Nuclear Safety Research and Facilities Department annual report 1998

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Nuclear Safety Research and Facilities Department Annual Report 1998

Edited by B. Majborn, K. Brodersen,
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Risø National Laboratory, Roskilde, Denmark
April 1999

Abstract The report presents a summary of the work of the Nuclear Safety Research and Facilities Department in 1998. The department´s research and development activities were organized in two research programmes: “Radiation Protection and Reactor Safety” and “Radioecology and Tracer Studies”. The nuclear facilities operated by the department include the research reactor DR3, the Isotope Laboratory, the Waste Treatment Plant, and the educational reactor DR1. Lists of staff and publications are included together with a summary of the staff´s participation in national and international committees.

Cover illustration:
1998 was the last full year of Dr. Asker Aarkrog’s employment at Risø National Laboratory, as he reached Risø’s ordinary age of retirement in January 1999. Asker Aarkrog has an outstanding international reputation in the fields of radioecology, radiation protection and environmental sciences. The cover shows some of the data obtained by his group during the last 40 years at Risø. For many years the heading ”There is no substitute for results” has been written on top of the blackboard in Asker Aarkrog’s office. This heading will prevail as the motto for the work to be carried out in the department in the coming years.

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Contents

1 Introduction

The Nuclear Safety Research and Facilities Department is engaged in research and development and in the operation of the nuclear facilities at Risø National Laboratory.

In 1998 the department´s research and development activities were organized in two research programmes: “Radiation Protection and Reactor Safety” and “Radioecology and Tracer Studies”. The task Applied Health Physics was transferred to the department from the Safety Department on February 1, 1998. The nuclear facilities operated by the department include the Research Reactor DR3, the Isotope Laboratory, the Waste Treatment Plant, and the Educational Reactor DR1.

The research and development work of the department is carried out in close co-operation with Danish and foreign universities and research institutes and also with the Danish nuclear and radiation protection authorities. The department participates in national and international research programmes including some European Commission programmes and the Nordic Nuclear Safety Research Programme.

This report presents a summary of the work of the department in 1998 with an emphasis on the results of the research and development activities. Lists of staff and publications are included together with a summary of the staff´s participation in national and international committees.

2 Radiation protection and reactor safety

The Radiation Protection and Reactor Safety programme works with research on and development of instruments and methods for radiation dosimetry, radiation protection and reactor safety. The aim is to contribute to the protection against the harmful effects of ionising radiation from both natural and man made radiation sources. In addition it is the aim to maintain and develop the basis for interaction with authorities, trades and industries concerning the utilization of ionizing radiation and radiation protection.

The work has been organised in six groups during 1998, encompassing beta dosimetry, retrospective dosimetry, natural radioactivity, emergency preparedness, contamination physics, and reactor safety.

In beta dosimetry the main task has been the development of software for control, data acquisition, and analysis for an advanced portable beta spectrometer. The instrument, which consists of three Si-SB detectors in a telescope set up, is able to measure the energy spectrum of beta radiation in the presence of an intense gamma radiation field.

New techniques have been developed in Optically Stimulated Luminescence (OSL) for retrospective dosimetry, including the implementation of stimulation facilities using high power IR laser diodes and blue Light Emitting Diodes (LEDs). Of particularly interest is the development of a X-Y scanning laser stimulation system which allows for individual measurements of more than 3000 mineral grains in a sequence lasting no longer than the measurement of a batch of 48 conventional samples.

The work on natural radioactivity has focused on the application of a new and interesting method to measure submarine groundwater supply to the sea. Radium-226 and radon-222 can be used as tracers for this purpose since groundwater often has a much higher level of radon and radium than seawater. Measurement and consulting services on indoor radon have continued. As an example a measurement protocol has been designed for radon-222 exhalation rate measurements of building materials on the request of H+H Industries A/S.

The work on emergency preparedness has been concerned with the development of a probabilistic model for long range atmospheric dispersion of radionuclides in case of a nuclear emergency. The model has been tested on fallout data from the Chernobyl accident in 1986. In the Nordic Nuclear Safety Research (NKS) 1998 – 2001 programme Risø is in charge of the BOK-1 project. This consists of a number of sub-projects covering measurement quality assurance, mobile measurements, data assimilation, countermeasures, and exercises.

In the field of contamination physics the main work has been a co-operation with ELSAMPROJEKT and FSL (Forskningscentret for Skov og Landskab). The project is aimed at identifying possibilities for a safe application in power generation of radioactively contaminated wood and other organic material originating from Belarussian forests. It is supported by the Danish Environmental Protection Agency, the Danish Energy Agency, and the Danish Forest and Nature Agency.

Studies on reactor safety issues were continued. The main subjects have been severe accident and decommissioning studies. The accident studies have given new insight into the so called recriticality accidents and contributed to the understanding of the cooling mechanisms in case of a core melt down. The decommissioning project is concerned with Risøs reactor DR2. Preparations for its decommissioning have continued and it is planned that the experience gained here should pave the way for participation in international projects on decommissioning of research reactors.

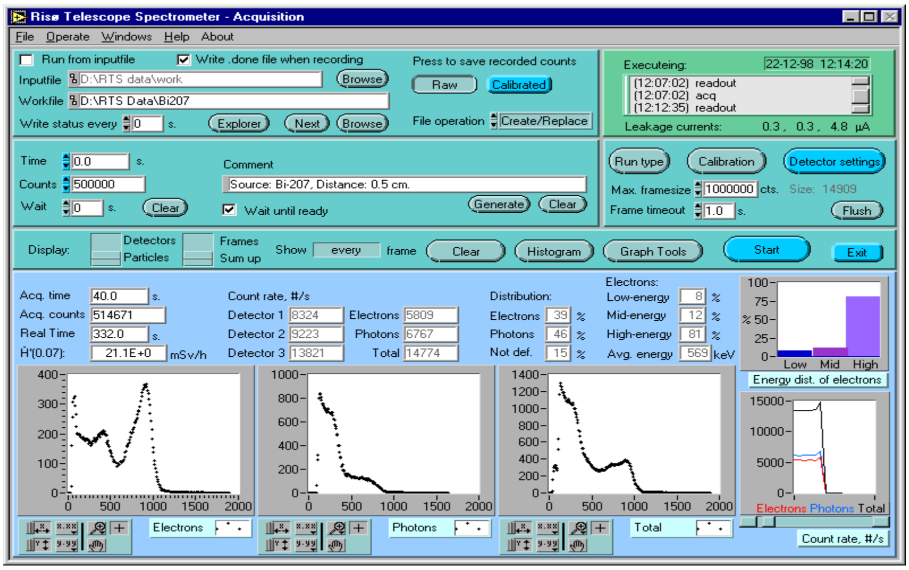
2.1 Dosimetry

Development of beta spectroscopy for skin dosimetry

Work on the development of a beta spectrometer containing three silicon detectors in a telescope set-up has continued as part of a three-year EU research project on dosimetry of weakly penetrating radiation. An important aim of the work is to achieve a compact, flexible survey instrument which can be used under normal working conditions as well as for radiological accident situations. The use of digital signal processing at an early stage of the signal chain has facilitated the achievement of a compact, low-weight device.

A main task of the work in 1998 was the development of software for data acquisition and analysis. This includes software for calculation of absorbed dose rate to tissue in terms of $H_p(0.07)$ evaluated from the measured electron spectra. The total software package contains three programs: 1) Bias- and temperature setting, 2) Acquisition and detector parameter settings, and 3) Data analyses.

All programs are developed in the LabVIEW™ programming system distributed by National Instruments. LabVIEW includes libraries for data acquisition and contains predefined elements for building graphical user interfaces, so-called „virtual instruments“. An example of a LabVIEW „front plate“ is shown in Figure 2.1.


Risø Telescope Spectrometer - Acquisition

☐ Run from inputfile
☑ Write .done file when recording
Inputfile: D:\RTS data\work
Workfile: D:\RTS Data\Bi207
Write status every: 0 s.
File operation: Create/Replace
Executeing: 22-12-98 12:14:20

```
(12:07:02) readout
(12:07:02) acq
(12:12:35) readout
```

Leakage currents: 0.3 , 0.3 , 4.8 µA
Time: 0.0 s.
Counts: 500000
Wait: 0 s.
Comment: Source: Bi-207, Distance: 0.5 cm.
☑ Wait until ready
Max. framesize: 1000000 cts. Size: 14909
Frame timeout: 1.0 s.
Show: every frame
Acq. time: 40.0 s.
Acq. counts: 514671
Real Time: 332.0 s.
Ḣ'(0.07): 21.1E+0 mSv/h
Count rate, #/s
Detector 1: 8324
Detector 2: 9223
Detector 3: 13821
Electrons: 5809
Photons: 6767
Total: 14774
Distribution:
Electrons: 39 %
Photons: 46 %
Not def.: 15 %
Electrons:
Low-energy: 8 %
Mid-energy: 12 %
High-energy: 81 %
Avg. energy: 569 keV

Figure 2.1. LabVIEW "frontplate" with a number of features for data acquisition program.

The program package is able to display useful information in parallel with the measurements, e.g. leak currents, detector temperature and measured spectra for each detector as well as electron and photon spectra based on predefined coincidence/anticoincidence settings. Based on the measured electron spectrum, absorbed dose rates to tissue in terms of $H_p(0.07)$ in mSv/h are calculated and displayed.

A number of important performance characteristics of the spectrometer has been studied:

- Energy calibration: Photon sources were used for the energy calibration. Detector 1 and 2 were calibrated by means of photo-peaks whereas compton edges were used for detector 3. A linear relationship between channel number and energy was observed in all three cases.
- Noise levels: For the thin front detector in particular (detector 1) it is important to obtain a low noise level due to the low energy signals (down to 18 keV) to be detected. Unfortunately an unexpected high noise level of about 45 keV was found for this detector, and although some compensation for the high noise level can be achieved by catching signals in the noise region, a lower noise level is needed to obtain optimal coincidence/anticoincidence operations. A problem of instability of the leak current observed for the thick detector of the Risø spectrometer has been addressed to the manufacturer of the detectors.
- Beta/photon spectra: A large number of spectra obtained from pure beta and mixed beta/photon fields have demonstrated the capability of the beta spectrometer. Figure 2.2 shows beta spectra of different beta radiation fields obtained by the spectrometer.
- Dose rate measurements: The dose rate evaluation facility of the spectrometer was tested in beta radiation fields with known dose rates determined by extrapolation chamber measurements. Good agreement was found for the fields with medium and higher beta energies (Sr/Y-90 and Tl-204) whereas an under-estimation of the dose rates by up to a factor of 2 was observed for those with lower energies (Pm-147 and C-14). This phenomenon will be further analysed.

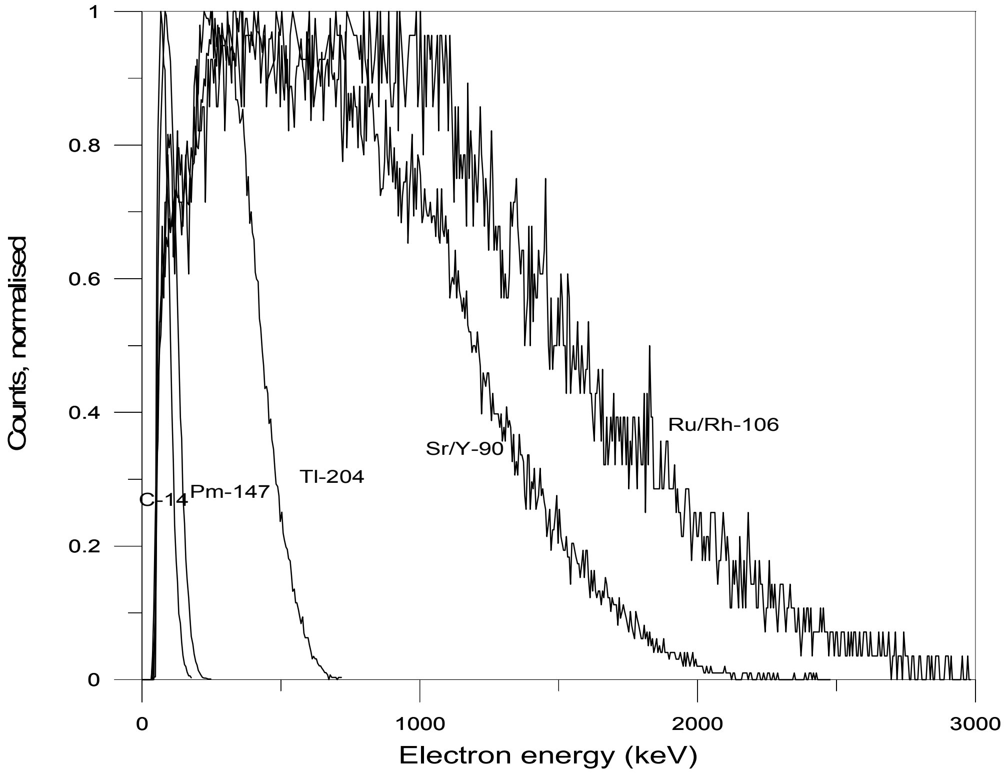


Figure 2.2. Measured beta spectra with different maximum energies.

Performance of European personnel dosimetry services

The group has contributed to the work of an EURADOS working group concerned with harmonisation and dosimetric quality assurance in individual monitoring for external radiation. One of the tasks of the working group is to develop a consolidated performance test for body dosimeters from the European countries for beta, photons and neutrons. Risø have contributed to this task by irradiating dosimeters from the participating laboratories with beta test doses.

Quality assurance in diagnostic radiology

In collaboration with TNO, The Netherlands, Risø has contributed to the preparation of a document concerning criteria and protocols for laboratories providing dosimetric services for quality control in diagnostic radiology. The work is supported by EU in the form of a Concerted Action Contract.

Characteristics of new dosimetry materials and dosimeters

In collaboration with Institute of Solid State Physics, University of Latvia, and Delft University of Technology, the group has studied the thermoluminescence characteristics of AlN ceramics for dosimetric applications. AlN has attracted interest for dosimetry purposes due to an exceptionally high radiation sensitivity.

In collaboration with Oklahoma State University, Risø has studied OSL responses of Al_2O_3 to beta radiation. Thin Al_2O_3 detectors are, in particular, suited for measurement of doses from low-energy beta radiation due to a high sensitivity and only a minor dependency on the beta energy.

Calibration of gamma-cells

Two gamma-cells at Odense University have been re-calibrated. For both radiation units the deviation from the previous calibration was below three percent.

2.2 Optically stimulated luminescence

IR laser diode stimulation

Normally IR light emitting diodes (LEDs) peaking at 870 – 880 nm have been used for stimulation of feldspars. However, the decay rate of the luminescence signal using IR LED stimulation is still about 100 times slower than from quartz illuminated with blue - green light. In regeneration methods in particular, higher power is needed to be able to deplete completely the IRSL (infrared stimulated light) signal over a short time, to allow repeated regeneration of the IRSL from the same sample. Accordingly, the application of solid state IR laser diodes was investigated in collaboration with Nordic Laser Systems A/S, Kvistgård, Denmark, and consequently a compact IR stimulation unit based on a 1.0 W laser diode emitting at 830 nm was developed. Using appropriate optics, such as cylindrical focal lenses, this provides a uniform illumination area of approximately 1 cm^2 at the sample position. The power at sample versus laser diode current is shown in Figure 2.3. The IR laser diode has been integrated with a new blue LED OSL unit providing a flexible high-power combined IR/blue light OSL attachment (see **Figure 2.4**). Typical IRSL decay curves from a feldspar sample obtained with 1) the laser diode running at 500 mW/cm^2

at the sample and 2) the conventional IR LED array (40 mW/cm^2) are shown in Figure 2.5. The greater stimulation power provided by the laser diode is seen to give an enhanced initial light output and a steeper initial OSL decay curve; the relative depletion after 75 s is much greater.

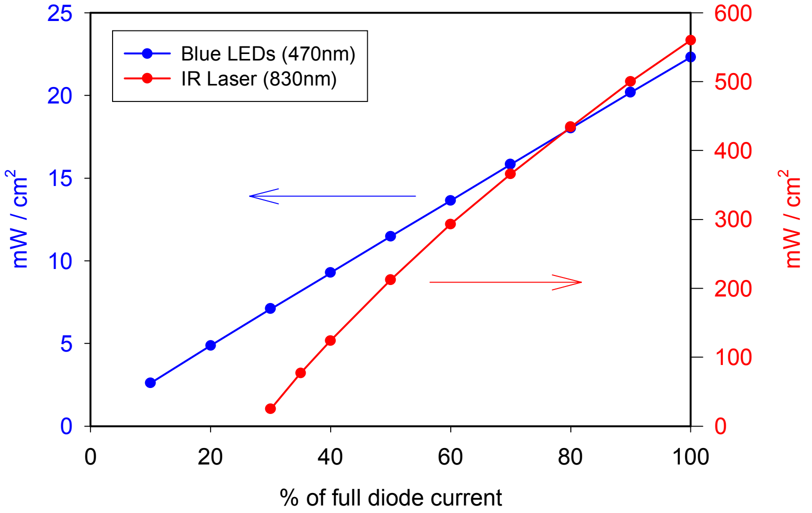


Figure 2.3. Power at sample position versus diode current setting.

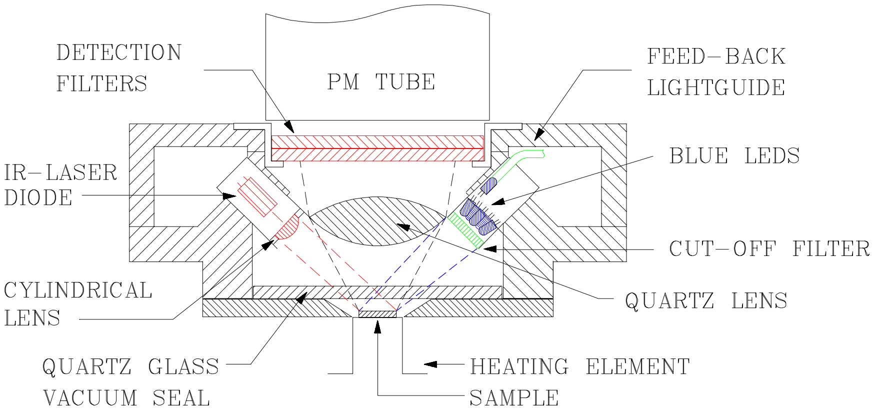


Figure 2.4. Schematic diagram of the new combined blue LED and IR laser diode OSL unit. 36 blue LEDs (in 6 clusters) emitting at 470 nm deliver max. 20 mW/cm^2 at the sample and the IR laser diode emitting at 830 nm delivers max 550 mW/cm^2 at the sample.

