Tjøtta. Transfer was correlated with organic content and pH in soil.

The main conclusions of the study in the Faroe Islands were:

- Deposition in 0-10cm soil layer decreased slightly on average from 1990 to 2000.
- Large temporal and spatial variations are observed in activities and transfer factors within and between pastures.
- Faroese soil has low pH and high content of organic matter.
- Transfer factors
  - decrease as pH increases
  - increase as potassium and loss on ignition increase.
- Effective ecological half-lives was impossible to estimate in some pastures, whereas in others estimates could be obtained:
  $T_{1/2Soil}$: 9.9-11.6y $T_{1/2Grass}$: 3.1-5.3y $T_{1/2Meat}$: 5.1-8.0y

The main results of the study in Iceland were:

- The concentration in vegetation and lamb meat was significantly different between the two different sites used in the study, an order of magnitude. Concentration in soil is similar. Preliminary results indicate that this is best explained by difference in relative plant abundance in these two regions.
- The range of values at these two different test sites fall within the range of values from the monitoring samples obtained regularly from slaughterhouses around Iceland, indicating that they may be regarded as representative for conditions at each site.
- Reduction of the levels of Cs-137 has been slow, indicating a very long ecological half-life.

In the BOK-2 project plan it was stated that the time series on Cs-137 in lamb could be continued, but only as a low-key activity. The value of a further extension on a joint Nordic basis for studying time series can be questioned. The studies done during the three NKS project periods (1990-2001) have however yielded results which should be compiled and reviewed critically, e.g. by identifying where the individual studies agree and if an explanation can be found where they do not agree. This would help to get maximum value out of the work done over these twelve years. Roots of the spatial variability are still to be explained.

BOK-2.1.1 - additional work submitted to BOK-2 by various groups

Some groups contributed to the BOK-2 work with their studies, without requesting extra financial contribution in return. These contributions were very welcome, they were presented at BOK-2 meetings and they contributed much to the networking value of the project. This type of additional work is summarised in the following 5 papers:

- **Cs-137 concentrations in mushrooms collected in 1989-2000 at different forest stands in Kivalo experimental area**
  Kristina Rissanen, Jarkko Ylipieti and Yrjö Norokorpi
- **Sr-90 in cow's and goat's milk in Norway**
  Astrid Liland, Elisabeth Strålberg, Trine Kolstad, Arne Sæbø
- **A Study of Plutonium in different fresh water systems**
  Mats Eriksson, Elis Holm, Per Roos, Henning Dahlgaard
- **Field Sampling, Preparation Procedure and Plutonium Analyses of Large Freshwater Samples**
  Elisabeth Strålberg, Trygve O. Bjerk, Kristin Østmo and John. E. Brittain
- **Plutonium in coniferous forests**
  Aino Rantavaara and Eila Kostiainen

Radiocaesium in mushrooms

The paper *Cs-137 concentrations in mushrooms collected in 1989-2000 at different forest stands in Kivalo experimental area* summarises results of a 12 year follow-up study on radiocaesium in different mushroom species in Finland. It shows effective accumulation of Cs-137 in mushrooms in different surface vegetation and soil layers and slow rate of reduction in concentration. The mushrooms can therefore continue to contribute significantly to Cs-137 intake by reindeer and other animals, as well as people collecting and eating mushrooms.

Radiostrontium in milk

Sr-90 in cow's and goat's milk in Norway

Samples from the Kjeller area show a general decreasing trend over the years according to deposition. Yet, there are some unexplained peaks. The samples from the dairies show a general decrease from 1997 to 1999 except for one location. By contrast, the samples from the livestocks show no general decreasing trend over the years 1998-2001.

The project confirms a general higher uptake of Sr-90 in goats compared to cows. In addition, a possible higher uptake of Sr-90 in milk is observed when AFCF is distributed to the livestock. More data is needed, though, to confirm this.

The Sr-90 activity concentrations in the Kjeller area in the late 1990's are comparable to the dairy measurements from the nearby areas Oslo and Østfold.

These values are among the lowest reported corresponding to a low impact from the Chernobyl accident in these areas. The reported values are higher in Vevelstad and Vega that experienced a medium impact, while the highest values are registered in Øystre Slidre, the most heavily affected municipality in Norway after the Chernobyl accident.

If further funding is available in the future, it will be interesting to investigate the Sr-90 deposition in Norway following the NWF and the Chernobyl accident, and estimate transfer factors to milk based on the monitoring data presented here.

Plutonium in lakes and forests

Plutonium in fresh water systems

A Danish-Swedish collaborative study was undertaken to investigate sedimentation and transport mechanisms in lakes of different characters.

Results

Arctic lakes and lakes from a temperate region were object for the study. The Arctic lakes with low humic and mineral nutrient content at Thule Greenland show a rapid transfer of plutonium and caesium to the sediments. The freezing conditions might play an important role for the radionuclide processes.

Lakes with high humic content in the temperate regions show high concentrations of plutonium and other actinides since they are associated with the humic colloides. This increases the mobility of these elements in the water sheds. Radiocaesium is to some extent associated indirectly via clay minerals to the colloides.

Plutonium in the catchment area of Øvre Heimdalsvatn, Norway

The results so far are in agreement with previous analyses from the Heimdalen area. However, up to 100 times higher concentrations were found in the lowlands in the eastern part of Norway. The reason for this is not fully understood, but may be caused by differences in the concentrations of humic substances, the fact that the mountain areas are covered with snow for a longer period of time every year and the flushing effect of the spring snowmelt.

Plutonium in coniferous forests in Finland

The aim was to study the uptake of plutonium by trees, undervegetation and some wild foods. The ratio of ^{238}Pu / Pu-239,240 in soil samples was determined for comparisons of the fallout origin The results were that in twelve years the Chernobyl derived plutonium had not reached the mineral soil. This refers to a very slow downward migration in podsolic soil. The study confirmed also the low Pu uptake by vegetation and an insignificant contribution to human doses through wild foods.

BOK-2.1.2 Internal doses

This part of BOK-2 dealt with a specific issue and it was the only part of the project that was run as an independent sub-project, co-ordinated by Tua Rahola, STUK, and Rolf Falk, SSI.

Aim: To improve methods for dose calculations based on dietary surveys (indirect method) and whole body counting (direct method)

The work was divided into the following main components:

2.1.2.1 Exercises on internal dose calculations
2.1.2.2 Calibration and intercomparison of equipment for direct measurements of radioactivity in the body and iodine in thyroid
2.1.2.3 Rapid monitoring of people and preparation of handbook for emergency situations
2.1.2.4 Comparison of methods for estimating internal doses to Nordic populations - whole body measurements and diet investigations
2.1.2.5 Activity losses during food preparation

The assessment of internal doses is based on direct measurements of people, on indirect measurements of excreta or on measurements of activity in food (dietary studies) and, for eg. iodine, air concentration. These measurements are mostly used to estimate the intake. The internal dose is then calculated using suitable metabolic and dosimetric models. Quality assurance in whole-body measurement and the associated calculation of internal doses is a complex matter. The measuring process is complicated and the uncertainty in the measurement geometry between the radiation source and the detector is unavoidable when measuring on humans.