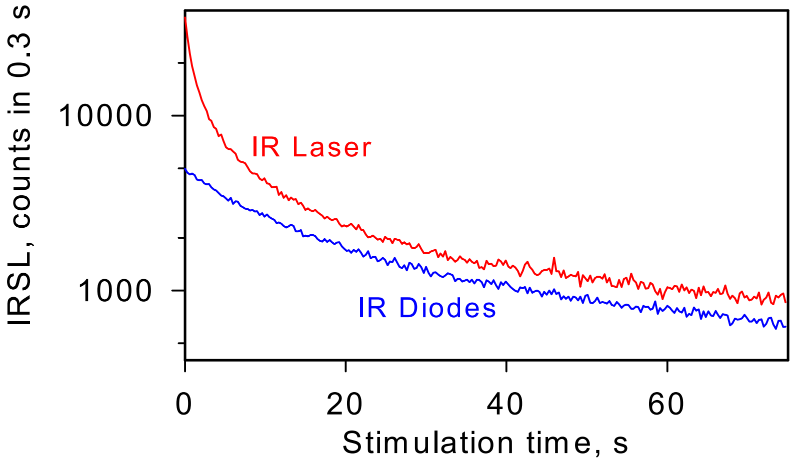


Figure 2.5. Plots of IRSL decay curves obtained from a sedimentary feldspar using (a) a normal LED array (40 mW/cm^2) and (b) the new 1W/830 nm laser diode (500 mW/cm^2). Note the logarithmic Y-axis.

Blue LED configurations

A comprehensive testing of different blue LED OSL stimulation configurations at Risø has in 1998 resulted in the design of a compact OSL attachment to the automated Risø TL reader. This unit is built up of clusters of blue LEDs contained in exchangeable tubes arranged in a ring between the sample heater plate and the PM tube (see **Figure 2.4**). Each cluster consists of six blue LEDs, each focusing the sample. The ring-shaped holder may contain up to seven clusters making a total of 42 diodes illuminating the sample at a distance of about 30 mm. However, normally one position is occupied by the focused IR laser diode described in the previous section (see **Figure 2.4**). A green long-pass GG-420 filter is fitted in front of each blue LED cluster to reduce the high energy photons, and so minimise the scattered blue light reaching the PM cathode. The total power (seven clusters) delivered to the sample position has been measured to 24 mW/cm^2.

To ensure the output stability, the blue diode array has an optical feedback servo-system. An extra diode in the LED array is facing an optical fibre light-guide connected to a phototransistor. The phototransistor output regulates the feedback comparator/amplifier that controls the LED current.

The new blue LED facility further offers the possibility of software control of the illumination intensity and brief illumination pulses (for normalisation) during experimental sequences. The software also allows for time varying (ramping) stimulation power. The latter feature has shown to be important in the analysis of OSL decay curves to determine the electron trap distributions.

An automated single grain laser luminescence (SGLL) system

A prototype of an OSL scanning system was developed for the measurement of sand-sized single grains. Under software control, a 120 µm focused beam from a 532 nm 10 mW diode pumped solid-state laser can be directed at any point on a standard 10 mm diameter aluminium sample disc; the measured power density at the sample is about 60 W/cm^2 . Single grains are placed in a regular pattern of holes on the sample disc (typically 8 x 8 holes 300 µm in diameter and 300 µm deep, on a 500 µm grid). The X-Y laser stimulation system and a 10 mm diameter sample disc with 64 holes to accommodate single grains are shown schematically in Figure 2.6. The steerable X-Y attachment and laser are mounted on a standard Risø reader, which allows the heating, irradiation, and automatic process control of 48 sample discs. During a measurement sequence for one sample disc, the laser beam is directed consecutively to each grain position. Thus, the system allows for the measurement of up to 3000 grains in a single automatic sequence, in about the same time as it takes to measure 48 conventional aliquots. Preliminary measurements have shown good reproducibility and confirmed that the signal strength from one grain to another varies by orders of magnitude.

The overall performance of the single grain laser OSL system was tested at Risø in 1998 using a set of 320 quartz grains mounted on 5 sample discs. The quartz grains were extracted from an Australian dune sand and had a natural dose of approximately 0.05 Gy. The grains were then exposed to a further beta dose of 17.6 Gy. The single aliquot regeneration (SAR) method (see next paragraph) was used in an attempt to measure this known dose. Figure 2.7 shows the distribution of the equivalent dose obtained for 80 grains from which relatively bright signals could be obtained. The distribution is normal with a mean value of 17.8 Gy and a standard deviation of 2.2. Gy.

The single grain system performance has been tested with a variety of samples and the described system provides possibilities for measuring luminescence behaviours of a large number of grains for the first time. The initial results described above show that it is possible to detect OSL from a significant amount of grains even with relatively low doses and that we now have a measurement procedure that allows us to construct the dose to which single grains have been exposed previously.

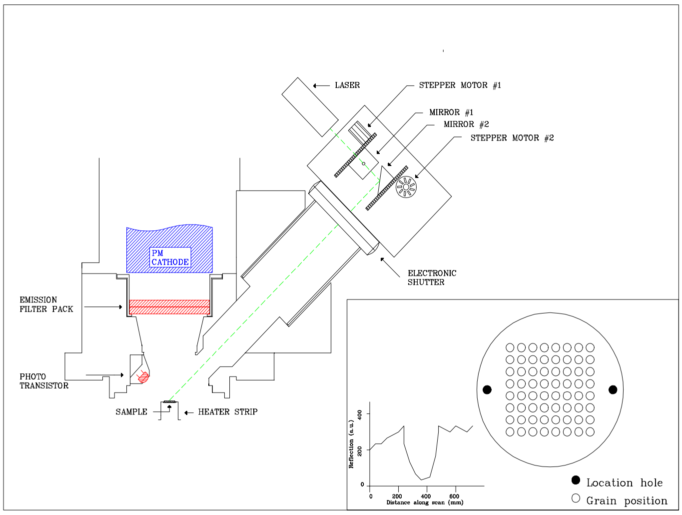


Figure 2.6. Schematic diagram showing the automated OSL X-Y laser scanning system developed at Risø. Also shown is the specially designed sample disc which can accommodate 64 single grains in a grid of 300 μm diameter holes.

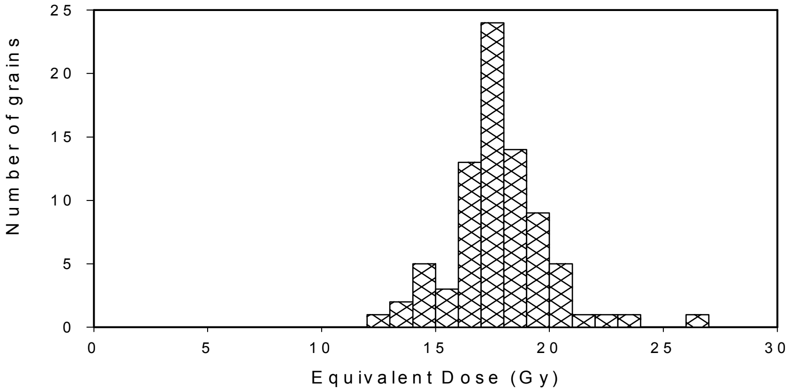


Figure 2.7. Dose distribution obtained from 80 single grains. The distribution is normal with a mean value of 17.8 Gy and a standard deviation of 2.2 Gy.

Retrospective dosimetry

As a further improvement of the single aliquot regeneration added dose (SARA) protocol we developed a "true" single aliquot regeneration (SAR) protocol with a system that compensates for any possible sensitivity changes occurring during repeated measurements of quartz. Small test doses are given in between the regenerated OSL measurements which monitor the sensitivity changes and subsequently corrects the final data for these changes. A total of 102 brick samples collected during field trips to Ukraine and Russia in 1997 and 1998 had their OSL signals measured and subsequently their doses evaluated using the new SAR protocol. Several depth dose profile curves were constructed and compared to similar curves obtained by our partners in the EU-luminescence group.

The results show that a precision of the order of 1-2 % can be achieved using OSL methods (compared to 5-6 % achieved earlier) even for samples that have received very low doses (< 100 mGy).

2.3 Natural radioactivity

Radium-226 and radon-222 as tracers of submarine groundwater flow

In 1998, Risø engaged in the EU project Sub-G.A.T.E. where submarine groundwater supply to the Eckernförde Bay in the western Baltic Sea is studied. In the area, groundwater and geogasses such as methane are believed to flow into the bay at special pockmark locations. Risø's role is to conduct measurements of radon and radium in seawater samples to help quantify the amount of groundwater supply.

One difference between seawater and groundwater is that groundwater often has a much higher level of radon than seawater. High levels of radon in groundwater result from radium in the geological structure through which the groundwater flows. In contrast, radon in seawater is supported only by the (low) content of radium in the water itself and from a thin layer of sand and sediments at the seafloor (radon diffusion). Likewise, groundwater also tends to have a larger content of radium than seawater. For these reasons, radon and radium can be used to trace groundwater supply to the sea.

The following measurement procedure is used: Water samples (5 or 10 L) are collected at the field site and brought back to the laboratory as soon as possible (the half-life of radon-222 is 3.8 days). In the laboratory, radon is extracted with a carrier gas (nitrogen) which is bubbled through the sample. The flow is led through a charcoal column cooled to a temperature below the freezing point of radon. This traps all radon in the flow. After the sample has been completely stripped for radon, the collected activity is transferred to an evacuated 200 mL scintillation cell by heating the cold trap. Essentially, this (first) measurement gives the radon concentration of the seawater sample. To obtain an estimate of the radium content of the seawater sample, the procedure is repeated a second time after radon has built up in the sample.

To provide a high quality of measurements as well as a relatively high throughput (about 25 samples per day), a semi-automatic radon extraction system has been constructed. The system consists of four units (see Figure 2.8). All solenoid valves are computer controlled and so are the flow rates. Trap pressures are monitored with electronic pressure gauges. A full extraction (including system flushing) is divided into a sequence of 12 steps. The computer steps through the sequence in accordance with pre-programmed settings as well as the online gauges.

The first results seem promising as there is a clear excess ^{222}Rn concentration in the bay, and furthermore, the concentration is largest at the largest water depths close to a known “pockmark” (location 2-1 in Figure 2.9 and Figure 2.10), where groundwater and methane gas supposedly seep out in the bay. The average ^{226}Ra concentration in the water samples from December 1998 given in Figure 2.10 was 3.3 mBq L^{-1} (SD=34%, n=19), whereas the average ^{222}Rn concentration was 10.9 mBq L^{-1} (SD=74%, n=19).

Figure 2.8. Seawater radon extraction systems.

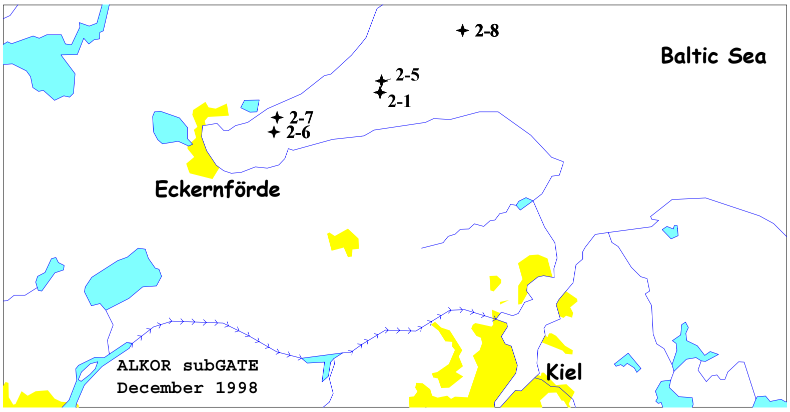


Figure 2.9. Radon-222 and radium-226 sampling locations in Eckernförde Bay, December 1998.

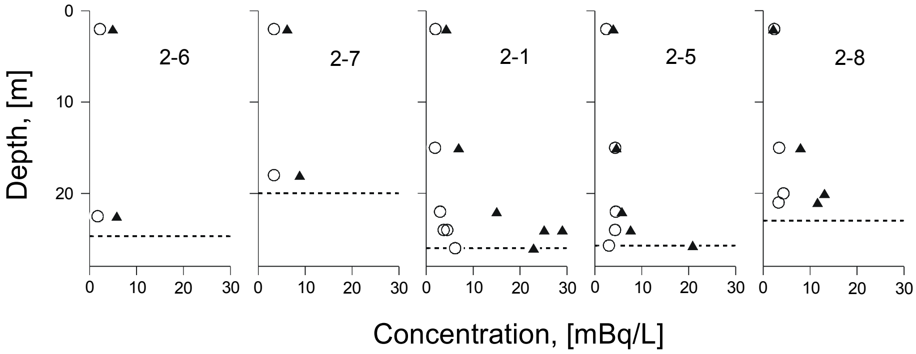


Figure 2.10. Measured concentrations (mBq L^{-1}) of ^{226}Ra (○) and ^{222}Rn(▲) in Eckernförde Bay December 1998. Dashed lines indicate the seafloor.

Building-material radon-222 exhalation rate measurements

Building materials such as bricks and concrete contain radium-226. As radium decays into radon, building materials therefore are sources of indoor radon. Although previous studies in the 1970's and the early 1980's have indicated that Danish building materials are only weak radon sources, it is of interest for the public as well as for producers of building materials to ascertain that this situation remains so. On the request of H+H Industri A/S (a Danish producer of building materials) Risø has carried out a project on this subject. A suitable measurement protocol has been designed, measurements have been conducted for selected samples of building materials, and a framework for extrapolation of laboratory measurements to full scale houses has been developed.

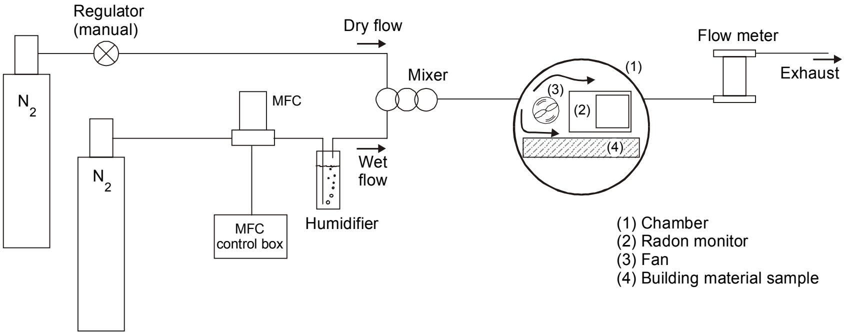


Figure 2.11. Experimental set-up for radon-222 exhalation rate measurements of building material samples.

Laboratory measurements were conducted with the experimental set-up shown in **Figure 2.11**. A 30 x 30 x 5 cm^3 sample is placed in the 60L chamber together with an ionisation chamber for continuous radon measurements. With the flow system, the sample is conditioned for about 24 hours with a carrier (nitrogen) of zero radon concentration and 40-50% relative humidity. Because radon exhales from the sample, the radon concentration in the chamber is non-zero. The radon concentration multiplied by the flow rate directly gives the radon exhalation rate under open-chamber conditions. As the concentration is (normally) very low this is a fairly uncertain estimate. Therefore results are also obtained under close-chamber conditions: The chamber is closed and the build-up of radon inside the chamber is monitored over 4-14 days. This is a more sensitive method for radon exhalation rate measurements, and it is used as primary method in the investigation. The sources of errors are studied in some detail theoretically (by numerical modelling) and experimentally (by comparison of the two methods outlined above).

In the project, 10 samples were studied (mainly bricks and different types of concrete). All materials were found to have a low radon-222 exhalation rate. A formalism was developed by which the laboratory measurements can be scaled to a real house. This formalism showed that the application of the tested building materials in an ordinary single-family house increases the indoor radon-222 level by 10 Bq/m^3 or less. This (small) level is comparable to the level of radon-222 in outdoor air.

Radon transport model benchmarking

ERRICCA is an EU concerted action with participation of more than 26 European laboratories. The project is divided into five topics, and Risø leads the topic on numerical modelling of radon transport. In 1999, Risø organised a model-model intercomparison exercise. The purpose was to help modellers to identify (gross) errors in model calculations, for example, as a result of incorrect programming or incorrect model use and to assess the accuracy of given models. The benchmark test included three relatively complex problems for which exact analytical solutions were not known. The main feature of this approach was that nobody would be biased towards known solutions. 7 laboratories participated in the intercomparison. Only few of the modelling results were in good agreement. Follow-up discussions seem to indicate that in some cases, the main source of the discrepancies is in the formulation used to describe radon diffusion through wet soil. The exercise has caused some of the participants to revise their models.

2.4 Emergency preparedness

NKS project: Nuclear Emergency Preparedness

Risø has undertaken the leadership of the BOK-1 project on nuclear emergency preparedness within the Nordic Nuclear Safety Research (NKS) 1998-2001 programme. The BOK-1 project consists of six sub-projects, listed as quality assurance in laboratory measurements, measurement strategies and mobile measurements, field measurements and data assimilation, countermeasures in agriculture and forestry, emergency monitoring in the Nordic and Baltic Sea countries, and emergency exercises. The data assimilation procedure is to integrate environmental monitoring data, e.g. from automatic measuring stations, into real-time emergency response systems, aiming at improving early prognoses for the consequences of an uncontrolled release of radionuclides to the atmosphere. The project includes both model investigation and experimental validation exercises.

Probabilistic methods for long range atmospheric dispersion

In the field of nuclear emergency preparedness research, a simple probabilistic dispersion model is proposed for the long range atmospheric transport of radionuclides. In this approach, the ensemble average dispersion is modelled as an Eulerian diffusion process, while single events (i.e., nuclear accidents) is described by superimposing stochastic fluctuations to the average behaviour. The model has been applied to fallout data from the Chernobyl accident in April 1986, cf. Figure 2.12. From observations of the gross deposition pattern of particulate radiocaesium, an effective long-range eddy diffusivity of the order of $K = 10^6$ m^2/s is inferred. A corresponding effective deposition length for caesium, defined as the effective distance from the release point to where the aerosols have been deposited is found to be of the order of 1,000 km.

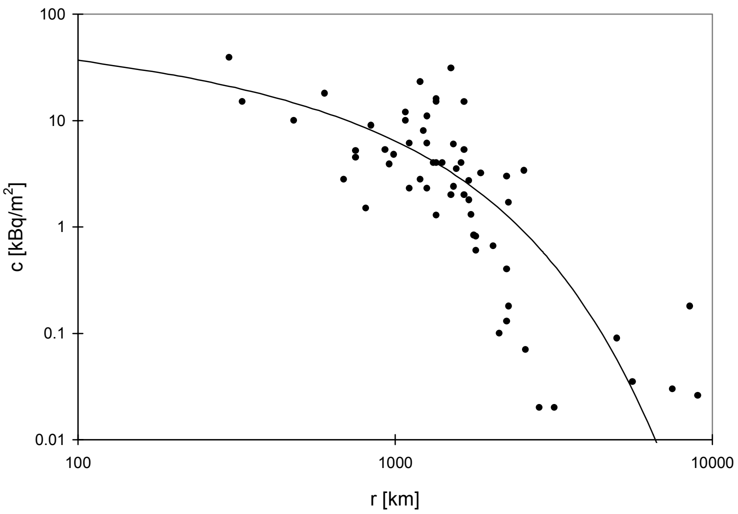


Figure 2.12. Average deposition density of ^{137}*Cs from Chernobyl vs. distance from the reactor. The solid line is the Eulerian dispersion model fit to the data.*

Industrial application of krypton

On the request of an industrial partner, Risø has made an assessment of the exposures and radiation risks from ^{85}Kr when krypton extracted from atmospheric air is used as filling gas in insulating window panes. Both occupational exposures during the production of the insulating window panes and exposures of the public using the windows have been evaluated. It is demonstrated that the application of krypton gas does not lead to significant exposures.

The Danish early warning system

Central computers at the Danish Emergency Management Agency (DEMA) and at Risø collect data on an hourly basis from 11 automatic stations monitoring gamma radiation. Risø has assisted DEMA in upgrading the computers to operate under Windows NT.

During 1998 the early warning stations gave off two false alarms, one from an ionisation chamber and one from a spectrometer. In both cases the alarms were caused by power supply problems.

Two new countries joined the European Union Radioactivity Data Exchange Platform in 1998, Slovenia having 38 automatic monitoring stations and Poland with 8 automatic monitoring stations. During the year, 88 old monitoring stations were cancelled and 417 new stations were installed, increasing the number of early warning stations within the European data exchange system from 936 to a total of 1265. From March 31 the data exchange rate was increased such that data now are being transmitted to JRC Ispra in Italy each day as compared to the previous system of transmitting data each week. Data from all of the 19 participating countries are still returned to all participants once a week. In case of an nuclear accident however, the data exchange rate could be increased to several times a day.

Exercises

On November 3 Risø together with the Danish Emergency Management Agency took part in the exercise INEX-2-HUN. The exercise dealt with an simulated accident at the Hungarian nuclear power plant Paks. In Denmark, the main objective of the exercise was that of information exchange, and the exercise began with a test of the alarm procedure.

2.5 Contamination physics

Power production from radioactively contaminated biomass

In Belarus alone, the Chernobyl accident caused a contamination of 4.6 10^5 ha of forest by radiocaesium levels exceeding 200 kBq m^{-2}. Of these, 4 10^4 ha were contaminated by more than 1500 kBq m^{-2}. A great part of the Belarussian population either live or pass much of their time in these areas, where it is very popular to gather forest food products, which may be highly contaminated.

Together with ELSAMPROJEKT and FSL (Forskningscentret for Skov og Landskab), Risø participates in a project supported by the Danish Environmental Protection Agency, the Danish Energy Agency and the Danish Forest and Nature Agency, aimed at identifying possibilities for a safe application in power generation of radioactively contaminated wood and other organic material originating from Belarussian forests.

Belarus, which has no nuclear power facilities, currently imports about 90 % of its energy. Therefore, an initiative to establish new power production facilities in the country is very attractive. At the moment, the forest floor contamination is confined to a thin organic top layer (duff). In order to significantly reduce the radiation doses in the forest area, this layer must be removed. The new, specially constructed power plant is therefore to be fired with both wood and duff. In the combustion process the radioactive material is concentrated in a small volume of ash, which will be safely deposited in specially constructed repositories.

The first step in the project was to investigate the current radiological situation in the affected forest areas. The importance of a number of different dose pathways was evaluated, including external doses from staying in the forest, extra doses to forest workers, ingestion doses through intake of forest food (primarily mushrooms), doses from forest fires and from domestic use of contaminated firing-wood. The results were to some degree based on calculations performed with the American consequence assessment model RESRAD and the European consequence assessment model COSYMA.

It was concluded that external doses received while staying in the forested areas are of significance. These are dominated by the contributions from the contamination on the forest floor rather than the trees and other vegetation. It was also found that consumption of mushrooms would give a rather large contribution to dose.

Further it was concluded from these investigations that doses received from a forest fire would only affect people over short distances, and the likelihood of a fire occurring in any particular forest area was found to be extremely low.

All dose pathways relating to domestic use of contaminated wood were found to be insignificant.

Having established this, an investigation was made to determine how deep a layer of the forest floor should be removed to obtain the optimal effect. Here, naturally, the depth should be sufficient to greatly reduce the external dose contribution from the forest floor. However, the removed layer must only contain very little mineral soil, as it is to be used as fuel in the bio-mass fired power plant. It was found from the vertical density profile throughout collected soil sample columns that the organic phases are dominant down to about 5 cm depth. By far the most of the contamination (80-90 %) lies in this top layer. A calculation, based on Monte Carlo photon transport modelling, showed that if the removed layer contained just 80 % of the radiocaesium, the external dose rate at the place would be reduced by 77-78 %. A subsequent deep-ploughing, prior to a re-plantation, would help to reduce the residual dose significantly.

Analyses based on in situ measurements have shown that even in the nearby settlements, which are relatively well cleared of trees, the contribution to the external dose rate from the surrounding forest is often 15-30 %. This means that even if the locals keep out of the forests as much as possible, they may still get about one-fourth of their external doses from the forest. The contribution could be more than twice as great to people spending much time in the forest.

It was found that the extra doses received by forest workers removing the bio-material would depend on the extra amount of time spent in the forest, rather than the closer contact to the contaminated wood during the working process. Due to the after all limited number of working hours in a year, these annual extra doses were found to be less than half of the annual doses that are received by the population in the nearest settlements. If the decontamination work is initiated in the areas that are closest to the settlement, and if it is assumed that the worker lives here, the reduction of the dose that he would receive in his spare time could well make up for the extra dose received at work. In any case, the extra doses in the considered areas would be about an order of magnitude lower than the maximal permissible occupational doses, as recommended by the ICRP.

If the contaminated forest areas are cleared, it would probably also mean that the intake of contaminated mushrooms would be greatly reduced. As it has been found that roughly one fourth of the total integrated lifetime dose to the people in the forest settlements comes from the consumption of mushrooms, the thereby achievable dose reduction would be substantial.

Further, a removal of parts of the contaminated forests (and subsequent re-plantation) would also provide an opportunity to improve the fire-breaks to reduce the probability of a forest fire, although its radiological consequences may not be great, at least from a collective dose point of view.

The overall conclusion drawn from the investigation of the effect of decontamination is that the removal of the trees and duff in the forested areas in Belarus has the potential to greatly reduce the doses to a large population.

Another aspect that had to be clarified was the justification of doses to operators of the bio-mass fired power plant. In collaboration with power plant experts from ELSAMPROJEKT, a total of 7 categories of geometries inside a power plant of the planned type were identified, at which contributions to radiation dose might be of some importance. The evaluation was mainly based on data from the Måbjerg plant in Northern Jutland.

The dose rates at these locations were calculated using the Monte Carlo photon transport code MCNP.

In the calculations the contaminant concentrations in the fuel and ash were based on a series of measurements of forest samples from the contaminated areas. It was assumed that the firing of the bio-material would reduce its volume by a factor of 10-100. Here, the highest factor applies to the wood mass. Due to the greater content of mineral phases in the duff, its volume was only assumed to have been reduced by a factor of 10 through the firing process. Dose rates were generally calculated to persons standing at a distance of 0.5 m and of 5 m from the vessel containing the contamination.

Table 2.1 summarises the results of the dose calculations for the different locations in the power plant, when fired with wood.

Table 2.1. Summary of calculated annual doses (in units of mSv) potentially received by persons standing throughout a whole working year at distances of respectively 0.5 m and 5 m from various parts of a power plant fired with wood from an area with a 1 MBq m^{-2} ^{137}Cs ground contamination level.

	Boiler	Bag house	Fly-ash silo	'Big bags'	Bottom-ash belt conveyor	Spiral bottom-ash conveyor	Bottom-ash containers
D = 0.5 m	0.25	0.14*	2.75	2.25	0.26	0.15	2.35
D = 5 m	0.12		0.58	0.06	0.0048	0.0027	0.17

* Doses to people standing directly under the bag house filter.

This data shows that the highest dose rates would be to persons standing near the fly-ash silo, the bottom-ash containers or the 'big bags', into which the fly-ash is filled. If the bio-material is taken from some of the most contaminated areas that will be considered in connection with this project, and the operators are very close to one of the high dose rate locations throughout an entire working year, the additional doses would amount to some 2-3 mSv. However, it is highly improbable that the workers are as close as 0.5 m from the containers for that much time, and a distance of 5 m instead would reduce the dose rate by at least a factor of 5.

A separate calculation showed that radiation doses that might be received from inhalation of contaminated dust at the power plant would be insignificant. This means that respiratory protection would not be required.

Based on the calculations, the overall conclusion was that the extra doses received by the power plant operators would not dominate compared with the environmental contamination doses to the general population in the area, where the power plant is to be constructed. Anyway, the extra individual doses are far below the recommended ICRP limit for occupational exposure, and from a collective population dose perspective these extra doses will be totally negligible.

An estimate has also been made of the risks associated with radiation doses received by the population in connection with routine stack releases from a power plant fired with bio-material from the contaminated Belarussian forests.

In this context, one very important parameter certainly deserves a thorough analysis: the fraction of the radiocaesium in the fuel that is released from the plant. A series of in situ filter tests will be conducted in 1999 to examine this. At this point, the calculations were based on the assumption of a probably rather high fractional release (10 %). Also a couple of other parameters need to be defined in the future in relation to the operation and specific location of the plant.

Most of the calculations were made with the European COSYMA model, which takes into account external doses received from the passing plume, as well as from deposition to environmental surfaces and to the human body. The model also accounts for the internal doses received through inhalation and digestion. However, the supported digestion model, FARMLAND, which is primarily designed to reflect western European consumption habits, has no option to include the contribution of mushrooms, which are in Belarus responsible for a great part of the dose. Separate calculations based on other data were therefore made to include these important dose contributions.

Apart from the release fraction, which is currently not known, it can generally be said that the parameters applied in the calculations were aimed at reflecting the most likely conditions. This applies to the dietary habits, which were based on the results of a recent survey, as well as to for instance the types of dwellings and weather conditions. The rain intensity was, not surprisingly, found to have a great bearing on the individual doses received in the near-zone around the power plant. An ordinary rain intensity was found to lead to more than 10 times higher doses than would be received in the absence of precipitation.

The dose contributions from external radiation and consumption of contaminated food were found to be almost equal in magnitude. About half of the consumption dose was estimated to be caused by the mushrooms.

Based on the assumption of a homogeneous population density of 50 persons per square kilometre (the average for Belarus), calculations indicate that the releases would result in one or two fatal cancer cases over a decade. If, however, the plant is constructed close to population centres (within few km), the risk could be considerably greater. Then again, with the appropriate filter, the doses might be reduced significantly. To put these health effects in the right perspective they should be compared with the radiological health effects at present in Belarus. In an area with a ground contamination level of 1 MBq/m^2, the total annual individual doses amount to some 10 mSv, depending on the area characteristics, including dwelling type. If a population of for instance 1,000,000 people receive such doses, this could according to the publications of ICRP result in 500 cases of fatal cancer. It is these highly significant health effects that the project aims to reduce.

The overall conclusion of this investigation is that individual as well as collective doses received from the routine stack releases would probably be acceptable, subject to the value of a few case specific parameters, that will be determined exactly at later stages of the project.

2.6 Reactor safety

Recriticality studies

In an accident where a reactor plant has lost its electricity supply, the reactor core may be left uncooled for a period long enough for the control rods to melt and disappear, at least partly, from the core, but not long enough for the fuel to melt. If the electricity supply is re-established during this period, the emergency core cooling system will start to inject water into the reactor. As (part of) the control rods have disappeared, an uncontrolled criticality may occur, and it will usually result in severe damage to the core.

The computer code RECRIT, has been further developed in a EU-project SARA (Severe Accident Recriticality Analysis). The neutronic part of the code has been developed at Risø and the thermo-hydraulic part at VVT, Finland.

The code is a stand-alone code, capable of following the accident from the start to the end. It contains models for all relevant phenomena, such as heating of the core by the decay power, heat losses from the core by radiation, melting of control rods as well as the dynamic variation of the neutron flux and the thermo-hydraulic conditions of the core.

The SARA project was concluded at the end of 1998. Some (cautious) conclusions and recommendations which resulted from the project are:

- If recriticality occurs and can not be quenched (by boron injection) the containment may fail in a few hours.
- A way to reduce the risk of recriticality could be a simple change of set-points for the automatic depressurisation system (ADS). At present the ADS starts when the water level in the reactor tank is 1 m above the top of the core. If this was changed to 1 m above the bottom of the core (or the

return of the electric power which ever comes first), about half an hour would be gained to restore the electric power supply.

Core meltdown and coolability

The development of a computer programme simulating the lower head coolability in the Three Mile Island accident was initiated on the basis of a literature study in connection with the participation in the RAK-2.1 core meltdown project under the Nordic Nuclear Safety Research Programme (NKS). The model is intended for use in investigations of TMI-like accidents in Nordic power reactors as part of the NKS/SOS-2.3 project now underway.

A commonly held belief is that a gap develops between the hot debris and the lower head vessel wall, thus creating a coolant flow path. However, it can be shown by thermal-mechanical analysis that the gap hypothesis can not be sustained. Instead a more plausible explanation can be given in terms of thermal cracking of the debris crust and water percolation in the cracks along the wall with countercurrent steam limitation. The loose debris forming the upper part of the debris bed is also found to be the result of cracking and water percolation cooling. Preliminary calculations seem to indicate that the estimated bulk permeability of the cracked debris is sufficient for the water to penetrate to the hot spot on the vessel bottom in the course of about half an hour. This agrees with the findings of the TMI Vessel Investigation Project. It should be emphasised that this result is based on incomplete analytic solutions of the heat conduction equation. The model is now being improved by implementing numerical solution techniques. The model is considered applicable to investigations of the influence on vessel coolability of various parameters such as system pressure, debris mass, composition dependent thermal properties and vessel wall thickness.

Risks connected to the decommissioning of old nuclear submarines

The NATO/CCMS Pilot Study on cross-border environmental problems emanating from defence-related installations and activities was concluded during the spring of 1998 with the publication of five reports to which the reactor safety group has contributed. One of the reports deals with environmental risks of non-defuelled, decommissioned nuclear submarines.

Decommissioning of research reactors

The planning group for the DR 2-project which was established in 1997, has during 1998 prepared the future project work. The reactor building has been cleaned, some components in the basement have been removed and further restoration work prepared. Measurements have been performed of the activity of the primary circuit and it appears to be quite low. A number of programmes and departments at Risø are involved in the project.

A description of the DR 2-project together with a safety documentation for the state of the DR 2-plant during the project are under preparation and will be submitted to the Danish nuclear safety authorities. Information on the reactor is also being collected to ensure that relevant information is available when the reactor is to be dismantled.

During the project the reactor tank, experimental facilities and the primary circuit will be opened to determine the amount and types of activity remaining in the reactor.

The group participates in an IAEA project on the decommissioning of research reactors and presented a paper at a IAEA Research Co-ordination Meeting in Mumbai. The members of the group have also visited the Salaspils research reactor in Latvia which was closed down during 1998, to discuss co-operation on research reactor decommissioning.

Calculation of neutron doses to reactor components at Forsmark 1

It is important to determine the neutron doses received by the various reactor components in order to assess the radiation damage they have suffered. It is also important to determine the induced activity of the components when planning their dismantling and subsequent disposal. Calculations of neutron doses and activity of reactor components were performed for the Forsmark 1 BWR by use of diffusion and Monte Carlo codes.

From a comparison of the results of the two methods the following could be concluded:

- The shape of the neutron spectra seems to be similar everywhere.
- The absolute neutron flux values are roughly the same within the moderator tank.
- Outside the moderator tank the agreement between the two methods becomes poorer and the disagreement increases with the distance. For instance at the bottom of the steam separator, the MC calculation gives a flux which is one order of magnitude larger than that obtained by the diffusion method. At the reactor tank, which is considerably closer to the core, the deviation is about a factor of 2.

It is important to note that the neutron spectra of the MC method are everywhere very similar to those of the diffusion method. This means that spectrum dependent quantities such as activation and fast neutron damage may simply be scaled by the ratios between the two total fluxes.

Figure 2.13 gives the geometry which was used in the calculations. It shows one eighth of the reactor which in axial direction is confined by two parallel planes, z=0 and z=10 cm. The vertical planes y=0 and y=x are reflective. This implies that the whole core is treated correctly, assuming rotational symmetry.

Figure 2.14 gives the relative variation of the total neutron flux along the periphery of moderator tank wall and of the reactor tank wall. The parts of the moderator tank closest to the fuel assemblies will be exposed to neutron doses about 2.3 times the average dose of the tank. For the fast flux (E_n>6 MeV) this ratio is only 1.5. The variation is less along the reactor tank, which is farther away. The ratio between the maximum exposure and the average exposure of the reactor tank is only about 1.25. The ratio for the fast flux is almost the same.

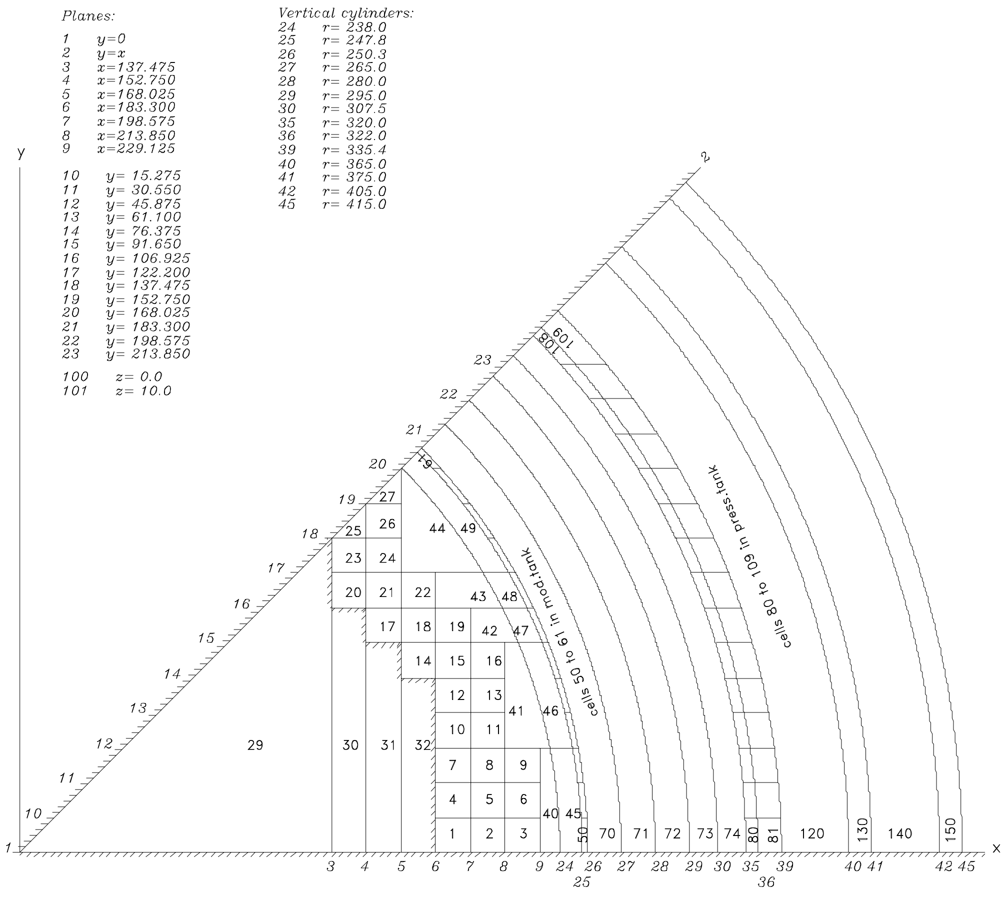


Figure 2.13. Forsmark 1 core geometry for xy-calculation.