There are 2 papers in BOK-2 Technical Report describing this work (one is actually the handbook produced within the project):

- **Assessment of internal doses**
  Tua Rahola, Rolf Falk, Mats Isaksson, Lavrans Skuterud and Göran Ågren
- **Mätning av radioaktiva ämnen i människa i beredskapssituationer. En metodhandbok vid jod och cesium-kontaminering** (in Swedish)
  Tua Rahola, Rolf Falk, Mats Isaksson

2.1.2.1 Exercises on internal dose calculations

An intercomparison on internal dose calculation within the European countries was conducted, shoving a need for harmonisation of dose calculation procedures. As only a couple of laboratories from each European country were allowed to participate a course in internal dose calculation was arranged with the intention to train experts in internal dose calculation. The course was held at STUK, Finland 13 –15 October 1999 where 29 persons from all Nordic countries attended the course.

The course was successful and a second similar course was held at STUK, Finland 7 – 8 March 2002 where 21 persons from Nordic countries and Estonia, Latvia and Lithuania attended the course. This second course contained also information on an "Integrated Modules for Bioassay Analysis (IMBA)"

There was great interest amongst participants in having this type of course, the second course was actually organised due to popular demand.

2.1.2.2 Calibration and intercomparison of equipment for direct measurements of radioactivity in the body and iodine in thyroid

The whole-body phantom used for this intercomparison exercise is the same as used during an intercomparison exercise 1996-97. The phantom was circulated among the participants together with 4 different sets of radionuclides. The activity content was unknown by the participants. Also a neck phantom with a source of Ba-133 was circulated at the same time to provide a possibility to calibrate for measurements of I-131 in thyroid. The Ba-133 source was used instead of a I-131 source, as we wanted all participants to use same source.

19 laboratories have participated and 15 have submitted results for the intercomparison. The results in the current exercise show similar (or even more) variability in reported results, and the variability was greatest for the radionuclides that are not measured on a routine basis.

2.1.2.3 Rapid monitoring of people and preparation of handbook for emergency situations

Experiences from accidents were many people might be internally contaminated show a need for rapid monitoring for screening purposes but also for later estimates of dose.

Calibration of hand-held instruments for measurement I-131 in thyroid and Cs-137 body-burden was arranged in conjunction with the workshop on internal dose calculation, STUK, Oct. 1999.

A handbook was written (the first version is in Swedish), taking into account the experience from the workshop and with the following content:

- Introduction
- Measurements with handheld instruments
- Measurement of ^{131}I in thyroid with handheld instrument
- Measurement of Cs-137 in the body with handheld instruments
- Measurements of ^{131}I and Cs-137 with gamma-camera and iodine-monitor
- Measurements with gamma-camera
- Measurements with iodine-monitor

Figure 4. Examples from the handbook, showing how hand-held monitors can be used for estimating I-131 amount in thyroid and Cs-137 body burden.

2.1.2.4 Comparison of methods for estimating internal doses to Nordic populations - whole body measurements and diet investigations

A series of studies were carried out in Norway and Finland to investigate the possible roots of the apparent discrepancy between estimates of Cs-137 body burden, according to whether the estimate was based on intake through diet studies or whole body measurements. Estimates based on intake seem still to be higher than those based on direct whole body measurements. Therefore a new component was added to the BOK-2.1.2 study: BOK-2.1.2.5, *Activity losses during food preparation*.

2.1.2.5 Activity losses during food preparation

Correction factors for losses in food preparation have been presented earlier, normally they are around 0.5. The results of the current study up to now show that for cooking of meat the losses are rather large with a retention factor of about 0.4. For frying of meat the losses are less, with retention factors around 0.8 -1.0 dependent on the size of the pieces of meat. So far the number of prepared meals are rather low, but the study will continue decreasing the uncertainties. If less caesium is retained in the food after processing than has been previously assumed, that could help to explain the apparent discrepancy between the two methods of estimating body burden.

Conclusions of BOK-2.1.2 work

There is a definite need for training in dose calculations. The first course was successful and was followed by a second, both courses were fully booked. An example of new tools for software products for bioassay analysis and internal dose assessment is the “Integrated Modules for Bioassay Analysis” (IMBA) were demonstrated at the second course. This suite of quality assured code modules have been adopted in the UK as the standard for regulatory assessment purposes.

The intercomparison measurements are an important part of the Quality Assurance work. In what is known as the “Outside workers’ directive” it is stated that the internal dose measurements shall be included in the European Union’s supervision system for radiation protection.

The emergency preparedness regarding internal contamination was much improved by the training with and calibration of handheld instruments from participants' laboratories. More improvement will be gained with the handbook giving practical instructions on what to do in case of emergency.

The comparison of results of different dose calculation methods show that on an individual basis both methods can be used. Using statistical data only for intake calculations will overestimate the internal dose. This has to be kept in mind when using such estimations in emergency situations. The results obtained in this project will also be published in the open literature

BOK-2.2 Radioactive tracers in Nordic Sea areas

In BOK-2.2 two main topics were defined:

BOK-2.2.1 Sea water transport

BOK-2.2.2 Biological and biogeochemical processes

(these were handled by the same project group, not different sub-projects)

BOK-2.2.1 Sea water transport

When applying radioecological models it is important to understand the complexity and variability of marine processes, e.g. to link current radioecological studies to advances in oceanographic models. Understanding of transport and processes is vital for assessing the effects of releases of radionuclides to the marine environment. In recent years, secondary effects are becoming noticable (releases of radionuclides from sediments, influx from rivers). Transport mechanisms can be studied using e.g.:

1. anomalies in salt concentration
2. Cs-137 discharges from Sellafield
3. Tc-99 discharges from Sellafield
4. I-129 discharges from LaHague

The first two have been used to study the system of currents in the North Atlantic for many years. The third type of release has made it possible to compare with and verify previous results during the last few years, including the BOK-2 project period. It is important for modelling to be able to study the transport mechanism using these different types of indicators. The Tc-99 flow could be traced into the Baltic Sea and along the coast of Norway. At the end of the project is was entering the East Greenland Current, but it had not yet been detected there with certainty.

BOK-2.2.2 Biological and biogeochemical processes

All the work in this section concentrated on the Baltic Sea, which is, with its catchment area, sensitive to radioactive fallout. Understanding of transport processes, including those of redistribution, is essential for the proper evaluation of the current situation and effects of possible contamination in the area.

The following 12 papers in the BOK-2 Technical Report summarise the results from studies within the project on the marine environment.