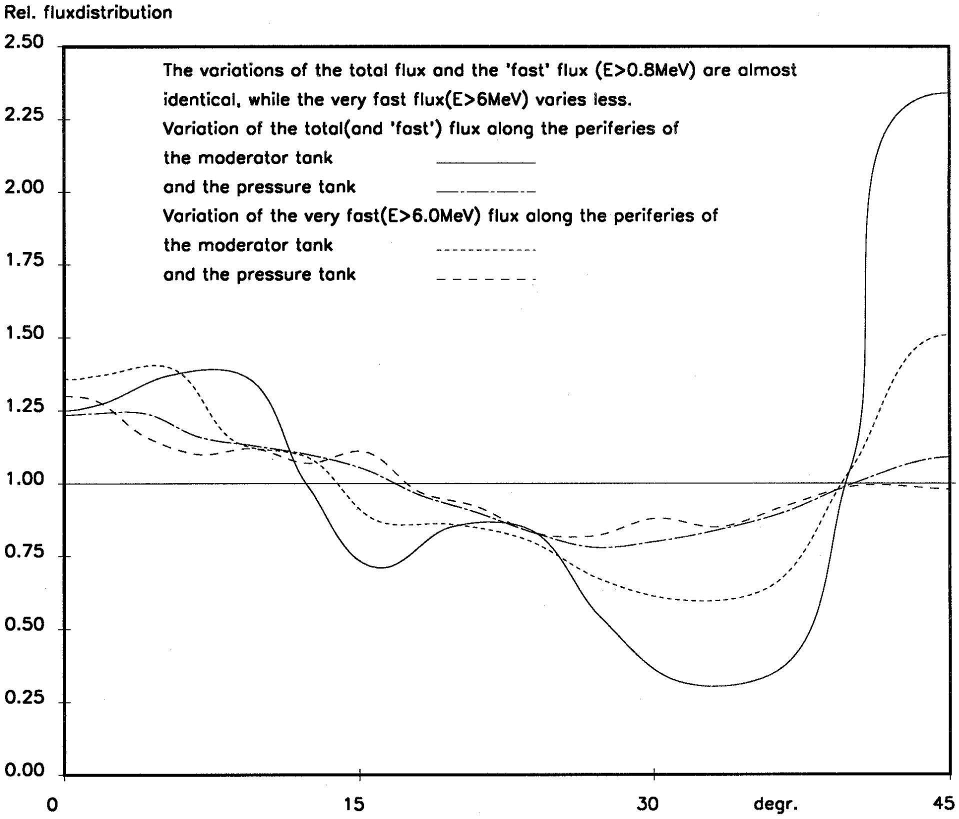


Figure 2.14. Fluxvariation along the periferies of the moderator tank and the pressure tank. (The angle refers to Figure 2.13)

Aerosol resuspension

In the case of a severe LWR accident fission products and structural materials will be released from the damaged core. A significant part of this material will be deposited as particles in the reactor coolant system. In a later phase of the accident these particles may become resuspended if the velocity of the steam-gas mixture in the system increases and further released to the containment atmosphere. This resuspension can be important for the magnitude of a release of radioactivity to the environment.

A series of experiments on resuspension is performed at the STORM facility at the European Union's Joint Research Centre at Ispra, Italy. A member of the reactor safety group takes part in the experiments and in the analysis of the results.

The resuspension experiments were continued in 1998. The aerosol material was a mixture of SnO_2 and CsOH. The resuspension of pure SnO_2 aerosol (which is "dry") takes place in "bursts". The same was found to be the case with the SnO_2-CsOH mixture which is expected to be "wet" because of the CsOH content. Another observation was that in one case the resuspension took place only some minutes after the increase of the wind velocity.

2.7 Nuclear power review

The Nuclear Knowledge Preparedness Group whose members come from the Risø National Laboratory, the Nuclear Safety Division of the Emergency Management Agency and the Technical University of Denmark has published its fourth annual report on the international status of nuclear power in the beginning of 1998. The purpose of the report which is published in Danish, is to keep politicians, civil servants and the media informed about the nuclear power development of the world.

The group also arranged two seminars where presentations about nuclear developments, in particular those related to nuclear safety, were made.

3 Radioecology and tracer studies

By January 1, 1998 the Ecology Programme was reorganised and renamed: Radioecology and Tracer Studies. The group for contamination physics was transferred to the programme for Radiation Protection and Reactor Safety. The groups for radioanalytical chemistry and radioactive waste studies - from the Isotope Laboratory and the Waste Treatment Plant respectively - were included in the reorganised programme.

The aim of the programme for Radioecology and Tracer Studies is to strengthen the nuclear research at Risø within the fields of chemistry and biology with special emphasis to improve our understanding of the bio-geochemical behaviour of radioactive, as well as stable elements. Furthermore, the purpose is to use radioecological principles and measuring methods including neutron activation analysis to solve general environmental problems. The programme maintains the professional standard and the international relations considered important for radioactive waste management. It is an obligation of the programme to maintain and develop a radioecological expertise in order to assist the Danish nuclear authorities with advice and laboratory assistance. The programme is deeply involved in international co-operation both in a Nordic (NKS), European (EU) and global (IAEA, UNSCEAR) context.

Among the major achievements in 1998 could be mentioned

- the finalisation of the EU-supported Marina Balt project, chaired by Risø
- The final reporting of the AMAP supported Thule expedition in 1997
- The successful determination of Pu-isotopes and ^{237}Np by HR-ICPMS in co-operation with the Department for Plant Biology and Biogeochemistry
- An ecophysiological study of the behaviour of silver in eel and rainbow trout
- A neutron activation analysis method developed for the determination of ^{129}I in environmental samples
- A method for the determination of total iodine and various chemical species of iodine in seawater
- Measurements of the exposure to platinum at a public school and at a car repair shop. In neither of these cases platinum could be detected.

3.1 Radioecology

Environmental radioactive contamination in Greenland : A 35 years retrospect

The Greenland environment has received radioactive contamination from three main sources: Global fallout from nuclear weapons testing in the atmosphere, waterborne discharges from nuclear reprocessing plants in western Europe (notably Sellafield) and the Chernobyl accident.

In the marine environment the main input of anthropogenic radionuclides to Greenland waters comes via the East Greenland Current and the maximum levels are observed along the east coast of Greenland where the concentrations of ^{90}Sr and ^{137}Cs typically are twice as high as those seen along the west coast. (Table 3.1). Compared with the levels found in the waters in Western Europe, the radioactive contamination of the Greenland marine environment is at least ten times less. The ^{90}Sr and ^{137}Cs concentrations in marine samples from Greenland peaked in the early sixties. The ^{90}Sr levels have since then decreased by a factor of approximately ten. Due to inputs of ^{137}Cs from Sellafield and Chernobyl the levels of ^{137}Cs in Greenland waters have decreased more slowly. The ^{137}Cs levels in fish, seabirds and sea-mammals are similar. A concentration factor of 100 between seawater and biota is applicable to these animals in Greenland. (Table 3.2).

In the terrestrial environment the spatial contamination pattern follows the distribution of precipitation. The depositions of ^{90}Sr and ^{137}Cs are about ten times higher in the southern part of Greenland than in the northern. The main source to the terrestrial contamination in Greenland is global fallout. The radioactive contamination of the inhabited parts of the Greenland territory is similar to that of other arctic areas.

Nevertheless reindeer-meat from Greenland contains less ^{137}Cs than reindeer from Arctic Russia, Norway and Finland, where the levels are significantly higher. This is partly because winter slaughtering of reindeer is not so common in Greenland as in other Arctic countries. It is in particular during the winter that the reindeers consume lichen which, compared with other constituents of the reindeer's fodder, is relatively high in radiocaesium.

The accumulated global fallout (^{90}Sr and ^{137}Cs) in Greenland soils increased from zero in the early fifties to a maximum in 1966 and has since then decreased by nearly a factor of two. Strontium-90 in drinking water has since its maximum in the early sixties decreased by a factor of 10 and so have the ^{90}Sr and ^{137}Cs levels in lichen and reindeer-meat. Radiocaesium from the Chernobyl accident in 1986 was detectable in Greenland terrestrial samples such as soil, vegetation, Arctic char, lamb and reindeer. The contribution from Chernobyl was, however, at most only about 10% of the total ^{137}Cs concentration. (**Figure 3.1**)

The committed dose from consumption of Greenland produced foods contaminated by ^{90}Sr and ^{137}Cs is estimated to be 0.6 mSv for an average Greenlander corresponding to an increase in the lifetime dose from natural background radiation by 0.35%. Groups with a high consumption of reindeer, lamb or freshwater fish may get doses which are 10-20 times higher. The relatively high consumption of marine products by Greenlanders keep their radiation exposure low compared with other Arctic populations.

Table 3.1. Cesium-137 in surface (0-100 m) seawater around Greenland (Unit: Bq m^{-3}).

Box	N	1960-1969		1970-1979		1980-1989		1990-1997	
		Mean ± 1 SD	n	Mean ± 1 SD	n	Mean ± 1 SD	n	Mean ± 1 SD	n
1	East >80°	-		-		6.6 ± 0.77	11	-	
2	East 80-75°	-		9.7 ± 3.2	3	6.9 ± 1.38	24	7.1 ± 1.26	3
3	East 75-70°	-		-		7.4 ± 1.39	42	7.1 ± 1.78	13
4	East 70-65°	-		8.0 ± 1.02	4	5.5 ± 2.0	35	7.1 ± 2.2	9
5	East 65-60°	-		5.9 ± 3.7	12	5.0 ± 2.5	19	2.3 ± 0.153	2
6	South 55-60°	-		6.0 ± 0.42	1	3.5 ± 0.73	8	-	
7	West 60-65°	-		5.9 ± 2.5	7	5.4 ± 0.94	40	4.5 ± 1.31	7
8	West 65-70°	-		6.4 ± 1.55	5	4.7 ± 0.80	121	3.6 ± 0.22	5
9	West 70-75°	-		-		3.6 ± 0.66	27	-	
10	West 75-80°	-		3.2 ± 1.12	4	3.5 ± 0.72	5	3.7 ± 0.82	5
11	West >80°	-		-		-		-	

Strontium-90 in surface (0-100 m) seawater around Greenland (Unit: Bq m^{-3})

Box	N	1960-1969		1970-1979		1980-1989		1990-1997	
		Mean ± 1 SD	n	Mean ± 1 SD	n	Mean ± 1 SD	n	Mean ± 1 SD	n
1	East >80°	-		-		4.9 ± 0.70	11	-	
2	East 80-75°	15.0 ± 8.8	6	10.1 ± 2.6	5	4.2 ± 1.15	23	2.9 ± 0.69	4
3	East 75-70°	-		-		3.1 ± 0.97	31	2.8 ± 0.77	10
4	East 70-65°	10.8 ± 4.6	4	7.3 ± 3.3	5	3.2 ± 1.18	28	2.8 ± 0.78	8
5	East 65-60°	8.5 ± 4.3	18	4.8 ± 2.4	14	2.7 ± 1.55	16	1.73 ± 0.15	2
6	South 55-60°	-		4.7 ± 0.140	1	2.3 ± 0.99	9	-	
7	West 60-65°	13.2 ± 5.3	28	5.6 ± 1.67	17	3.2 ± 0.70	34	1.96 ± 0.166	9
8	West 65-70°	8.7 ± 4.8	5	4.9 ± 1.43	9	3.1 ± 0.70	93	1.59 ± 0.075	5
9	West 70-75°	-		5.2 ± 0.78	1	2.7 ± 0.63	23	-	
10	West 75-80°	8.5 ± 5.2	6	4.9 ± 1.78	13	2.6 ± 0.177	5	2.0 ± 0.29	5
11	West >80°	-		9.4 ± 1.23	4	-		-	

Table 3.2. Infinite time integrals (ITI in Bq kg^{-1} year) and concentration factors CF = ($\frac{(Bq\,kg^{-1}\ year)\,biota}{(Bq\,kg^{-1}\ year)\,seawater}$) in marine samples from Greenland compared with recommended IAEA values.

Sample	Strontium-90			Caesium-137		
	ITI	CF	Recom.CF (IAEA)	ITI	CF	Recom.CF (IAEA)
Seawater	0.26	-	-	0.36	-	-
Fish	1.3	5	2	31	86	100
Shrimps	1.3	5	2	9.6	27	30
Sea mammals	0.63	2	-	41	114	-

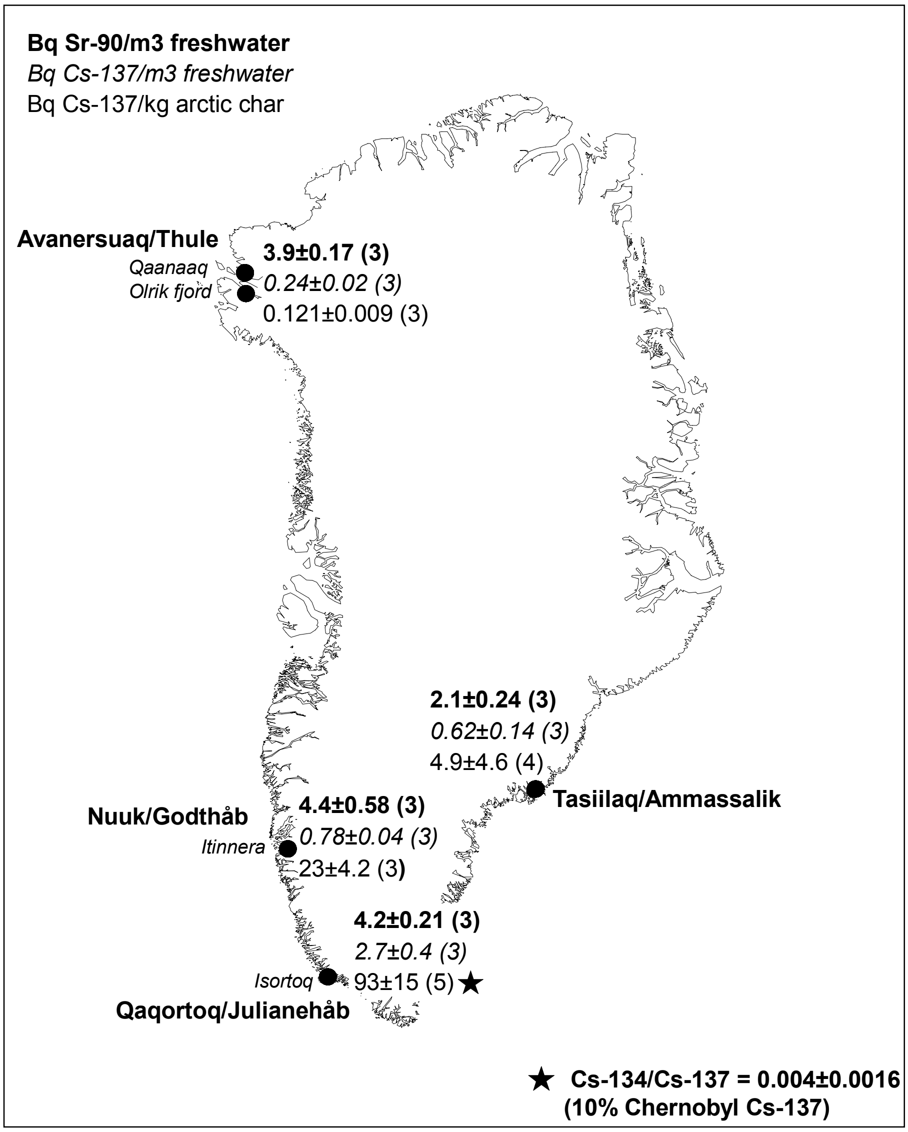


Figure 3.1. ^{90}Sr and ^{137}Cs in fresh water collected in Greenland in 1994 compared with ^{137}Cs in Arctic char from the same locations (AMAP, 1997). <u>Notice</u> the water samples were lake water except the sample from Avanersuaq/Thule which was drinking water.

3.2 Aquatic tracers

Radon and radium as tracers for submarine groundwater

In the EU project Sub-G.A.T.E. we investigate the possibility of utilising the two tracers, ^{226}Ra and excess ^{222}Rn, to quantify submarine groundwater in the Eckernförde Bay in the western Baltic Sea. The two tracers are measured by extracting ^{222}Rn from 5 L or 10 L water samples two times: as soon as possible after sampling, and again after ^{222}Rn is built up from the decay of ^{226}Ra dissolved in the seawater. The last measurement gives the ^{226}Ra concentration, and the difference between the two gives the excess ^{222}Rn. The radon extraction method and the first results are described in section 2.3.

Analysis of ^{237}Np in environmental samples

Compared to other transuranic elements such as Pu and Am, present environmental levels of Np are very low. In the longer term, however, ^{237}Np will become one of the most important radionuclides remaining in high-level radioactive waste because of the long halflife: 2.1 × 10^6 yr. The developed procedure introduces a new method for controlling the valence state at Np^{+4} by applying the redox system SO_3^{2-} / Fe^{3+} at low acidity.

^{237}Np results obtained by applying the described procedure on various environmental materials including two IAEA intercomparison samples are given in Table 3.3. A set of 50 L seawater samples taken in the Danish waters at the entrance to the Baltic showed concentrations in the range 0.85–2.3 mBq m^{-3} measured by ICPMS. These levels are below the detection limit for α-spectrometry, but well above detection limits for the used ICPMS system.

Table 3.3. ^{237}Np results using the described procedure on various environmental materials including two IAEA intercomparison samples

Reference	*Matrix*	*Location*	*^{237}Np, Bq kg^{-1} or L^{-1} ICPMS*
IAEA-300	*Sediment*	*Baltic Sea*	*0.0014±20%*
97160	*Sediment*	*Urals*	*0.13*
970014	*Sediment*	*Urals*	*0.14*
IAEA-381	*Sea water*	*Irish Sea*	*0.0076±17%*

Neptunium and plutonium isotopes measured by HR-ICPMS

The river system draining the Russian nuclear weapons production facility "Mayak" in the Urals has received a variety of radionuclides from the production and processing of weapons plutonium from the late 1940's and onwards. Discharges include scheduled as well as accidental releases.