- **Timing of fluxes in the Nordic Seas - overview**
  Svend Aage Malmberg
- **Long term study of Tc-99 in brown seaweed from the Swedish west coast**
  P. Lindahl, T. Gäfvert, P. Roos, S. Mattsson, B. Erlandsson and E. Holm
- **Radioactive Tracers in Nordic Waters, Tc-99, Cs-137 and I-129**
  Henning Dahlgaard, Xiaolin Hou, Sven P. Nielsen
- **Outflow of radiocaesium from the Baltic Sea detected in brown algae along the southern Norwegian coast**
  Elisabeth Strålberg and Gordon C. Christensen
- **Tc-99 in Norwegian Marine Environments**
  Anne Kathrine Kolstad, Justin Brown and Anne Liv Rudjord; Elisabeth Strålberg, and Gordon C. Christensen; Deborah H. Oughton
- **Cs-137 and Tc-99 in the ocean and at the shores around Iceland related to timing of fluxes in the Nordic Seas**
  Elísabet Dolinda Ólafdóttir, Magnús Á Sigurgeirsson, Þórhallur Ingi Halldórsson, Svend Aage Malmberg, Sigurður Emil Pálsson, Kjartan Guðnason
- **Cs-137 and Tc-99 in seawater and seaweed around the Faroe Islands**
  H. P. Joensen, T. Vestergaard, J. Zachariasen and M. Mortensen
- **A sediment trap experiment to study seasonal variations in vertical fluxes in the Baltic sea**
  Per Roos, Örjan Gustafsson and Per Andersson
- **Use of Tc-99 as tracer for Sellafield discharges in the Baltic Sea: Technetium-99 in biota samples collected along the Finnish coast in 1999**
  Erkki Ilus, Vesa-Pekka Vartti, Tarja K. Ikäheimonen, Jukka Mattila and Seppo Klemola
- **Radionuclide processes in the Baltic Sea and its catchment and the adjacent areas: Discharge of Cs-137 and Sr-90 by Finnish rivers to the Baltic Sea in 1986-1996**
  Ritva Saxén and Erkki Ilus
- **Old data on Sr-90, Cs-137 and Pu-239,240 in Baltic Sea sediments prior to the Chernobyl accident (1966-1980)**
  Erkki Ilus and Jukka Mattila
- **Cs-137 in the sediments of the Gulf of Bothnia: additional data on total inventory in sediments**
  Jukka Mattila and Erkki Ilus

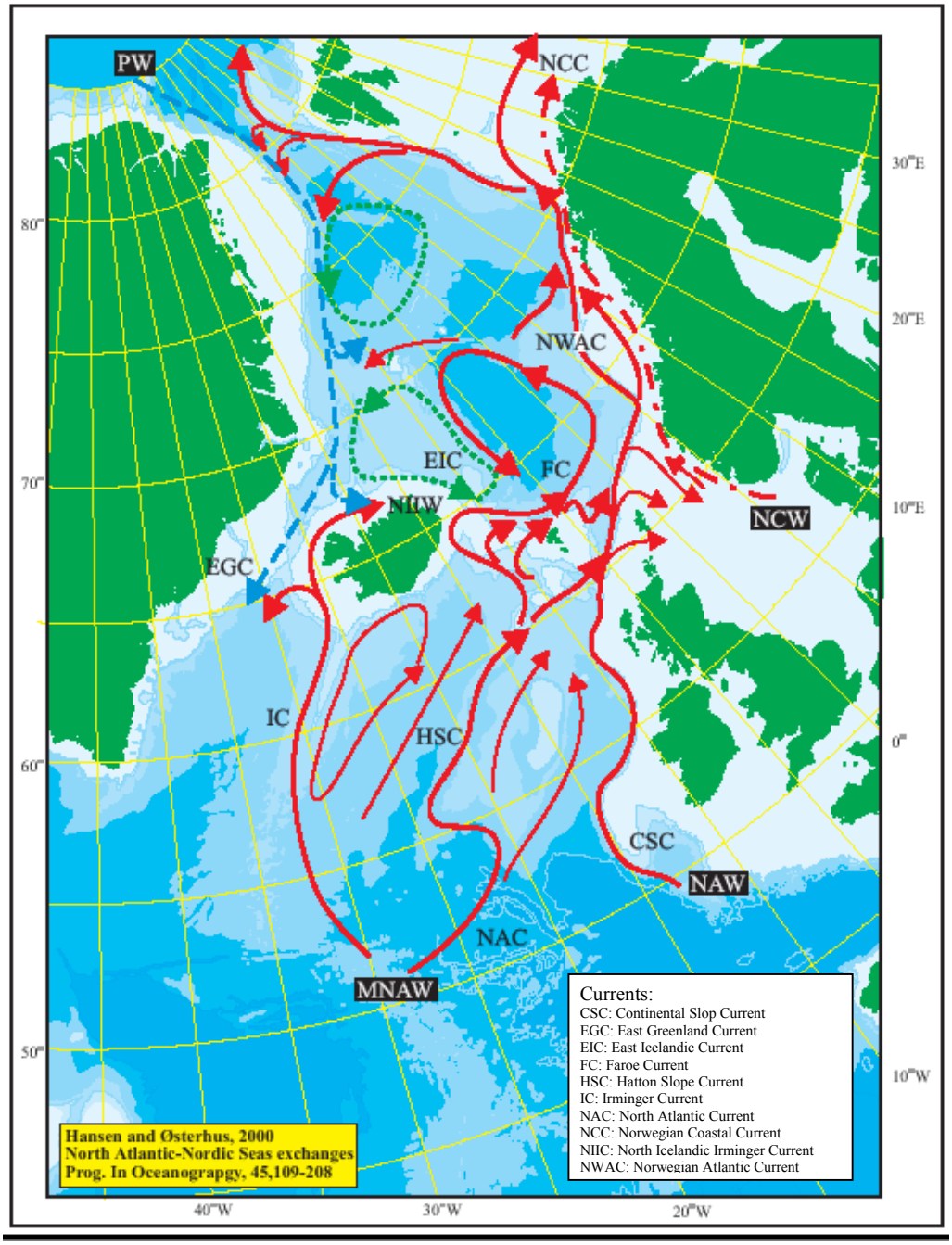

Figure 5. Ocean currents in the Nordic seas (from S.A. Malmberg, *Timing of fluxes in the Nordic Seas - overview*)

Increased releases of Cs-137 and Tc-99 from the Sellafield nuclear reprocessing plant during a limited time period can be used for tracer studies, combining oceanography and knowledge about the chemical behaviour of these two radionuclides.

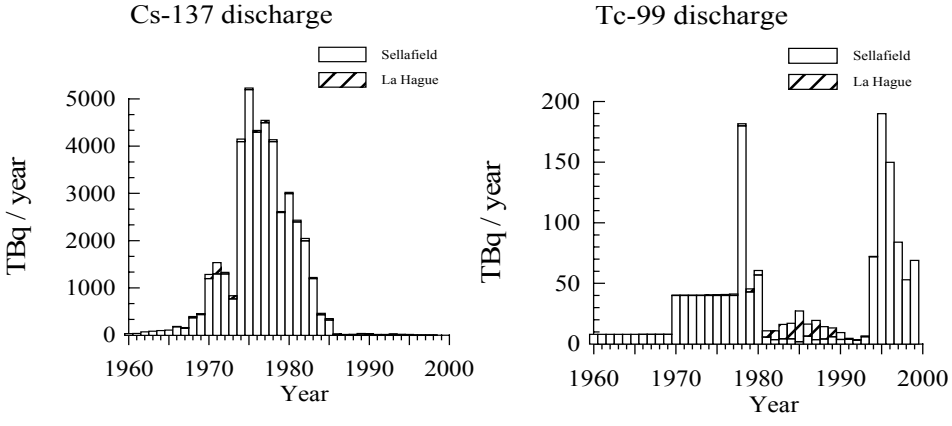

Figure 6. Discharges to the marine environment used as radioactive tracers (from H. Dahlgaard et al., *Radioactive Tracers in Nordic Waters, Tc-99, Cs-137 and I-129*)

The recent increased release of Tc-99 into the sea has caused considerable public concern in some of the Nordic countries. Even though the doses resulting from this are minor, there is a strong demand for more information about the behaviour of Tc in Nordic marine ecosystems. This recent release also offers a good opportunity to the study focused mainly on the re-evaluation of transfer factors for Tc from Sellafield to Nordic Marine areas. Seasonal effects were included where possible as well as uptake of Tc-99 by biota.