Figure 3.2 show depth distributions of activity concentrations and atom ratios for plutonium and neptunium in a Techa River sediment core taken at Nadirov Bridge approximately 50 km downstream from the release point to the Techa River from the Mayak complex. It is seen that although there is a considerable variation in concentrations with depth, the ^{240}Pu/^{239}Pu atom ratios are very stable with depth, or in other words, with time. The ^{240}Pu/^{239}Pu atom ratios, average 0.0167, show a remarkably low variation of the same size as the average statistical error of the ICPMS ratio measurements (SD = 0.0005; n=14).

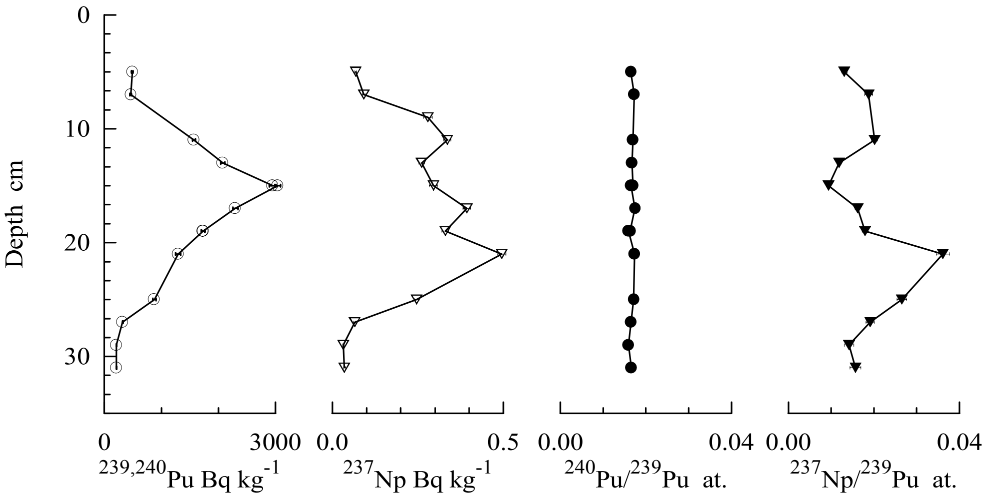


Figure 3.2. Nadirov Bridge, Techa River 50 km from Mayak. Depth distribution of $^{239+240}$*Pu and* ^{237}*Np activity concentrations and* ^{240}*Pu/*^{239}*Pu and* ^{237}*Np/*^{239}*Pu atom ratios.*

Plutonium in marine benthos at Thule

In January 1968, a B52 plane carrying 4 nuclear weapons caught fire and crashed on the sea ice in Bylot Sound off Thule Air Base, northwest Greenland. During August-September 1997, a new sampling campaign was performed. Sediment cores from Bylot Sound analysed for plutonium are all clearly affected by the accident. In several cores, the depth distributions show a clear biologically mixed layer at the top and a gradual decrease with depth. If the deeper part of the high-concentration layer is assumed to correspond with the accident in 1968, 29 years before the sampling, a sedimentation of 8-12 cm, i.e. 3-4 mm per year, has taken place since then. This corresponds well with ^{210}Pb dating of earlier cores. The penetration of plutonium to much deeper layers – down to more than 30 cm - and the absence of very low concentrations in the top layers are both attributed to biological mixing processes performed by the rich benthic community.

Figure 3.3 gives the plutonium concentration, Bq ^{239,240}Pu kg^{-1} dry, in 0-3 cm surface sediments. The picture shows the highest concentrations centered around the accident site, and it indicates a fairly even distribution in the remaining deep part of Bylot Sound, whereas fallout background concentrations prevail outside Bylot Sound. The accident site with the highest concentrations is situated at a depth of 180 – 230 metres.

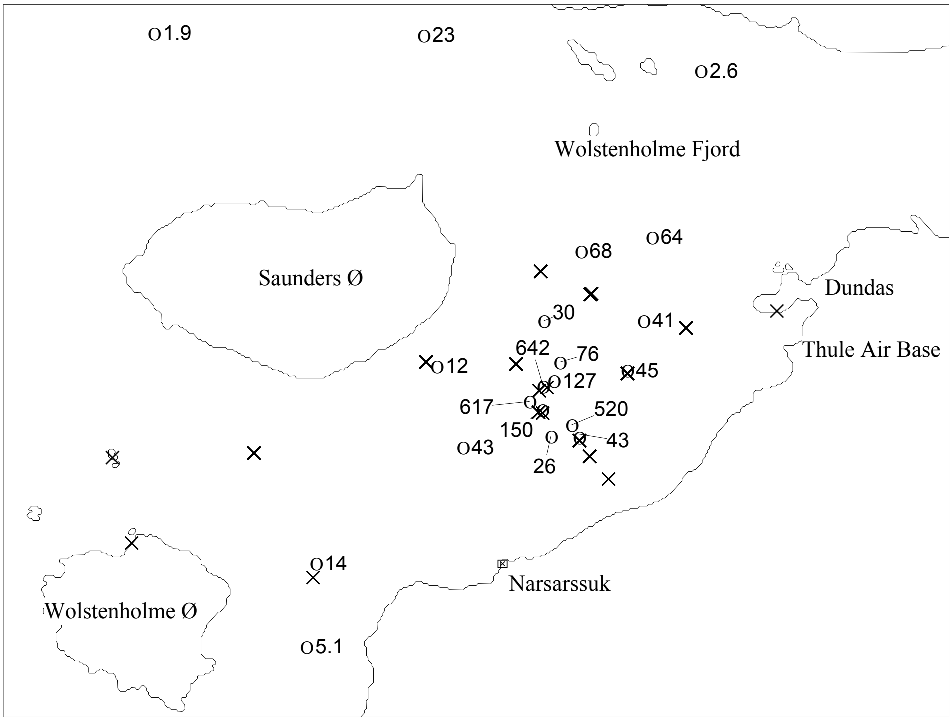


Figure 3.3. Thule-97. Plutonium concentrations in surface sediments. Bq ^{239,240}Pu kg^{-1} dry, 0-3 cm.
o: sediment core, ×: biota sampling location.

Plutonium concentrations in biota samples have been compared with concentrations in 0-3 cm surface sediments to give a “Concentration Ratio”, CR, Bq ^{239,240}Pu kg^{-1} biota/ Bq kg^{-1} dry sediment (Table 3.4). It is noted that although most of the biota is living buried in the sediments or on the sediment surface, the CR values indicate, that plutonium is not readily transferred to biota. One single bivalve sample showed a much higher level, apparently due to a hot particle.

Table 3.4. Thule-97. Plutonium Concentration Ratios, CR, between biota and upper 3 cm of sediments. Average values, dry weight basis.

Species	CR, Bq kg^{-1} biota/ Bq kg^{-1}sediment		
	Average	SD	n
Bivalves	0.025	0.024	13
Macoma calcarea	37*		1
Snails	0.0033	0.0018	9
Squid, Rossia sp.	0.00036		1
Sea stars	0.0094	0.0139	9
Brittle stars	0.013	0.0159	4
Feather stars	0.0070	0.0060	4
Sea urchins	0.12	0.16	4
Sea Cucumber	0.0080	0.0083	4
Shrimp	0.0048	0.0088	4
Pectinaria	0.068	0.05234	4
Fish, Liparis sp.	0.00035		1

Plutonium in freshwater lakes at Thule, NW Greenland

For the first time since the Thule accident 1968, the Thule-97 expedition included a limnological investigation of the surrounding area, east- and north east- (where the lakes are located) of the impact point. The main focus on this program was to see if these environments have been exposed by radionuclides from the aircraft accident. There were reasons to believe that this could be the case as it took several weeks before the clean-up program Crested Ice took place [1]. Meanwhile the debris and the contaminated ice were exposed to hard weather with several storms that could spread the nuclides around the area. Hanson (1980) [2] found at some locations, Saunders Island (west-), Wolstenholme Island (south west-) and near Narsarssuk (south of the impact point), see **Figure 3.3**, activities of ^{239,240}Pu higher than the fallout level. Hanson concluded that these higher levels were due to resuspension or close-in fallout from the accident. From these contaminated areas resuspension has now been going on for 30 years. Another source for resuspension could be the so-called "Tank farm" [1]. In this area the debris and the scrapped contaminated ice were loaded in smaller tanks for further transport to USA.

On the Thule-97 expedition sediment from 3 lakes, water from 4 lakes and soil samples (not reported here) were collected. The lakes were chosen so that a lateral spatial spreading of the sample locations were achieved, see Figure 3.4. Sedimentation rates were determined to see if the isotopic ratio (^{239,240}Pu/^{137}Cs) were changing in the post-accident period. This would indicate that resuspension is a factor to consider.

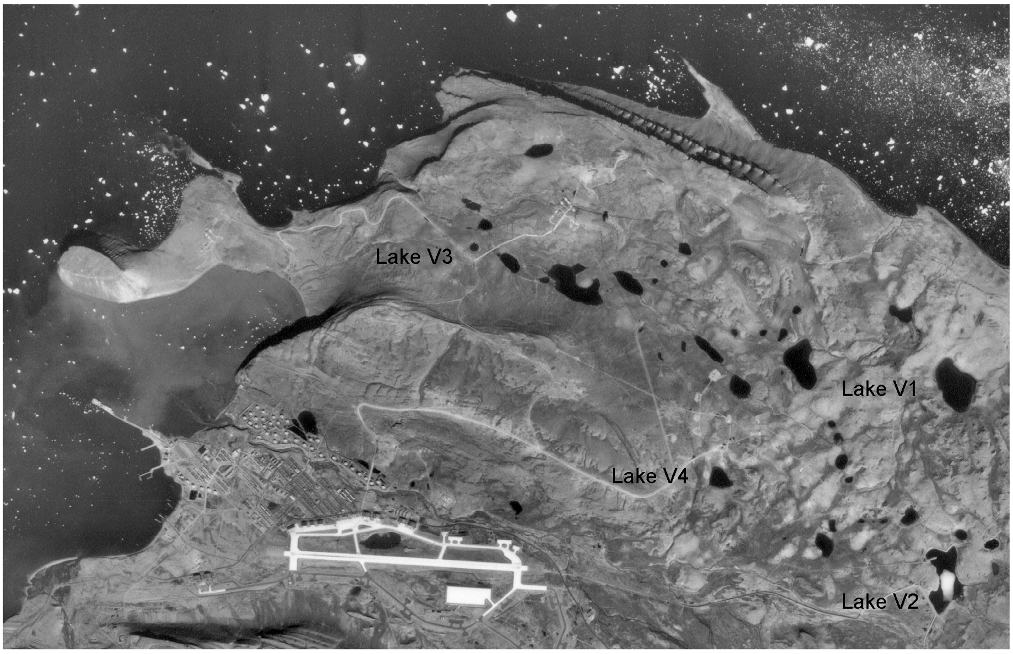


Figure 3.4. The Thule Air base region. The studied lakes have their label to the left of them. The impact point is about 30 km west of V2. The distance between V2 and V3 is 11 km. © Kort & Matrikelstyrelsen (A. 23-99)

In Figure 3.5 it can be seen that the lakes have quite different limnological features such as sedimentation rate. In the lake V1 we have the highest sedimentation rate and this is also the lake with the largest catchment area. There is no indication of plutonium from the accident in any of the lakes.

However only the ^{239,240}Pu/^{137}Cs ratio is used, and further isotopic ratios are needed to confirm this conclusion.

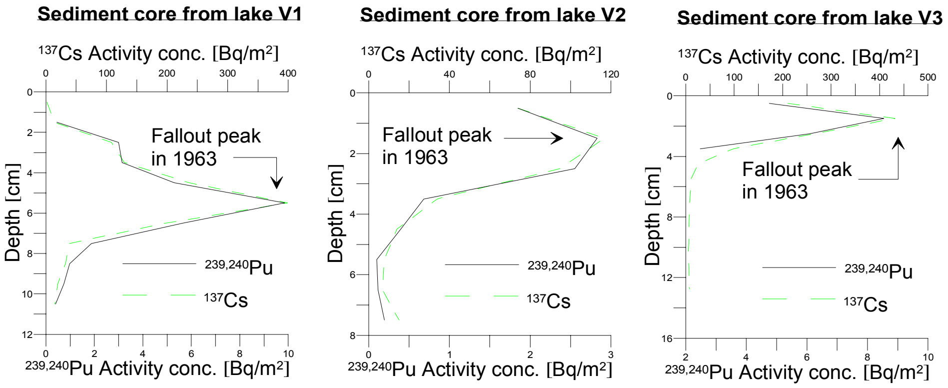


Figure 3.5. Activity concentration profiles in lake sediment from the Thule area.

References:

1. USAF Nuclear Safety, Project Crested Ice, AFRP 122-1 Jan/Feb/Mar 1970, No.1 **Vol 65**(1970)
2. W. C. Hansen, Transuranic elements in the Environment, Editor W. C. Hansen **A 441** (1980)

3.3 Radioecologial models

The radiological exposure of man from radioactivity in the Baltic Sea

In 1996 the European Commission (EC) initiated the Marina Balt Project to examine the overall impact on the population of the Community Member States from natural and man-made radionuclides in the Baltic Sea. The project group included participants from all countries bordering the Baltic Sea and the Netherlands and the work has covered the following items:

- collection of information on input of radioactive materials into the Baltic Sea,
- collection of data on environmental radioactivity in marine waters, sediments and biota,
- collection of data on quantities, distribution and utilisation of marine products,
- calculation of doses to man from nuclear discharges, weapons test fallout, Chernobyl fallout and natural radioactivity.

Sources of radioactivity

Input of radioactivity into the Baltic Sea has been considered for the time period 1950-1996 covering nuclear weapons fallout, Chernobyl fallout, discharges to sea from the European reprocessing facilities Sellafield and La Hague, discharges to sea from nuclear installations around the Baltic Sea, and dumping of low-level radioactive waste. Information on annual fallout of ^{137}Cs and ^{90}Sr from the atmospheric nuclear tests over the Baltic Sea was based on data from Risø, Denmark, and St. Petersburg, Russia. The direct input of ^{137}Cs from the Chernobyl accident in 1986 into the Baltic Sea has been estimated to 4.7 PBq. The amount and distribution of Chernobyl radiocaesium in the regions of the Baltic Sea is based on information given by HELCOM. Reported releases to sea of radioactivity from the European reprocessing facilities Sellafield and La Hague have been considered involving ^{90}Sr and ^{137}Cs for both facilities and 14 additional radionuclides from Sellafield. The transfer to the Baltic Sea was estimated from model calculations, which indicate that only a few percent of these discharges reach the Baltic Sea. Data on radionuclides released to sea from nuclear facilities in the Baltic Sea area are based on information from HELCOM and additional data obtained during the project. The facilities include 9 nuclear power plants and 3 nuclear research centres and the data base contains about 5200 annual discharge data for 62 radionuclides representing a comprehensive compilation of past discharges of radionuclides into the Baltic Sea.

Environmental data

The Baltic Sea has been monitored for man-made radioactivity since the beginning of the 1960's. The Marina Balt Project has had access to the HELCOM/MORS database, which contains environmental data on radioactivity in the Baltic Sea collected since 1984. These data have been supplemented with other data available to cover the time period 1961-1995 in particular on ^{137}Cs and ^{90}Sr in seawater, biota and sediments. For these two radionuclides the total number of seawater data is about 11,000 and for biota about 2,000.

Human habits and fishery statistics

Information on human habits was collected for estimating radiation doses to individuals and populations. For critical groups the habits were assumed to be applicable on a regional basis based on an annual individual ingestion of 90 kg fish, 10 kg crustaceans and 10 kg molluscs and beach occupancy of 700 h involving external exposure and inhalation of seaspray and resuspended sediment particles. For populations, data were collected on national catches and landings of marine products from the Baltic Sea. Data on import and export of marine products of EU Member States and other Baltic States were obtained from EUROSTAT and FAO fishery statistics. Based on this information and some simplifying assumptions, the amounts of marine products from the Baltic Sea available for human consumption in the EU Member States and the other Baltic States were derived. Collective beach occupancies were determined for each country based on occupancy factors and lengths of coastlines on the Baltic Sea.

Environmental modelling

A computer model was used to simulate the dispersion of radionuclides in the marine environment, the transfer of radionuclides to biota, and the calculation of doses to individuals and populations. The dispersion model is based on box-model analysis and includes 12 water and 12 sediment boxes for the Baltic Sea area. The physical processes covered by the model are net advection and mixing of water between adjacent boxes, sedimentation of particulate material from the water column to the top sediment, and biological mixing of the top sediment. The model is intended for the prediction of annual average concentrations of radionuclides in the marine environment. The reliability of the model predictions was investigated by comparing predicted annual average levels of ^{137}Cs and ^{90}Sr with observed levels. The comparison indicates that the model in general tends to overpredict annual average concentrations of ^{137}Cs and ^{90}Sr in Baltic seawater by about 20% and that two thirds of the predicted concentrations range within a factor 2 of the observed concentrations.

Doses to man

Dose rates to individuals in the critical groups were calculated for each of the regions in the Baltic Sea. The dose rates were calculated for the source terms: Chernobyl fallout, nuclear weapons fallout, nuclear reprocessing facilities, nuclear power plants, nuclear research facilities, and for comparison the estimated upper bounds of the contribution from the dumpings in the 1960's were also included. Figure 3.6 shows the predicted annual dose rates to the critical group in the West Baltic region. The contribution from nuclear weapons fallout has affected all regions in a similar manner with an annual dose rate that peaked at about 0.01 mSv y^{-1} around 1965 and then declined. The contribution from European reprocessing was highest close to the North Sea where the peak annual dose in the Kattegat region around 1980 was predicted at about 0.02 mSv y^{-1}. This contribution from reprocessing was reduced further into the Baltic Sea with predicted peak annual doses around 1990 at 0.4 μSv y^{-1} in the Bothnian Bay and 0.05 μSv y^{-1} in the Gulf of Finland. The fallout from the Chernobyl accident in 1986 has dominated the annual doses to critical groups in every region of the Baltic Sea. The maximum annual doses range from 0.2 mSv y^{-1} in the Bothnian Sea and the Gulf of Finland to 0.04 mSv y^{-1} in the Gulf of Riga and the Kattegat.

Figure 3.6. Predicted annual doses (Sv y^{-1}) to individuals of critical groups in the West Baltic area shown by source category.

3.4 Radioanalytical chemistry

The development and use of sensitive and accurate analytical methods for research and quality assurance purposes are the most important tasks of the programme in radioanalytical chemistry.

The analysis of biological materials as a contribution to the certification of European reference materials by BCR, has been a main part of our research in 1998. Thus, the elements Cl, Br, As, Cd, Cr and Hg were determined by INAA (instrumental neutron activation analysis) as an intercomparison of a polymer reference material for SM&T in co-operation with DSM Research in Holland.

Furthermore, in co-operation with Mermayde, Holland, the following elements were determined in CRM 668, Mussel Tissue: Sc, Ce, Sm, Eu, Th, Zn, Cr and As, in CRM 669, Tuna Muscle: Zn and As, in CRM 670, Aquatic Plant: Sc, La, Ce, Sm, Eu, Tb, Yb, Th, Zn, As and Cr using INAA.

5 trace element determinations, using INAA, have been performed as quality control of the production of pharmaceuticals in co-operation with Dumex-Alpharma A/S, Copenhagen.

INAA has also been used for the control of occupational exposure for platinum at a public school and at a car repair shop. In both cases no platinum could be detected.

The co-operation with the John F. Kennedy Institute has continued with the determination of Cu in 8 chorionic villi and placenta samples by RNAA (radiochemical neutron activation analysis) for the diagnosis and verification of Menkes disease. For the verification of Wilson disease, Cu was determined in liver samples of 3 patients from 3 different hospitals, using RNAA.

The results of Pt-determinations in the air of Copenhagen city have been presented as a poster at the 6th FECS Conference on Chemistry and the Environment, held the 26-28th August in Copenhagen.

Determination of ^{129}I in environmental samples by neutron activation analysis

A neutron activation analysis method was developed for the determination of ^{129}I content and ^{129}I/^{127}I ratio in some environmental samples, such as seawater, seaweed, grass, and thyroid tissue. Firstly, different pre-concentration methods for iodine from various matrixes were set up; separated iodine was then sealed in quartz ampoules as LiI or MgI_2 for neutron irradiation; after decay of about 10 h, a post-irradiation purification was carried out by using CCl_4 extraction method. Finally, iodine was precipitated as PdI_2 for measurement of ^{129}I and ^{127}I via counting ^{130}I and ^{126}I. The recoveries of iodine reach 60~95% and more than 95% in pre-concentration and post-irradiation purification procedures, respectively. The detection limit of this method for ^{129}I reaches $2\sim3\times10^{-13}$ g (or $1\sim2\times10^{-6}$ Bq). A sample with a ^{129}I/^{127}I ratio as low as 10^{-10} can be analyzed.

Some grass samples collected from Risø and Valby, seawater from Roskilde Fjord, seaweeds from Iceland, Utsira and Klint, have been analyzed for ^{129}I concentration and ^{129}I/^{127}I ratio. Figure 3.7 shows the variation of ^{129}I/^{127}I ratio in seaweed (Fucus ves.) collected at Klint from 1986 to 1992.

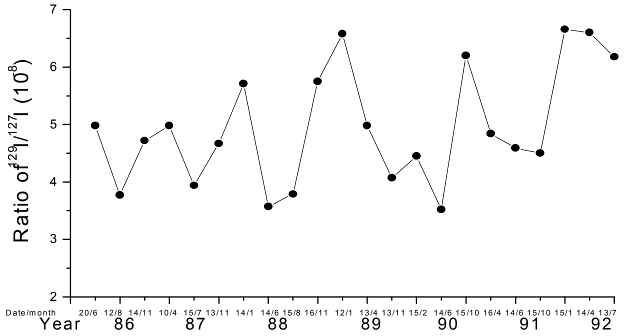


Figure 3.7. The variation of $^{129}I/^{127}I$ *ratio in Fucus ves. collected from Klint, Denmark.*

Radiochemical neutron activation analysis of seawater for the chemical species of iodine

A method of radiochemical neutron activation analysis combined with ion exchange pre-separation was developed for the determination of total iodine and various chemical species of iodine in seawater. Iodide was separated from other iodine species and other ions by directly passing filtered natural seawater through an anion-exchange column (AG1×4, Cl form), after removal of Br^-, Cl^-, IO_3^- and other ions by washing with de-ionised water and 0.5 mol/l KNO_3 solution, eluted with 2.0 mol/l KNO_3. Organic iodine was separated by passing seawater through the ion-exchange column after iodate has been converted to iodide by $KHSO_3$ and collecting effluent during loading and washing with de-ionised water. The contents of total iodine, iodide and organic iodine were determined by counting 443 keV γ-ray of ^{128}I after neutron activation followed by an purification process using CCl_4 extraction. The content of iodate was calculated by the difference between total iodine and iodide and organic iodine. The effect of chlorine, bromine and iodine concentrations on the recovery of iodine in the extraction separation procedure was also studied. Under the experimental condition, a detection limit of 0.2 µg/l seawater (or 0.2 ng) for iodine was obtained. The concentrations of total iodine, I^-, IO_3^- and organic iodine in seawater collected from Roskilde Fjord, Denmark, were determined.

3.5 Ecophysiology

Gill lipid metabolism and ^{24}Na uptake in the European eel (*Anguilla anguilla)* after transfer to dilute media: further evidence of membrane lipid modification as an endogenous regulator.

Is the synthesis of phosphatidylethanolamine (PE) used by fish gill cells *in viv*o to regulate the function of ion transport proteins? Eel gill lipids were labelled with (^{32}P) phosphate and (^{14}C) acetate as precursors - added to the water in the incubation tank - and assayed by thinlayer chromatography. Salt transport was assayed in the same fish by the uptake of ambient $^{24}Na^+$ into blood plasma. All fish fully adapted to their ambient medium, be it to sea water (SW), brackish water (BW) or freshwater (FW), showed about 50% ^{32}P-activity in PE. Shortly after transfer either from SW or BW to FW, or from FW to demineralized water (SFW), this percentage went down to about 15 (^{32}P)PE%. During the following week in the more dilute media (FW or SFW) there was a gradual return to the original gill lipid incorporation pattern with 50(^{32}P)PE%. No such change was seen regarding (^{14}C)PE% which remained constant throughout at about 15%. Instead, there was a corresponding temporarily enhanced relative incorporation of (^{14}C) acetate into gill wax alcohols. Correlating total incorporation into gill lipids with plasma ^{24}Na, we could furthermore show a positive linear regression during the first week after transfer to dilute media. We conclude that shortly after transfer to dilute media the eel seeks to reduce ion loss apparently by closing apical channels and secreting wax alcohols. The observed change in the (^{32}P) phosphate incorporation pattern may reflect a closing and gradual reopening of gill apical channels.

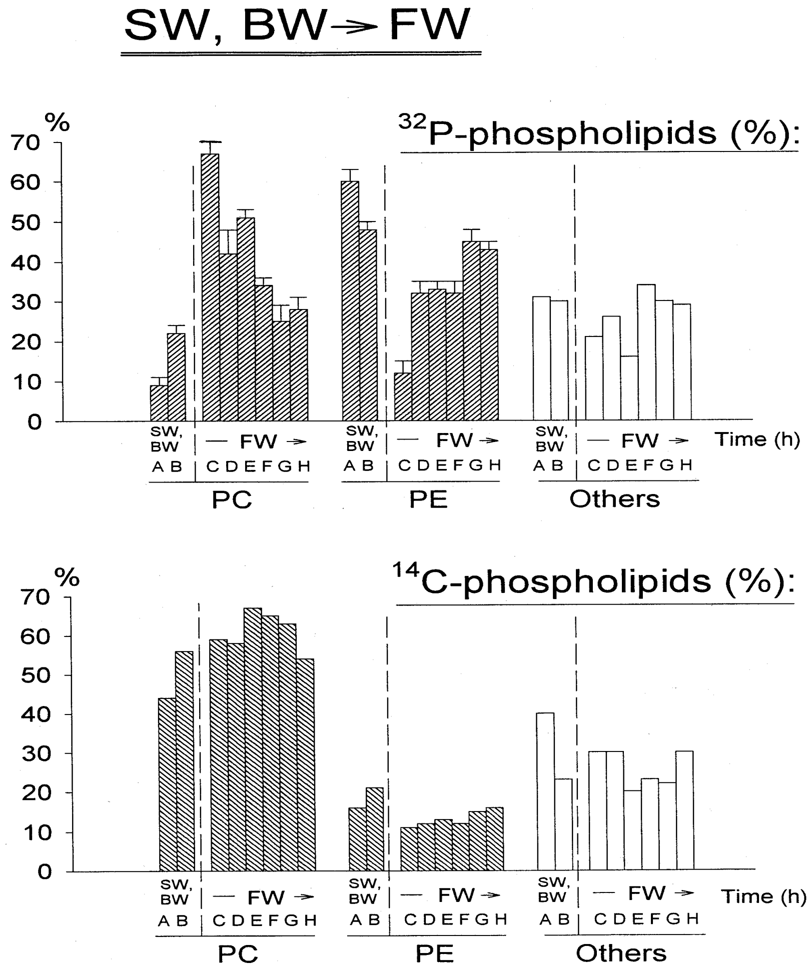


Figure 3.8. Distribution patterns (%) of ${}^{32}P$ - and ${}^{14}C$-activities among various gill phospholipids, after incorporation into eels in vivo *in SW, BW or FW at 19°C of both (${}^{32}P$) phosphate and (1- ${}^{14}C$) acetate, added to the water in the incubation tanks. Eels were adapted to either SW or BW > 1000 h and then transferred to FW. Results were not significantly different in SW and BW adapted animals and are thus pooled throughout. Eels were incubated during the following periods: A=3 h in SW or BW; B=24 h in SW or BW; and then, after transfer to FW, C=0-5 h in FW; D=0-24 h in FW; E=24-48 h in FW; F=72-96 h in FW; G=167-192 h in FW; H=503-528 h in FW.*

A nose to nose comparison of the physiological effects of exposure to ionic silver and silver chloride in the European eel (*Anguilla anguilla)* and the rainbow trout (*Oncorhynchus mykiss)*.

Mechanisms of silver toxicity to the sensitive trout (*Oncorhynchus mykiss)* (96h LC50: 10 µg silver l^{-1}) and the more tolerant European eel (*Anguilla anguilla)* (96h LC50: 34 µg silver l^{-1}) were investigated during acute exposure to silver, both as ionic silver and silver chloride, using concentrations ranging from 0 to 22 µg silver l^{-1}. $^{36}Cl^-$ and $^{24}Na^+$ were used as tracers to assay ionic influx. Inhibition of the branchial Na/K-ATPhase enzyme activity and active uptake of Na^+, leading to net Na^+ loss and reduced plasma osmolarity, were the target of silver toxicity in both species. In the rainbow trout, but not in the European eel, Cl^- influx was also impaired during silver exposure. Differences in whole body Na^+ turnover rates between the two species (1.1% per day in the European eel and 26% per day in the rainbow trout), together with the lack of effect of silver exposure on Cl^- homeostasis only in the European eel, are hypothesized to be the main reasons for the different silver tolerances observed in the two species. Water Cl^- clearly protected against the silver induced physiological disturbance in rainbow trout, presumably by changing the speciation of silver from ionic silver to AgCl complexes. Such a protective effect was, however, not observed in the European eel.

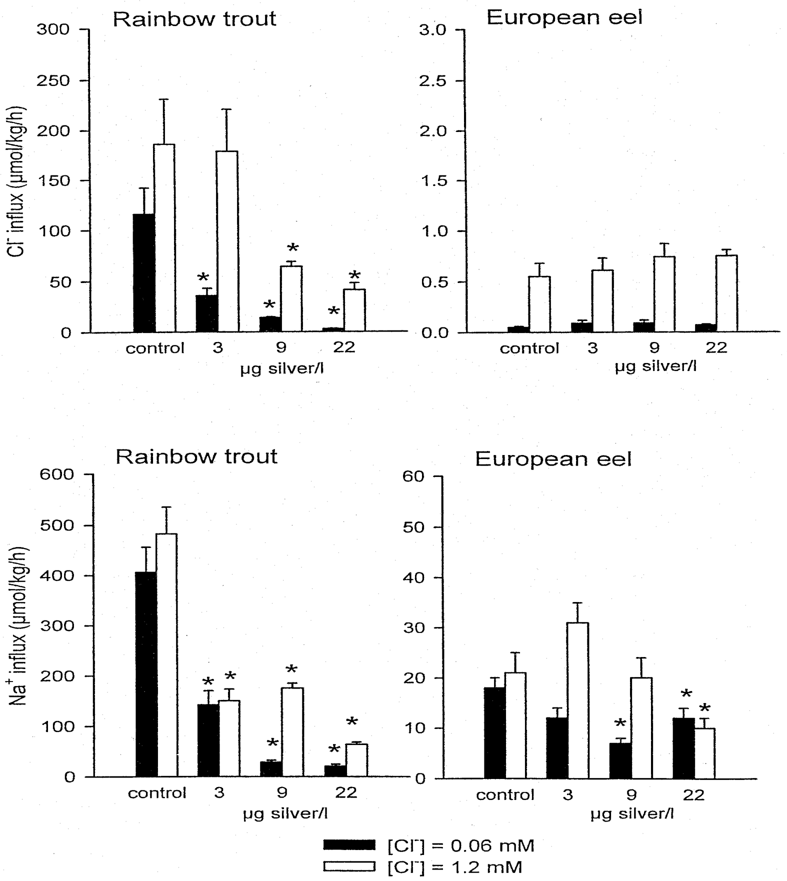


*Figure 3.9. ^{36}Cl and ^{24}Na influx ($\mu M\ kg^{-1}\ h^{-1}$) in rainbow trout and European eels exposed to a range of silver concentrations at two different ambient Cl^- concentrations for a total of 12 and 38 hours, respectively. Mean ±SEM (n=8). *indicates statistically significant differences from controls, t-test, $P<0.05$. Note the different scales on the Y-axis.*

3.6 Radioactive waste

Experimental work and modelling concerned with long-term properties of radioactive waste or barriers in disposal systems maintain the professional standard and the international relations considered important also for the practical waste management, see Section 4.4. Such studies have been conducted by staff at the Waste Management Plant through many years. In the previous 3 years the studies belonged to the Radiation Protection Programme, but from 1998 they were transferred to the Radioecology Programme.

A considerable part of the work is carried out within the EU Fission Research Programme or the Nordic co-operative programme NKS. However, due to obligations connected with practical waste management, the research efforts had to be diminished in 1998. Further work on bituminized waste had to be postponed.

Cemented waste and concrete barriers

Studies of pore systems, leaching behaviour and influence of various types of defects on transport behaviour in cemented waste or concrete barriers have been performed under various EU contracts. The main effort during the second year of the present EU contract has been some 7 months experiments with permeation of de-ionised water through specimens cast from a special type of highly porous material developed by Nirex, UK, and intended as backfill in voids between waste units in a repository. The study supplement experiments with two other types of cementitious backfill materials carried out in 1997. Information which may be used in a comparison of the three types of materials are available. This includes effects of thin cracks and identification of some conditions which may result in such cracks. Additional studies using other feed solutions will be performed during the last year of the contract.

The pseudo 2-dimensional CRACK2 model of transport and filling with calcite of cracks in concrete has been further generalised in various manners. It describes the pore system and the macro-chemistry, including correction for diffusion potential of simultaneous migrating ionic species, together with the behaviour of one or two radioisotopes present in the concrete or entering with calcium bicarbonate containing solution. Solving the diffusion equations for transport through pores in the thin calcite layers with porosity decreasing due to precipitation gives rise to numerical stability problems and requires long calculation times. A simulation of a cut through the cracked cement after 8 days exposure to calcium bicarbonate solution is shown in Figure 3.10. This and other results are in reasonable agreement with experimental observations.

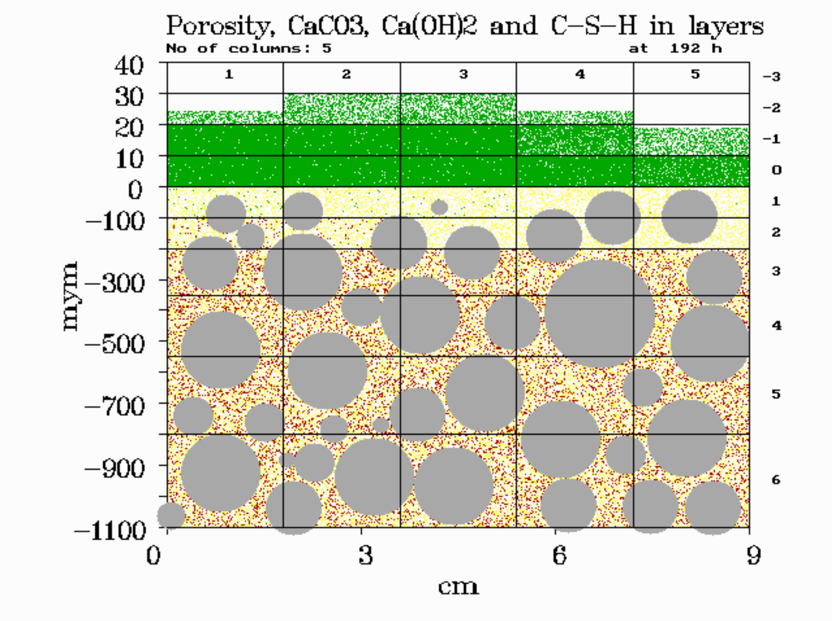


Figure 3.10. Cut through a cement mortar specimen with crack surface covered by calcite as simulated by the CRACK2 model. In the mortar the gray dots represent sand grains, dark points $Ca(OH)_2$ crystals while light grey are C-S-H and pores are white. The 10 µm grid cells in the crack are drawn to a larger scale. Calcite is dark grey with minimum 2% white pores.

Radioactivity in Risø waste products

Methods for determination of activity inventories in waste products are important for waste acceptance and future safe disposal. A lot of small samples of old evaporator concentrates have been measured by γ-spectroscopy in view of comparison with results from external γ-scanning of whole drums containing the corresponding concentrates.

Much effort has gone into determination and reporting of low activity levels in materials and components which might be declassified in connection with ongoing decommissioning efforts, see Section 4.4. Documentation methods in this contexts are seen as important fields for future development.

Contributions to the NKS programme

The final report from the previous NKS-AFA programme about radioactive waste was issued in 1998. Staff from the Waste Management Plant contributed to the set up of the pre-programme for the waste related part of the next NKS programme. Aspects of Environmental Impact Statements as employed in Scandinavia were discussed in connection with a visit to the new Norwegian disposal facility in Himdalen.

4 Nuclear facilities and services

4.1 Research reactor DR 3

DR 3 is a heavy-water moderated and cooled nuclear research reactor, which has been in operation since 1960. It was originally built as a material testing reactor, but today it is used as a multipurpose research reactor. The operation cycle is 4 weeks, of which 23½ days is continuous operation and 4½ days is shut down. The vertical experimental facilities comprise 13 tubes in the core, 50 mm diameter, and 14 tubes in the D_2O and graphite reflectors with sizes ranging from 10 to 18 cm in diameter. Four tubes, 18 cm diameter, pass horizontally and tangentially to the core. These facilities were intended for loop experiments, but turned out to be excellent beam ports. Two beam ports are supplied with thermal neutrons from a water scatterer; two others are supplied with cold neutrons from a 38K cold hydrogen neutron source.