The collection of samples (e.g. at sea) and the measurements of Tc-99 are demanding tasks and expensive. The extent of project work was therefore deliberately kept limited in this section.

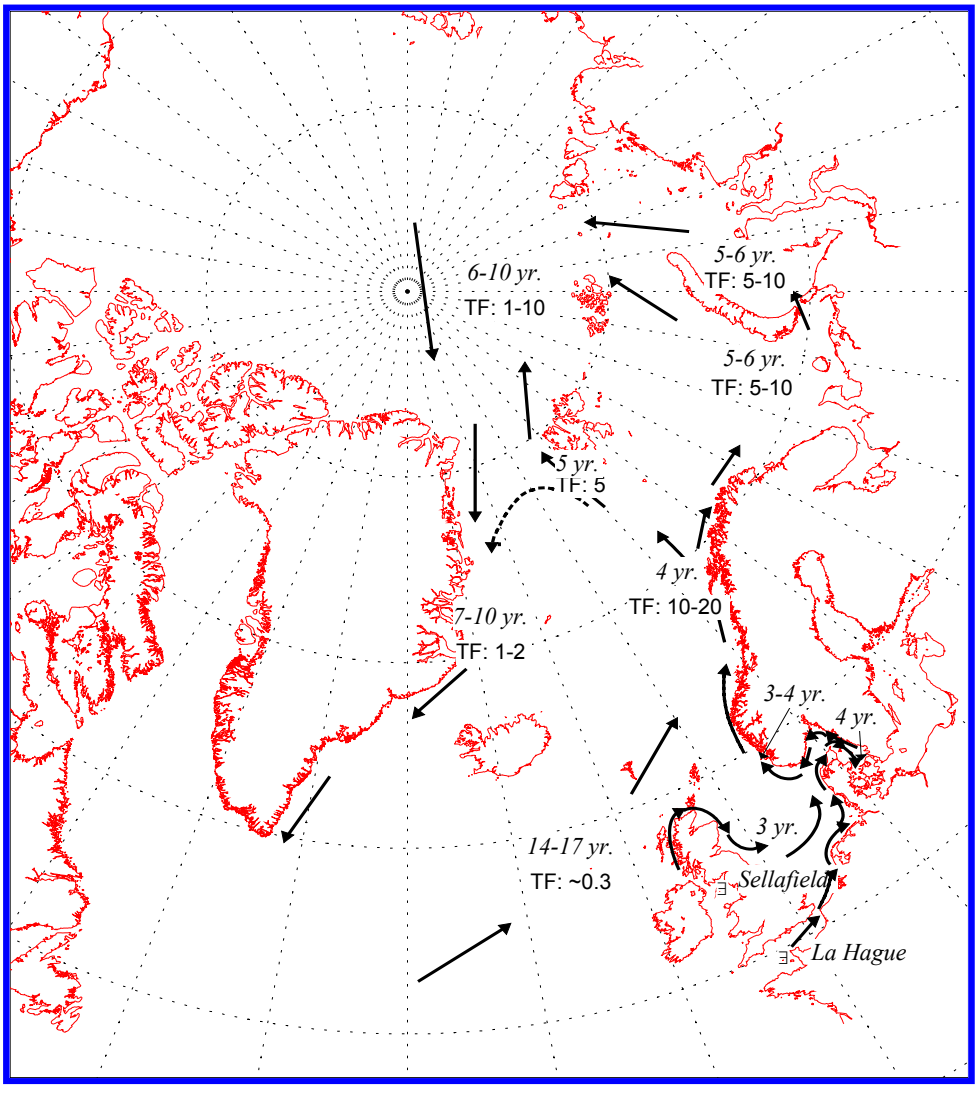

Figure 7. Transit times and transfer factors from Sellafield and La Hague to various Nordic seas. TF: Bq m^{-3} / PBq y^{-1} (H. Dahlgaard, personal communication)

Studies of Tc-99

Measurement techniques

Not all participants had experience in measuring Tc-99 at the beginning of the project. An informal seminar was organised at an early stage and this was followed up by exchange of information and even exchange visits for training purposes. At a later stage other measurement techniques, such as mass-spectrometry, were introduced and made available to the participants, e.g. in the form of a course organised under BOK-2.3 which also involved a follow-up visit to use the technique on own samples.

Studies using seaweed

Even though the studies were run individually, it was emphasised in the early phase of the project that sampling, analysis and interpretation should be done in as harmonised manner as feasible. Participants exchanged initially information about location of sampling sites to be used and later on results, as they became available.

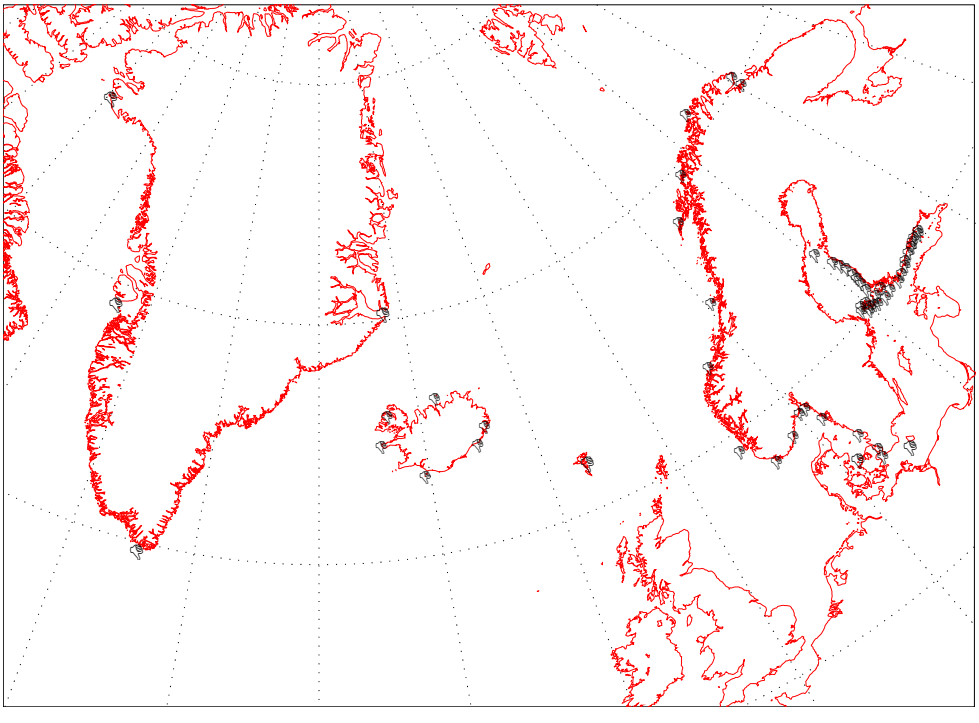

Figure 8. Tc-99 seaweed sampling stations used in the BOK-2 project.
(map by H. Dahlgaard).

Earlier data were also reviewed and combined with more recent ones, as was e.g. done in the study by Lindahl *et al*.

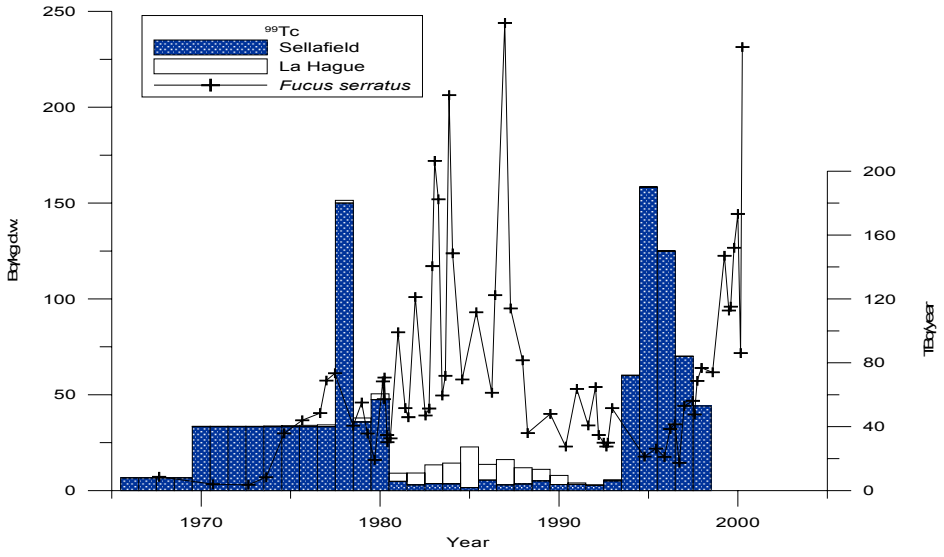

Figure 9. Activity concentration of Tc-99 (primary axis) in Fucus serratus from Särdal and annual Tc-99 discharge from Sellafield and La Hague (secondary axis)
(From *Long term study of Tc-99 in brown seaweed from the Swedish west coast*
P. Lindahl, T. Gäfvert, P. Roos, S. Mattsson, B. Erlandsson and E. Holm)

This study shows that for the two significant pulses, 1977-78 and 1994 – 1999, the time to reach the Swedish west coast is 3-4 years. The Transfer factor in Fucus serratus are about 1 Bq kg^{-1} dry weight per TBq released per year. With a concentration factor of about 80 000 the Transfer factor to water is 0.11 Bq m^{-3} per TBq released per year. The residence time of Tc at the coast is short due to the large outflow of water from the Baltic sea during spring-summer.

Transport along the coast of Norway

In February and July 1999, the Tc-99 concentrations varied between 0.09 Bq m^{-3} and 1.14 Bq m^{-3} in the Barents Sea and in the Norwegian Sea. The highest levels of Tc-99 were observed in the eastern part of the Seas. The results reflect the general circulation of water masses in the Norwegian Sea and the Barents Sea.

It is evident from the seaweed data from Utsira that the discharge *front* from Sellafield reached Utsira waters already in the winter 1996/97.This is in agreement with seawater data from late 1996 and 1997 (Brown et al, 1998). Sea water data from Hillesøy show a best-fit transit time of 42 months (3 years, 6 months), with an estimated uncertainty of ± 9 months.

The transit time for Tc-99, from Sellafield to the Norwegian coastal current (Kvitsøy), is estimated to be about 3 years from the results of the Laminaria Hyperborea study. The Utsira data indicates a longer transit time, probably 3-4 years.

The distribution of technetium in *Laminaria Hyperborea* is clearly not homogenous with the stipes containing more technetium than the leaves. The observed Tc-99 concentrations in *Laminaria Hyperborea* from the Kvitsøy, Buskøy and Smøla are in the range 20-72 Bq kg^{-1} (d.w.), corresponding to concentration factors of about 7,000- 9,000 Bq kg^{-1}(*d.w.*)/ Bq l^{-1} for the leaves and 11,000-17,000 Bq kg^{-1}(*d.w.*)/ Bq l^{-1} for the stems.

In 1997 and 1998, the seaweed results from Utsira show an annual variation in the Tc-99 concentration with a peak in the winter, but for the years 1999 and 2000 the results are however different. The observed variations may instead be related to varying seawater concentrations due to large variations in the monthly Sellafield discharges. The results of the stable analogues study for seaweed show that Re (the closest analogue to Tc) shows a slight seasonal variation, yet with peaks in the summer rather than winter months as observed for Tc-99. At Hillesøy substantial variations are observed, and there seem to be a seasonal variation with higher concentrations of Tc-99 in winter and spring seasons.

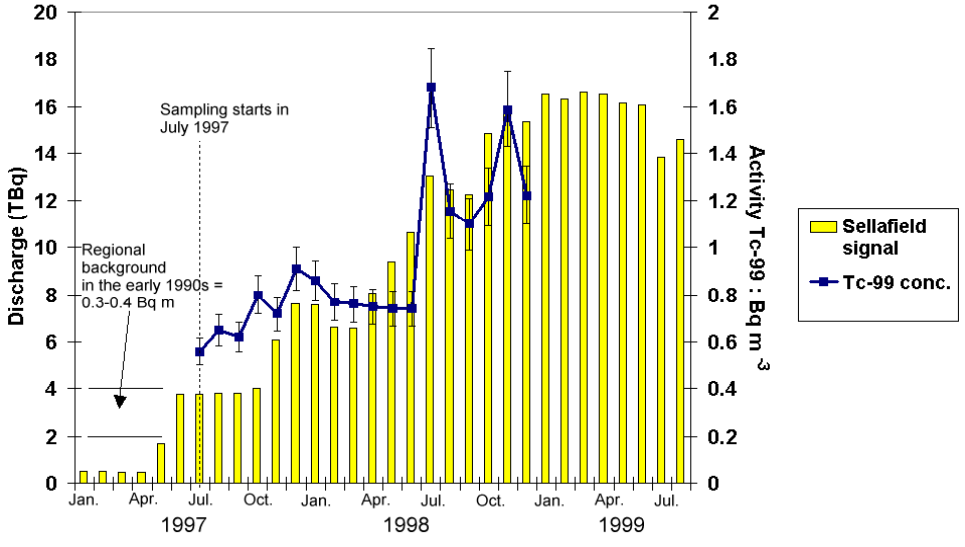

Figure 10. A comparison of «smoothed» Tc-99 discharges from Sellafield with Tc-99 activity concentrations (Bq m^{-3}) in sea water at Hillesøy. (From A.K. Kolstad *et al.*, *Tc-99 in Norwegian Marine Environments*)

Comparison with Cs-137
A study done at IFE study concludes, based on measurements of Cs-137 in *Fucus vesiculosus*, that at present the major source of radiocaesium in the seaweed at the coast of southern Norway is the Chernobyl fallout. The major part of this activity is due to the outflow from the Baltic Sea. A maximum of 25 % of the radiocaesium in the seaweed may originate from Norwegian rivers.

Iceland and the Faroe Island
At present (autumn 2002) increased Tc-99 levels have not been detected in water masses close to Iceland or the Faroe Islands or with certainty in seaweed at the shores of these countries. Model calculations suggest that increased levels should become visible in the East Greenland Current soon and it may already be there, undetected.

The Danish straits and into the Baltic
The Sellafield discharge rate of Tc-99 showed a distinct peak in 1995. A study by Henning Dahlgaard *et al*. showed the peak to be present in the in-flowing bottom water in the Danish straits in June 1999, i.e. 4 years after the discharge. Since then, concentrations have decreased in accordance with the discharge rate. This confirms an earlier estimate of the transit time based on the large Cs-137 discharges before the Chernobyl accident. The Cs-137 concentration in the Danish straits is now dominated by the outflow of low-saline water from the Baltic and is thus inversely related to the salinity, whereas Tc-99 concentrations are positively correlated with salinity as the concentration is dominated by the Sellafield discharges.