Six three-axis spectrometers and a Small Angle Neutron Scatterer (SANS) instrument are supplied by the neutron beams from the four beam ports belonging to the tangential 18cm diameter tubes. One of the cold source beam ports is connected to a building outside the reactor hall, by means of a neutron guide tube. The monochromatic cold neutron flux at the sample position is: $7 \cdot 10^6$n cm^{-2}s^{-1} (E_n = 5 meV). Two of the three-axis spectrometers are multipurpose instruments with a high degree of flexibility, facilitated by five different detector arms which can be attached or detached in less than one hour.

Neutron scattering is an important technique for the study of large molecules such as polymers and biological molecules and for the study of superconductivity and magnetism in high-temperature super-conductors. These are examples of recent applications of the beam facilities of DR 3. DR 3 is appointed as a European Large-Scale Facility and the neutron beam instruments are intensively utilized by researchers from Risø and from other EU-countries.

Neutrons from DR 3 are also used for activation analysis, isotope production and transmutation doping of silicon. These activities are described in sections 3.4, 4.2 and 4.3.

The reactor was kept in operation at 10 MW for 7097 hours, corresponding to 81% of the year. The reactor was kept in operation according to the plan, but with difficulties. Six of the operations staff left with short notice. New personnel have been engaged, but training of new members takes from three to six months. The remaining staff has worked overtime for a longer period.

4.2 NTD silicon

Neutron Transmutation Doping of silicon takes place in seven irradiation facilities in the reactor DR 3. Three facilities are placed in the heavy water in vertical positions, and two facilities are placed in the horizontal position in the heavy water.

The test phase of the new horizontal 5” facility is completed, and commercial irradiations are now carried out with good results. The axial variations are small. The modern instrumentation and the Windows based software is working faster and more reliable, and a project for changing the control system of the oldest horizontal facility has started.

New instrumentation with built-in checking of the system has reduced irradiation errors in the vertical facilities.

The Danish Standard Association approved the quality management system at its annual audit, and renewed the ISO 9002 certificate.

The production of NTD-silicon has decreased in 1998 due to the recession in Asia.

4.3 Isotope Laboratory

From the beginning of 1998 the Isotope Laboratory was abolished as an organizational unit. The programme Radioanalytic Chemistry became incorporated in the programme Radioecology and Tracer Studies. In December the task unit NTD silicon was moved to the DR3 building. The staff at the nuclear facility, The Isotope Laboratory, now only includes the Basic Irradiation Service and some from the Radioecology and Tracer Studies programme.

Basic Irradiation Service

This section continues to fulfil our commitment to cover all needs for neutron-irradiated materials for technical and scientific purposes in Denmark. The Isotope Laboratory is responsible for the production of radioactive isotopes and other radioactive materials for industry, hospitals, and research institutions. An increasing part of the deliveries to domestic as well as foreign customers is unprocessed irradiations from dedicated reactor irradiation facilities. All radioactive materials needed for Risø's own research are delivered as ready-to-use preparations.

A total of 1087 irradiations were carried out for use by Risø and 28 different external customers in Denmark, Sweden, Finland, Germany, Switzerland, Italy, and the U.K. The number of dispatched $NH_4{}^{82}Br$ is still increasing and was almost 10 % higher than in 1997. Altogether 96 shipments of other radioactive products were sent to a variety of institutes, industry and hospitals.

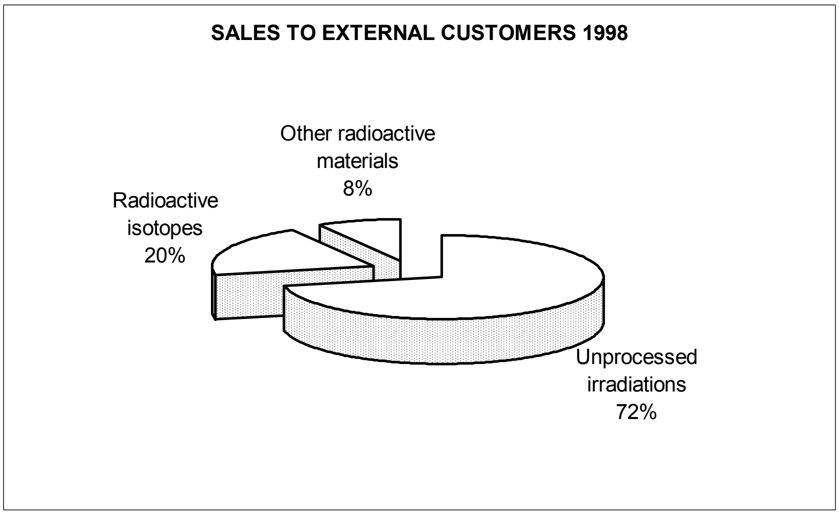


Figure 4.1. The figure shows the size in the turn-over for the three groups of radioactive material.

In January a contract for the transport of the radioactive materials produced was awarded to a forwarding agent with a section specialized in transport of radioactive material.

For research applications at Risø, 75 irradiations were performed and 88 deliveries of radioisotopes in specially prepared forms were made. For educational purposes 210 solid radioactive sources were supplied to the Nordic countries.

4.4 Waste Management Plant

The Waste Management Plant takes care of radioactive and chemically toxic waste from the laboratories and nuclear facilities at Risø. Waste from other Danish users of radioactive materials is also received and stored at Risø. Purification of ordinary sewage water and laundry and decontamination facilities are other obligations. The staff takes part in international work, notably within EU, and in research activities as described in Section 3.6.

Radioactive waste

Low-level liquid waste from the facilities at Risø is purified by distillation as described in more detail in the annual report 1997. After control for β-activity the distillate is released to Roskilde fiord via the ordinary sewage purification system. The total gross-β release in 1998 was 77 MBq corresponding to 1 % of the permitted activity. A considerable part is ^{40}K in the sewage with minor contributions of other isotopes from the 1180 m^3 distillate and other sources. In addition about 4200 GBq tritium was released with water and 11 GBq ^{14}C as carbon dioxide and 1.8 MBq gross-β as particulates with the off-gas from the plants. The last figure is somewhat higher than usual.

The concentrate from the process was evaporated to dryness in the small bituminization plant in operation since 1970. About 1.4 m^3 bituminized product was produced distributed on 16 drums of the Risø standard type, i.e. a 100 L steel drum positioned inside a 220 L drum with the annulus filled with cement mortar. The content of β-activity stored in this form was only about 0.9 GBq.

By agreement with the Danish Institute for Radiation Hygiene radioactive waste from other Danish users of radioisotopes must also be stored in the facilities at Risø. This service is provided on a commercial basis. On the island of Zealand the Waste Management Plant is running an external waste collection service.

About 3.2 t out of the total 6.0 t of low-level solid waste was of external origin. This waste contained about 237 GBq radioisotopes with half-life longer than 1 year, mostly in form of sealed sources. 63 drums were filled with solid waste in 1998.

The total number of drums transferred to the Risø Storage Hall for low-level waste was 80 including 8 which had been stored temporarily for decay in a shielded facility at the Waste Management Plant. The storage hall presently contains 4506 drums and has a remaining capacity sufficient for about 10-15 years. Equipment ensuring a reasonably low atmospheric humidity in the hall was installed.

The concrete silos remaining at the previous – now empty - storage area for low-level waste 'Betonrørslageret' were taken apart, control measurements for contamination were performed, and the concrete rings etc. transferred to an open area west of the Waste Management Plant where they were crushed using hired equipment.

The work was performed according to permissions from the nuclear authorities. The crushed concrete – with mean contamination considerably lower than natural activity in concrete – was declassified and permitted for use as inactive fill material provided this takes place inside the Risø area.

A report is underway describing the drum transfer and improved storage project. The general experience will be presented at the ENS-Topseal conference in October 1999.

Some uranium - mainly in form of yellow cake from the old uranium extraction pilot plants - and a special lead shielded drum with 8 large cobalt sources were transferred to 'Centralvejslageret', the storage facility intended for waste with high radiation level or a content of fissile material. The remaining capacity is slight but construction funds for a minor extension will be made available in 1999.

The storage facilities at Risø are only for temporary use, and so far no planning for actual disposal has been carried out. Relevant information about the waste and possible disposal concepts are collected in connection with research carried out at the Waste Management Plant and by following international developments.

Inactive systems

The new sewage purification plant with nitrogen removal has now been in operation in 2½ years. After some initial problems the system has operated quite satisfactorily in 1998 where the plant treated 52200 m^3. The mean concentrations in the effluent was 5.3 mg (total) N/L and 1.9 mg P/L where the permissible weighed mean concentration is 6 mg N/L. Expressed in another way: prevention of the release of about 1.0 out of 1.3 t nitrogen, 0.12 out of 0.22 t phosphorus and 6.6 t out of 6.8 t BOD (organic components expressed as biological oxygen demand).

The other services of the Waste Management Plant (collection of chemical waste and transfer for treatment at Kommunekemi, decontamination of protective clothing and the ordinary laundry facilities) were operated as previously.

Figure 4.2.Crushing of concrete rings from the obsolete low-level storage facility 'Betonrørslageret'

5 Other tasks

5.1 Applied health physics

The major task for the Section of Applied Health Physics is radiation protection of Risø employees, including radiation hygiene surveillance, professional advice and teaching in radiation protection for staff members at the nuclear facilities. In order to improve and extend its professional qualifications the section performs research within the fields of internal dosimetry, radiation transport, radiation risks, protection philosophy and optimisation of interventions. Highlights of the work performed within the section are shown in the following.

Radiation levels in the working environment at DR 3

In addition to the standard monitoring programmes a project has been initiated with the purpose of getting more details of the size and variation of the dose rates at the DR 3 reactor and at the adjacent Neutron-house. The project also aims at locating the radiation sources and to quantify their contributions to the dose rate at places where the physicists and the reactor personnel are working. In 1998 the project included: (a) mapping of the average dose rate for 3 month periods at some 100 places, (b) continuous measurements of the dose rate during some weeks at a few places and (c) spot measurements around the spectrometers while changing the spectrometer settings. No surprisingly high dose rate levels have been observed.

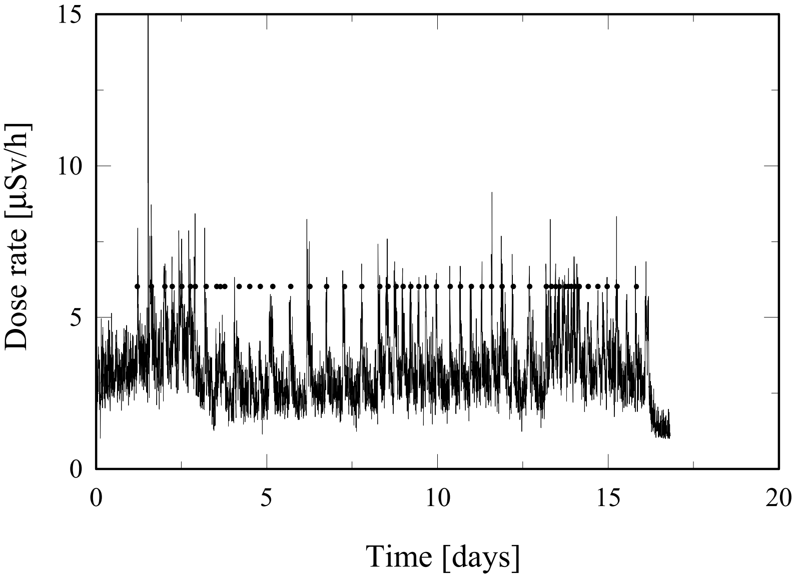
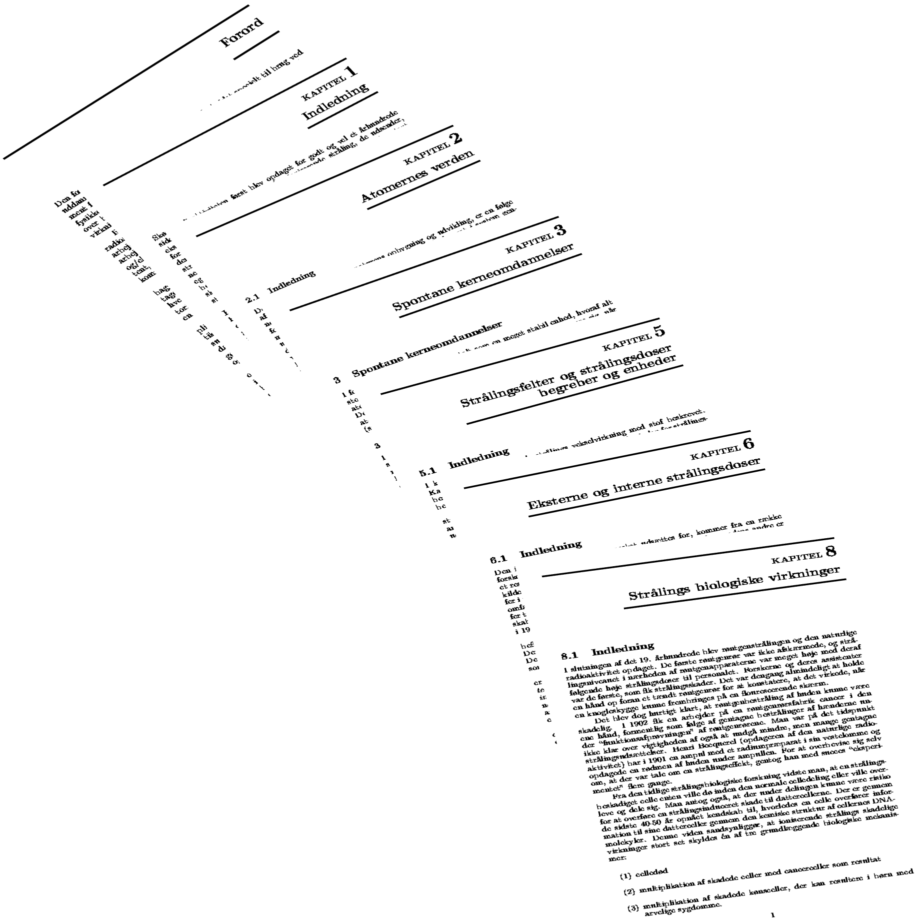


Figure 5.1. Dose rate as a function of time at a control desk for a spectrometer in the reactor hall. The times of pile in of Si-crystals in the 7V1 system are shown (•). The peaks in the spectrum correlate well with the pile in of Si-crystals. Although there are many peaks in the spectrum their contribution to the average dose rate is only 10 %.

From the measurements it might be concluded, that the main part of the doses to the physicists arise from radiation from the spectrometers. The project will continue in 1999. **Figure 5.1** shows the results from one of the continuous measurements.

Textbook on radiation protection

A major part of the Danish text book *General Health Physics* (title in Danish: *Almen Helsefysik*), has been finalised in 1998. The book is being prepared for the education of radiation protection technicians at Risø and it contains a broad and aggregate presentation of the many disciplines of health physics.



Forord

KAPITEL 1
Indledning

KAPITEL 2
Atomernes verden

KAPITEL 3
Spontane kerneomdannelser

KAPITEL 5
Strålingsfelter og strålingsdoser begreber og enheder

KAPITEL 6
Eksterne og interne strålingsdoser

KAPITEL 8
Strålings biologiske virkninger

8.1 Indledning

The book can also partly be used at high schools and universities. The chapters that have been finalised in 1998 are shown above.

Whole body counter measurements

In 1995 the Human Monitoring Laboratory (HML), which is Canada's National Calibration Reference Centre for In-Vivo Monitoring, proposed to conduct an International inter-comparison/inter-calibration programme for whole body counting facilities.

Forty-six laboratories world-wide participated in the programme. Each laboratory had five days to complete the measurements and send the phantom to the next laboratory. The whole programme would thus take about two years to complete. The phantom should have been returned to Canada at the end of August 1998, but due to inevitable delays it has still not been returned. The final report will not be published before all participants have completed their measurements and the report is therefore delayed until March 1999.

Batelle Pacific Northwest Laboratories prepared the phantom used in the programme. The phantom is a Reference Female (ICRP 23) BOMAB phantom, which is composed of ten elliptical plastic bottles. The bottles can be filled with a resin containing variable amount of radionuclides.

The phantom was filled with tissue equivalent material and an unknown (to the participants) activity, which was distributed homogeneously throughout the phantom.

Figure 5.2. The BOMAP phantom in the chair at Risø's whole body counter; the germanium detector is not in the measuring position

Four tasks had to be completed:

- ❑ identification of the unknown radionuclides in the phantom (the ^{40}K content could be disregarded)
- ❑ determination of the activity of the found radionuclides. The accuracy of the counting given by the bias for ^{137}Cs would the be calculated by HML
- ❑ determination of the minimum detectable activity (MDA) for all the detected radionuclides in the phantom
- ❑ precision of counting based on the ^{137}Cs measurements

The results from Risø National Laboratory are given in Table 5.1. The bias shown in the table is kindly supplied by HML.

Table 5.1. Results from the Risø whole body counter in the international inter-comparison/inter-calibration programme for whole body counting facilities.

Radionuclide	**Activity [Bq]**	**Bias**	**MDA [Bq]**	**Precision**	
				Based on gross count	Based on net count
^{137}Cs	$1.84 \cdot 10^4 \pm 2 \cdot 10^2$	– 5.86 %	95	1.06	1.66
^{60}Co	$1.96 \cdot 10^4 \pm 2 \cdot 10^2$	13.98 %	80	-	-

Common approach for restoration of contaminated areas (CARE)

A study entitled *Investigation of possible bases for a common approach with regard to the restoration of areas affected by lasting radiation exposure as a* *result of a past or old practice or work activity* (CARE) has been performed with funding from DG XI. This study include:

(a) an overview of sites in Europe for which restoration needs to be considered and identification to what extent the sites are not regarded as part of a controlled practice

(b) an overview of existing methodologies for assessment of exposures of the population and parameters relevant for the long-term environmental behaviour of the radioactive contamination

(c) an overview of current experience with remediation techniques and identification of different categories within restoration strategies, including a judgement of the effectiveness of each option together with their economic costs and social implications

(d) an overview of restoration criteria defined within specific restoration policies in the EU, in other countries and by international organisations (ICRP, IAEA) and examination on which basis restoration policies have been established

One type of contaminated sites in Europe is that of the phosphate industry. For a selected site of this type assessments have been made in the CARE study of the ranking of remediation strategies based on site-specific data on dose estimates, monetary costs and social costs. Operational criteria in terms of action levels above which remedial measures would be justified have been derived for a number of specified remedial measures for this site based on generic data. Action levels in terms of activity concentration are shown in **Figure 5.3** for the selected site.