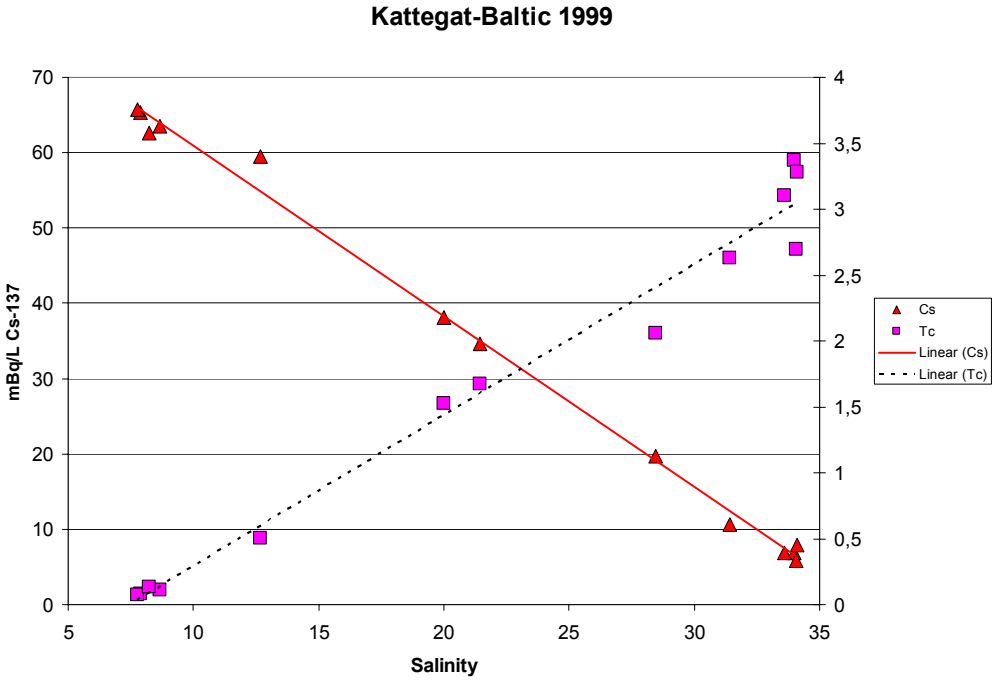

Figure 11. Tc-99 and Cs-137 in water masses flowing through the Danish straits.
(H. Dahlgaard et al., *Radioactive Tracers in Nordic Waters, Tc-99, Cs-137 and I-129*)

A sediment trap experiment to study seasonal variations in vertical fluxes in the Baltic Sea

Objectives. To study seasonal changes in vertical fluxes of particulate matter in the Baltic Sea, using Th-234 as a flux tracer in the sediment trap material.

Main Results. Strong seasonal changes in the fluxes shows that there is a need to be careful in extrapolating 'snapshot' data to cover whole year fluxes. Highest fluxes occur during spring as an indirect result of increased primary productivity. The real reason is however to be found in the seasonal effect which has its origin in the mixing of the water column, leading to an offshore transfer of nutrients and suspended matter which together with the increase in light triggers the biological productivity. The presence of 'anchor' particles in the form of resuspended sediments seems to be very important in regulating the flux, even though these particles in themselves does not primarily carry the Th-234.

Use of Tc-99 as tracer for Sellafield discharges in the Baltic Sea: Technetium-99 in biota samples collected along the Finnish coast in 1999

The aim of the study was to develop a method for analysing Tc-99 at STUK, and to establish whether Tc-99 can be detected in Finnish coastal waters. Samples of *Fucus vesiculosus, Myriophyllum, Macoma baltica, Mytilus edulis, Saduria entomon* and seawater were collected at more than 30 stations along the western and southern coasts of Finland for Tc-99 analysis. Small amounts of Tc-99 were observed in all the *Fucus* samples collected; the activity concentrations ranged from 1.6 to 11.6 Bq kg^{-1} dry wt. The highest concentrations were found in two samples taken from the northernmost stations in the Quark, probably for biological reasons. Due to the low salinity of the water, *Fucus vesiculosus* is very slow growing and small in this area, which is at the extreme limit of its permanent distribution range in the Baltic Sea. In seawater and in all the other biota samples, the concentration of Tc-99 was below the detection limit, which supports the use of *Fucus* as an indicator organism for Tc-99 in the marine environment. Global fallout from atmospheric nuclear weapons tests carried out in the 1950s and 1960s is certainly the most important source of Tc-99 detected in *Fucus* on the Finnish coast. In addition, the samples were analysed for gamma-emitting radionuclides.

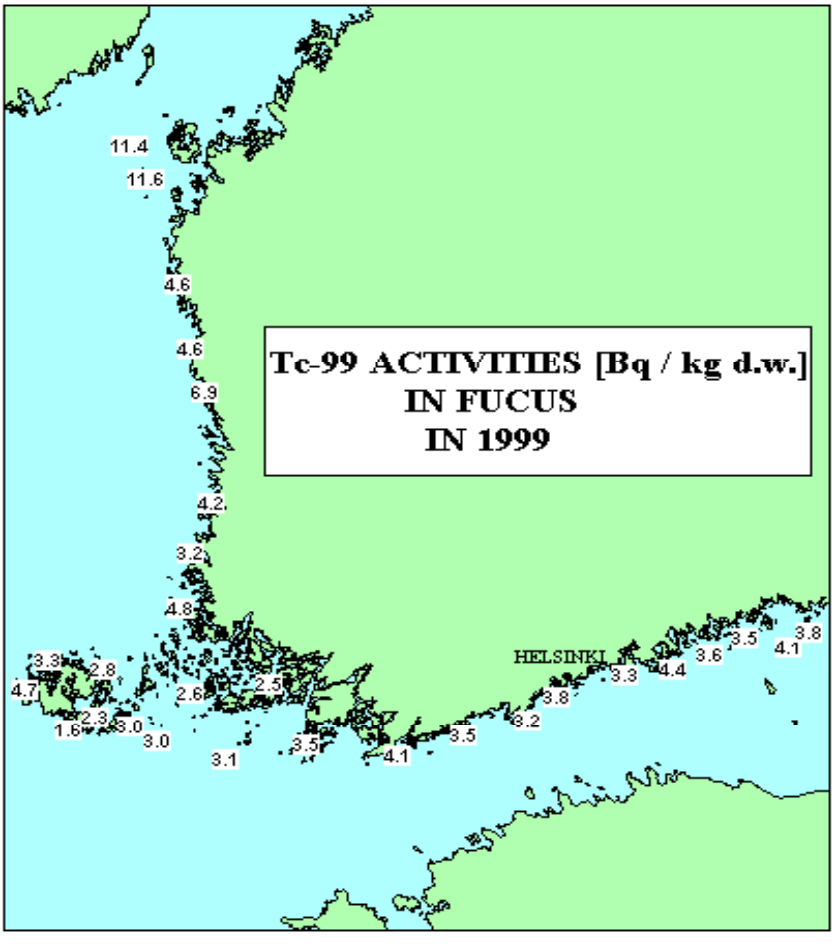

Figure 12. Tc-99 concentration in seaweed at numerous stations along the western and southern coast of Finland. The two high values at the top (11.4 and 11.6 Bq/kg) are due to biological reasons, not increased concentration in the seawater itself. From E. Ilus *et al.: Use of Tc-99 as tracer for Sellafield discharges in the Baltic Sea: Technetium-99 in biota samples collected along the Finnish coast in 1999*.

Radionuclide processes in the Baltic Sea and its catchment and the adjacent areas: Discharge of Cs-137 and Sr-90 by Finnish rivers to the Baltic Sea in 1986-1996

The total amounts of Cs-137 and Sr-90 transported from Finland by rivers into the Gulf of Finland, Gulf of Bothnia and Archipelago Sea since 1986 were estimated. The estimates were based on long-term monitoring of Cs-137 and Sr-90 in river and other surface waters and on statistics of water discharges from Finnish rivers to the above sub-areas of the Baltic Sea.

The total amounts of Cs-137 and Sr-90 removed from Finland into the Baltic Sea during 1986 - 1996 were estimated to be 65 and 10 TBq, respectively. The results show that, although the deposition of Cs-137 was much higher than that of Sr-90 after the Chernobyl accident, the amount of Cs-137 removed from Finland is only six times as high as that of Sr-90. This emphasizes the importance of Sr-90 while considering radiation doses from surface waters and of Cs-137 while estimating doses via pathways from catchment soil, lake sediments and biota after a fallout situation.

Old data on Sr-90, Cs-137 and Pu-239,240 in Baltic Sea sediments prior to the Chernobyl accident (1966-1980)

The aim of the Finnish BOK-2.2 project was to give an overall view of radionuclide processes in the Baltic Sea, in its catchment and in adjacent areas. Plenty of data have been published considering quantities of certain long-lived radionuclides in the Baltic Sea sediments after the Chernobyl accident, while the data published from the period of the weapons tests fallout prior to the Chernobyl accident are relatively few.

STUK has long traditions in the Baltic Sea studies. Radioactive substances in its water, sediments and biota have been monitored since the late 1950s. However, considerable amounts of results from the 1960s and '70s concerning Sr-90, Cs-137 and Pu-239,240 in sediments have not been published and collated with the existing data on seawater.

The objectives of this study were

- to collect and prepare the existing old data for publication
- to compare the old data with that published after the Chernobyl accident
- to consider the earlier published inventory results of these nuclides in the Baltic Sea sediments prior to the Chernobyl accident in the light of the new knowledge
- to consider the role of sedimentation in losses of radionuclides from water column into the seabed

The old sediment data consist of 114 sediment profiles taken in 1966-1980 from the Bothnian Bay, Bothnian Sea, Archipelago Sea, Gulf of Finland and the Northern Baltic Proper. A majority of the samples has been taken from the areas surrounding the sites of the Finnish nuclear power plants, Loviisa and Olkiluoto.

Sr-90, Cs-137 and Pu-239,240 were quite evenly distributed in the areas studied. In general, however, the total amounts of these nuclides (per m^{-2}) were slightly higher in the coastal areas than at the open sea.

The total amounts of Sr-90 ranged from 10 to 260 Bq m^{-2}, those of Cs-137 from 50 to 13.000 Bq m^{-2}, and those of Pu-239,240 from 4 to 340 Bq m^{-2}. The amounts of Cs-137 were significantly lower than those reported after the Chernobyl accident. The maximum value (13.000 Bq m^{-2}) found from the Archipelago Sea was almost one order of magnitude lower than the highest values reported from the Bothnian Sea after the Chernobyl accident.

Cs-137 in the sediments of the Gulf of Bothnia: additional data on total inventory in sediments

In 1993-1997 STUK and the Finnish Institute of Marine Research carried out an extensive study on the total inventory of Cs-137 in the Baltic Sea sediments. The study was linked with the Finnish EKO-1 Project: "Sedimentation rate in the Baltic Sea" supported by the NKS. The results were published in IAEA-TECDOC-1094 "Marine Pollution, Proceedings of a symposium held in Monaco, 5-9 October 1998". The study showed that the proportion represented by the Bothnian Sea was clearly dominant in the total Baltic Sea inventory of Cs-137, but the areal representativeness of these results remained unverified.

The objectives of this study were

- to improve the knowledge of Cs-137 amounts in different parts of the Gulf of Bothnia by taking some additional samples and by repeating sediment sampling at certain stations sampled before
- to improve the knowledge of the role of sedimentation in losses of radionuclides from water column into the seabed.

Results

- the results confirm our previous results on the high amounts of Cs-137 in the sediments of the northern Bothnian Sea
- the results improve the knowledge of the areal distribution of Cs-137 in the sediments of the Gulf of Bothnia, and the role of sedimentation in losses of Cs-137 from the water column into the seabed.

BOK-2.3 Applications of ICP-MS for measuring radionuclides

The aim with work within this sub-project was to introduce possibilities (and limitations) of inductively coupled plasma mass spectrometry (ICP-MS) to Nordic participants. The work involved two main components:

a) Course in ICP-MS analysis at NLH followed by the opportunity to visit ICP-MS facilities again with own material for analysis
b) Studies and tests involving use of the ICP-MS technique

The studies are described in the following two papers found in the BOK-2 Technical Report:

- **Comparison of two ICP-MS systems for measuring Tc-99 in large volume samples**
  Miranda J. Keith-Roach, Stefan Stürup, Deborah H. Oughton and Henning Dahlgaard
- **Test of using ICP-MS for fast determination of Tc-99 in Icelandic coastal waters**
  Þórhallur Ingi Halldórsson, Níels Óskarsson, Magnús Á Sigurgeirsson, Kjartan Guðnason, Sigurður Emil Pálsson

Course in ICP-MS analysis at NLH followed by analysis visits
Additionally the a course in ICP-MS measurement technology was held at NLH in November 2000, attended by 10 students from Iceland (2), Sweden (2), Norway (2), Denmark (2) and Finland (2). Radionuclides of interest included: Tc-99, I-129, Pu-isotopes, Np. The students were offered the opportunity to come again later, with their own samples, and practice the use of the mass spectrometry, as relevant for their own needs.

BOK-2.4 Methodology for defining exemption levels of radionuclides in timber

Timber industry is very important in many Nordic areas. The NKS Board therefore approved that a study could be included in BOK-2 on the methodology for defining exemption levels for radionuclides in timber. This study is described in the following paper in the BOK-2 Technical Report:

- **Methodology for Defining Exemption Levels of Radionuclides in Timber and Wood Products**
  Elis Holm

Large area of forests in Belarus, Russia and Ukraine are contaminated following the Chernobyl accident. Timber from these forests is subject to export. Doses at different scenarios, pulp plants, saw mills, living in timber house etc. were calculated. Depending on which dose restraints that will be used, 1 mSv, 0.1 mSv or 0.01 mSv per year the exemption levels of timber were derived. From these data and using aggregated transfer factors exemption areas can be identified. If the level 1 mSv per year to individuals is used most timber can be used for export. However if the trivial level of 0.01 mSv per year is used, large areas must be excluded with economical consequences for exporting and importing countries.

Concluding remarks

Research in radioecology is very expensive and NKS can only finance a part of the total cost, most of the studies within BOK-2 were mostly funded nationally. This meant that the BOK-2 work had be based on the nationally funded work in each country, and the ability to steer and harmonise was limited, let alone the possibility of initiating some new joint studies.

The main value of the BOK-2 project was:

- Introduction of a joint Nordic element into nationally based studies, often leading to co-operation
- Providing a joint Nordic forum for exchanging views and results, a stimulating environment (e.g. for young scientists)
- It helped to promote / maintain informal international contacts with leading experts by inviting them to seminars or as lecturers
- It was a forum for Baltic scientists active in this field, to present results, exchange views and form ties useful in future work

The BOK-2 project was a relatively open project, at least for scientists working for organisations directly involved in the work. It was open to contributions from groups wanting to make use of this Nordic network and this meant that it could be viewed as lacking focus.

The BOK-2 Technical Report, containing 32 papers, most of them summarising work published in scientific journals and/or in proceedings from scientific conferences, is a tribute to the activity and dedication of the participants. The enthusiasm of the participants for their work made the work of a project leader a pleasure and a privilege

Publications

Project reports

- NKS-35: Summaries of studies carried out in the NKS/BOK-2 project. Technical report
- NKS-70: Proceedings of the 8th Nordic Seminar on Radioecology. 25-28 February 2001, Rovaniemi, Finland

Appendix

Glossary, acronyms

Explanations of some abbreviations used

EU	European Union
FOA / FOI	Defence Research Establishment (SE)
GIS	Geographical information system(s)
Gr	Icelandic Radiation Protection Institute
HR-ICP-MS	High resolution inductively coupled plasma mass spectrometry
ICP-MS	Inductively coupled plasma mass spectrometry
MS	Mass spectrometry
NKS	The *Nordic Nuclear Safety Research* co-operation. The abbreviation NKS can cover all activity and persons associated with the Nordic Nuclear Safety Research. However, when a reference is made in this report to the views or decisions of the NKS without further specification, the abbreviation is used to refer to the NKS Board, the executive secretary, the reference group or its chairman, or some other governing body of the NKS.
NRPA	Norwegian Radiation Protection Authority
RALA	Agricultural Research Institute (IS)
SLU	Swedish University of Agricultural Sciences
SSI	Swedish Radiation Protection Authority
STUK	Radiation and Nuclear Safety Authority (FI)
WWW	World Wide Web (on the Internet)

(In some cases the abbreviations refer to words in a Nordic language and may therefore show little connection with the English explanation)

Participating institutes

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Risø National Laboratory[1,2] (DK)
University of the Faroe Islands[1,2] (FO)
Faroese Natural History Museum[1,2] (FO)
Radiation and Nuclear Safety Authority[1,4,6,7] (FI)
The Finnish Forest Research Institute (Metla)[6], Rovaniemi (FI)
Icelandic Radiation Protection Insitute[1,2] (IS)
Agricultural Research Institute[1,2] (IS)
Icelandic Meteorological Office[1] (IS)
Norwegian Radiation Protection Authority[1,2,3,4,7] (NO)
Institute of Energy Technology[1,2,3,4] (NO)
Agricultural University of Norway[1,2,3,4] (NO)
University of Oslo[5]
Swedish Radiation Protection Authority[7] (SE)
Lund University, Department of Radiation Physics[5] (SE)
Department of Radiation Physics, Sahlgrenska, Göteborg[7] (SE)
FOI, Umeå[7] (SE)

1: Participates in data compilation / vulnerability study
2: Participates in lamb study
3: Participates in milk studies
4: Participates in Pu studies
5: Participates in lake studies
6: Participates in mushroom study
7: Participates in internal dosimetry study

BOK-2.2

Risø National Laboratory[1,2] (DK)
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The Faroese Fisheries Laboratory[1] (FO)
Radiation and Nuclear Safety Authority[1,2] (FI)
Icelandic Radiation Protection Institute[1] (IS)
Marine Research Institute, Iceland[1] (IS)
Norwegian Radiation Protection Authority[1,2] (NO)
Institute of Energy Technology[1,2] (NO)
Agricultural University of Norway[1,2] (NO)
Institute of Marine Research[1,2] (NO)
Malmö University, Department of Radiation Physics[1] (SE)
Lund University, Departments of Radiation and Nuclear Physics[1,2] (SE)

1: Participates in Tc-99 study
2: Participates in Baltic Sea study

BOK-2.3

Risø National Laboratory (DK)
Radiation and Nuclear Safety Authority, STUK (FI)
Icelandic Radiation Protection Institute (IS)
Nordic Volcanological Institute, Iceland (IS)
Norwegian Radiation Protection Authority; NRPA (NO)
Agricultural University of Norway, NLH (NO)

BOK-2.4

Lund University, Department of Radiation Physics (SE)

List of participants

BOK-2.1.1 Radioecological vulnerability
BOK-2.2 Radioactive tracers in Nordic sea areas,
BOK-2.3 Applications of ICP-MS for measuring radionuclides
& BOK-2.4 Methodology for defining exemption levels of radionuclides in timber

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Sven P. Nielsen, Risø (DK)
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Miranda Keith-Roach, Risø (DK)
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Mette Øhlenschlæger, SIS (DK)
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Financing

Funding of the NKS/BOK-2 studies and other project activities was of three types:

- the basic NKS funding as originally defined in the project plan
- extra NKS funding due to tasks taken over from other projects (mainly the BOK-2.1.2 sub-project on internal doses) and new work approved by the NKS Board (such as BOK-2.3 and BOK-2.4)
- value of work and use of facilities by participants. It is difficult to given an exact estimate of the value of contributed work and resources. Such an estimate depends e.g. on how sharing work and resources with other studies is taken into account.

All amounts in the following table are in k DKK (thousand Danish crowns)

Year	Basic NKS funding	Total NKS funding	Value of national contribution (rough estimate)
1998	1130	1210	5000
1999	1650	1850	7500
2000	1650	1985	8000
2001	1450	2109	8500
Total for all years:	**5880**	**7154**	**29000**

The value of the national contribution is thus estimated to be approximately four times higher than the NKS contribution. The importance of the NKS funding was nevertheless greater that this share in the total costs would suggest. The studies had mostly to be based on nationally ongoing or planned work, but the NKS funding provided the Nordic added value, helped to harmonise the studies where possible and to create a joint Nordic environment for carrying them out and exchange views on the results.

Bibliographic Data Sheet **NKS-64**

Title	Radiological and Environmental Consequences Final Report of the Nordic Nuclear Safety Research Project BOK-2
Author(s)	Sigurður Emil Pálsson
Affiliation(s)	Geislavarnir ríkisins (Icelandic Radiation Protection Institute)
ISBN	87-7893-119-3
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No. of pages	58
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Abstract	Final report of the Nordic Nuclear Safety Research project BOK-2, *Radiological and Environmental Consequences*. The project was carried out 1998-2001 with participants from all the Nordic countries. Representatives from the Baltic States were also invited to some of the meetings and seminars. The project consisted of work on terrestrial and marine radioecology and had a broad scope in order to enable participation of research groups with various fields of interest. This report focuses on the project itself and gives a general summary of the studies undertaken. A separate technical report summarises the work done by each research group and gives references to papers published in scientific journals. The topics in BOK-2 included improving assessment of old and recent fallout, use of radionuclides as tracers in Nordic marine areas, improving assessment of internal doses and use of mass spectrometry in radioecology.
Key words	Radioecology, radioactive fallout, sheep, radiocaesium, radiostrontium, technetium, seaweed, oceanic tracers, mass spectrometry, internal doses, doses to man

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