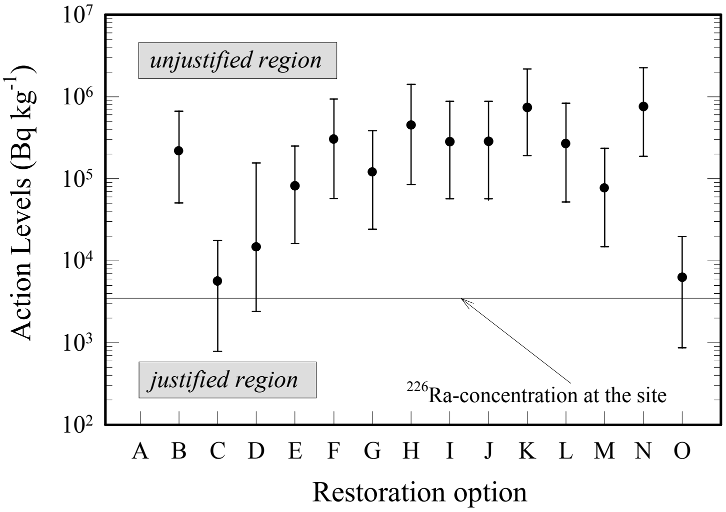


Figure 5.3. Calculated action levels for remediation options at a phosphate industrial site. Action levels above the actual radionuclide concentration represent unjustified remedial measures and action levels below the actual radionuclide concentration represent justified remedial measures.

An evaluation of the scores for fifteen different remediation options (A - O) has been made from a multi-attribute utility analysis. None of the options are justified from a pure economical point of view. The 'do nothing' option has a zero net benefit compared to the remedial options, which all have a negative net benefit. The 'do nothing' option often has a high score (sometimes the highest) in a multi-attribute optimisation in situations with low values of collective dose and high values of monetary costs as is the case for the sites considered here. The partners in the CARE study are the Research Centre SCK•CEN, Belgium (co-ordinator), Westlakes Scientific Consulting Ltd, England, and the Section of Applied Health Physics, Risø.

Restoration of contaminated land (RESTRAT)

Five European sites have been contaminated as a result of the operation of a practice at the site. These sites have been studied with regard to optimisation of clean up. Various remedial measures have been envisaged with respect to the optimisation of the protection of the populations being exposed to the radionuclides at the sites. The evaluation has been based upon optimisation of scores for the different remediation measures by the use of multi-attribute utility analyses. The attributes that have been considered in this study of the example sites have been structured as shown in Table 5.2.

Table 5.2. Attribute hierarchy for restoration of a contaminated site

Restoration strategy		
Health factors	Economic factors	Social factors
Radiation doses (population) Radiation doses (workers) Non-radiological exposures	Costs of waste disposal Costs of remedial measures Costs of monitoring Loss/gain of taxes due to loss/gain of income	Disturbance Reassurance Loss/gain of income

Evaluation of the scores for nine different options (A - G2) has been made and the results are shown in Figure 5.4 for the Molse Nete River site in Belgium, the banks of which have been contaminated with ^{60}Co, ^{137}Cs, ^{239}Pu and ^{241}Am as a result of discharges into the river.

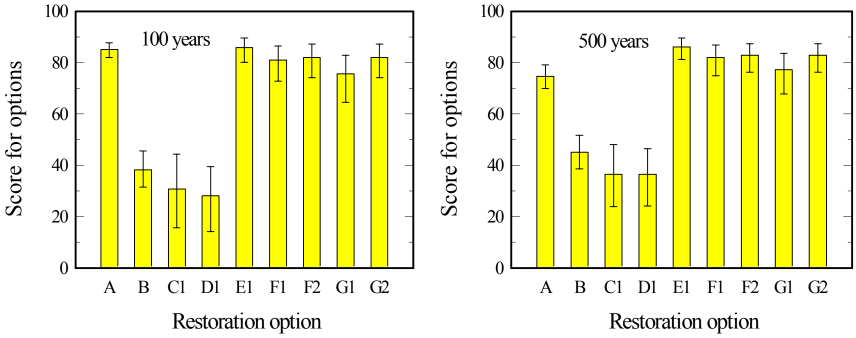


Figure 5.4. Overall evaluation of scores for different remediation strategies for the Molse Nete River site. The two pictures represent a time period of 100 and 500 years for the averted doses to the population from the different remedial measures A - G2.

None of the remedial measures considered for each of the contaminated sites are justified from a cost-benefit point of view. Multi-attribute analyses on the ranking of different remedial measures at each site nearly all give the result that 'no remediation' is the best option, *i.e.* having the highest score. The reason is the low collective doses and the potential for only low collective dose savings by remediation together with relatively high economical costs of the remedial measures, which results in low weighting factors for health and social factors. The partners in the RESTRAT study within the 4'th European Framework Programme are the Research Centre SCK•CEN, Belgium (co-ordinator), Westlakes Scientific Consulting Ltd, England, Studsvik Eco & Safety, Sweden, Forschung Zentrum Rossendorf, Germany, and the Section of Applied Health Physics, Risø.

NKS Project Emergency and Consequences (BOK-1)

Under the chairmanship of the Section Head of Applied Health Physics proposal for activities in the Nordic NKS project BOK-1, *Emergency and Consequences* (in Danish: ***B**eredskab **O**g **K**onsekvenser*) for the time period 1998 - 2001 has been prepared. The BOK-1 project deals with many aspects of measurement techniques and quality assurance relevant to an emergency preparedness programme, including β-measurements of ^{90}Sr and γ-spectroscopy. It also deals with modelling aspects and the interaction between measurements and model calculations as well as with the data that are necessary for decisions on the introduction of countermeasures to obtain an optimised dose reduction. The proposed content of BOK-1 is summarised below.

BOK-1.1	*Laboratory measurements and quality assurance*
BOK-1.2	*Mobile measurements and measurement strategies*
BOK-1.3	*Field measurements and data assimilation*
BOK-1.4	*Countermeasures in agriculture and forestry* (a) Agricultural countermeasures strategies (b) Data bases on dose reduction and waste treatment operations
BOK-1.5	*Emergency monitoring in the Nordic and Baltic Sea countries*
BOK-1.6	*Emergency exercises*

5.2 Personnel dosimetry

Risø's personnel dosimetry service covers the individual monitoring of the personnel at Risø and the Niels Bohr Institute Tandem Accelerator. Only persons actually involved in radiation work are equipped with a personal dosimeter. In areas where the use of personal dosimeters are not required, the radiation levels are controlled through an extensive area-monitoring programme using thermoluminescence (TL) dosimeters.

The main statistics of the dosimetry service for 1998 are shown in Table 5.3 and Figure 5.5

Table 5.3. Statistics for monitoring of Risø Personnel in 1998.

No. of persons monitored	734
No. of persons receiving external doses above 0.2 mSv (the registration level)	132
No. of persons receiving internal doses from intake of tritiated water	43
Total collective equivalent dose to the monitored personnel: External doses Internal doses Total	 155 mSv 4mSv 159 mSv

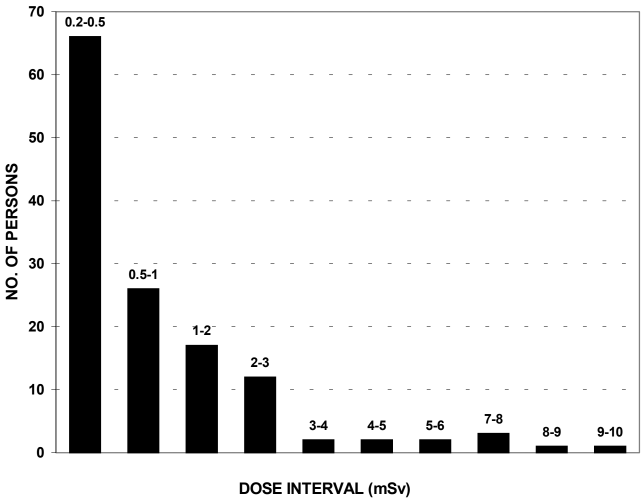


Figure 5.5. Distribution of whole-body doses (effective doses) in 1998.

5.3 Environmental monitoring

The department is responsible for the monitoring of radioactivity in the environment at Risø. The programme carried out for this purpose comprises regular monitoring of air, precipitation, sediments, seawater, grass, sea plants, milk and wastewater from the Waste Treatment Station. The samples are measured for γ-activity, tritium and gross β-activity. External γ-radiation is monitored at 25 stations around Risø.

The results are reported semi-annually in the Risø-I-Report series "Radioactivity in the Risø District". The results of the latest report from January-June 1998 show that the mean concentrations in air were 0.48 μBq m^{-3} of Cs-137, 3.1 mBq m^{-3} of Be-7 and 0.2 mBq m^{-3} of Pb-210. The average external background dose rate measured by TLD in the Risø area was 90 nSv h^{-1}. None of the measured levels were of any concern from a radiological protection point of view and the levels were similar to those observed in 1997.

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6.6 Internal reports

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Thomsen, K.L., Status report on development of a TMI-2 lower head coolability model. Risø-I-1359(EN) (1998) 20 p.

Ølgaard, P.L., Technical aspects of research reactor decommissioning experience from the DR-2. Risø-I-1255(EN) (1998) 14 p.

Ølgaard, P.L., The landmine scourge - what to do about it?. Risø-I-1348(EN) (1998) 7 p.

7 Education

7.1 Ph.D. theses

Metz, Hans Peter, 1998: Stability Analysis on Natural Circulation Boiling Water Reactors. Risø National Laboratory and Technical University of Denmark. Risø-R-1050 (EN) 139 p.

7.2 External teaching

The Section of Applied Health Physics has given lectures in radiation protection and emergency response for external personnel and at courses run by international organisations in different European countries. The following lectures on different health physics subjects have been presented in 1998:

- ☐ lecture for teachers in physics at the Royal Danish School of Educational Studies
- ☐ lecture for students at the Technical School of Roskilde
- ☐ lecture for personnel at the Royal Danish Air Force in Værløse
- ☐ lecture at a workshop in the Condensed Matter Physics and Chemistry Department at Risø
- ☐ lecture for personnel from the Civil Defense
- ☐ lecture for a group of educational consultants from the Danish industry
- ☐ four lectures at post-graduate courses within the EU-programme ERPET (**E**uropean **R**adiation **P**rotection **E**ducation and **T**raining) arranged by SCK•CEN in Mol, Belgium.

Reactor physics lectures at the Technical University of Denmark

The department runs a reactor physics lecture course for engineering students at the Technical University of Denmark at Lyngby.

The course comprises lectures on principles and design of nuclear reactors, interaction between neutrons and nuclei, neutron behaviour in nuclear reactors, criticality conditions for reactors, and determination of reactor physics parameters for thermal reactors and their variation with time.

The course is a prerequisite for the reactor physics lab course at the DR 1 reactor (see below).

Courses at the DR 1 reactor

The DR 1 reactor has been used almost exclusively for educational purposes. About 40 high school classes have carried out one-day or half-a-day experiments at the reactor. The total number of high school pupils visiting DR 1 in 1998 was about 600.

A number of students from the Technical University of Denmark have participated in the reactor physics lab course at DR 1. During this course they have carried out experiments at the reactor over a period of three weeks. Examples of the experiments performed are:

- Determination of the temperature, power, and bubble coefficients of the reactor
- Neutron activation analysis
- Measurements of neutron cross sections
- Neutron radiography
- Health physics experiments
- Core flux distribution

7.3 External examiners

Damkjær, A. Examiner in physics at the University of Copenhagen and at the Technical University of Denmark.

Fynbo, P.B. Examiner in physics at the University of Odense.

Højerup, C.F. Examiner in reactor physics at the Technical University of Denmark.

Jacobsen, U. Examiner in isotope techniques at the Technical University of Denmark.

7.4 Internal teaching

The Section of Applied Health Physics has given lectures and courses in radiation protection for Risø staff members. The following lectures on different health physics subjects have been presented in 1998:

Periodic internal courses

- ☐ five introduction courses for new Risø-employees
- ☐ one course in health physics for 13 Risø-staff members and 7 persons from private companies seeking authorisation to work with radioactive substances

Education of new staff members

- ☐ four specialised courses for new staff members at the nuclear installations at Risø

8 Committee memberships

8.1 National

The advisory committee on protection measures in the case of accidents in nuclear facilities (§ 9 stk 2)
C.F. Højerup and B. Majborn
(E. Nonbøl and P. Hedemann Jensen, substitutes)

The coordination committee of the Emergency Management Agency and Risø National Laboratory
A. Damkjær and B. Majborn

The coordination committee for nuclear safety in Central and Eastern Europe (Ministry of Foreign Affairs)
B. Majborn

The advisory coordination committee for research in environmental medicine (Ministry of Health)
B. Majborn

The Board of the Danish Nuclear Society
B. Majborn and M. Bagger Hansen

Danish National Council for Oceanology
A. Aarkrog

The Academy of the Technical Sciences
K. Heydorn

The DK-BCR committee
K. Heydorn

The Contact Committee for Chemometry. The Society of Danish Engineers
K. Heydorn

8.2 International

European Union

Consultative Committee for the Specific Programme on Nuclear Fission Safety 1994-1998
B. Majborn

European Community Standards, Measurements and Testing
K. Heydorn

Technical Experts on Radiation Protection Dosimetry
P. Christensen

Technical Experts on Environmental Radiation Monitoring
L. Bøtter-Jensen

EURADOS working group 2. Skin Dosimetry
P. Christensen

EURADOS working group 12. Environmental Radiation Monitoring
L. Bøtter-Jensen

Article 31 Group of Experts
P. Hedemann Jensen

Articles 35 and 36 of the European Treaty (Environmental Monitoring)
S.P. Nielsen

Article 37 Group of Experts
S.P. Nielsen

National Correspondents on Assistance and Emergency Planning in the Event of a Nuclear Accident or Radiological Emergency
F. Nielsen

Working groups within IAEA to prepare Safety Requirements and Safety Guides on contaminated environments
P. Hedemann Jensen

Working Party set up by the EU Article 31 Group of Experts to develop European criteria on clean up of contaminated land
P. Hedemann Jensen

Working Party on Criteria for Recycling Materials from the Dismantling of Nuclear Installations
M.S. Carugati

ACPM for the Community Plan of Action in the Field of Radioactive Waste
K. Brodersen

International Technical Division on Reference Materials
K. Heydorn

Scientific Committe of STORM (Simplified Test on Resuspension Mechanisms)
P.B. Fynbo

Group for Nuclear Safety Research Index, NSRI
E. Nonbøl

OECD/NEA

Committtee on Radiation Protection and Public Health (CRPPH)
P. Hedemann Jensen

Nuclear Science Committee
C.F. Højerup

NEA Data Bank Executive Group
C.F. Højerup

CSNI (NEA) Committee on the Safety of Nuclear Installations
P.B. Fynbo

Principal Working Group 4, PWG 4
P.B. Fynbo

Editorial Advisory Boards

Journal of Environmental Radioactivity
A. Aarkrog

Radiation Measurements
L. Bøtter-Jensen

Radiation Protection Dosimetry
L. Bøtter-Jensen

Journal of Radioanalytical and Nuclear Chemistry
K. Heydorn

Revista Nucleotecnica
K. Heydorn

Analytical Letters
B. Rietz

Nuclear Europe Worldscan
K. Hjerrild Nielsen

Other Committees

The Board of the Nordic Nuclear Safety Research Programme, NKS
B. Majborn

NKS Reference Group for Radioecology and Emergency Preparedness
A. Aarkrog

NKS Reference Group for Radioactive Waste
K. Brodersen

The Board of the Nordic Society for Radiation Protection
A. Aarkrog (President) and A. Damkjær (Executive secretary)

Baltic Marine Environment Protection Commission Helsinki Commission (HELCOM), Group of Experts on Monitoring of Radioactive Substances in the Baltic Sea (MORS)
S. P. Nielsen

ICRP Task Group to prepare recommendations on protection of the public in situations of chronic exposures
P. Hedemann Jensen

International Solid State Dosimetry Organization
L. Bøtter-Jensen

Standing Committee for the International Solid Sate Dosimetry Conferences
L. Bøtter-Jensen

International Technical Division on Reference Materials
K. Heydorn

MTAA International Committee
K. Heydorn

European Atomic Energy Society (EAES) Working Group
B. Majborn

European Atomic Energy Society (EAES). Research Reactor Operators Group
H. Floto

Dido-Pluto Operators Meetings
H. Floto

9 Personnel

Head of department
Benny Majborn

9.1 Scientists and engineers

Radiation protection and reactor safety
Anders Damkjær (head af programme)
Claus Erik Andersen
Kasper Andersson
Debabrata Banerjee (post doc)
P.E. Becher
Lars Bøtter-Jensen
Poul Christensen
Peter Bille Fynbo
C.F. Højerup
Bent Lauritzen
Jørgen Lippert (until 30 September)
Flemming Nielsen
Erik Nonbøl
Jørn Roed
Knud Ladekarl Thomsen
Povl L. Ølgaard (consultant)

Radioecology and tracer studies
Asker Aarkrog (head of programme)
Qiangjiang Chen
Henning Dahlgaard
Else Damsgaard (until 30 June)
Christian Lange Fogh
Heinz Hansen
Xiaolin Hou (post doc, from 16 March)
Sven P. Nielsen
Bernd Rietz

Applied health physics
Per Hedemann Jensen (head of task)
Bente Lauridsen
Jens Søgaard-Hansen
Lisbeth Warming

Isotope Laboratory (Irradiation and isotope services, NTD silicon)
Kaj Heydorn (head of laboratory until 31 March)
Kirsten S. Andresen (head of NTD silicon)
Nils Hegaard
Ulf Jacobsen (head of Irradiation and isotope services)
Jesper C. Jørgensen

Research reactor DR3
Heinz Floto (reactor manager)

Mogens Bagger Hansen (deputy reactor manager)
Niels Ole Birkelund (until 31 October)
Carsten Cederqvist (from 1 October)
Søren Erik Jensen
Mogens Mariager Kristensen (from 1 October)
Kirsten Hjerrild Nielsen
Jens Svane Qvist
John A. Sørensen (until 31 August)
Poul Winstrøm

Waste Management Plant
Knud Brodersen (head of waste management plant)
Massimo Steen Carugati

9.2 Technical staff

Radiation protection and reactor safety
Birthe Berg
Henrik E. Christiansen
Lissi Sture Hansen
Jørgen Jakobsen
Nina Jensen
Finn Jørgensen
Svend K. Olsen
Finn Pedersen
Henrik Prip
Lis Sørensen
Finn Willumsen

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Oda Brandstrup
Pearl Baade-Pedersen
Tove Christensen
Birgitte Christiansen
Jytte Clausen
Elly Hansen
Trine Hansen
Henrik Hougaard Pedersen
Vibeke Jørgensen
Alice Kjølhede
Karen Mandrup Jensen

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Helle Vibeke Borch
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João Silva

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Jette Iversen
Michael Jacobsen
Gert Ragner Jensen
Svend E. Kerchhoff
Leif Laursen
Kirsten M. Madsen
Mads Wille

Research reactor DR3

Axel B. Andersen
Bent Steen Andersen (until 30 June)
Stig Andersen
Søren Holm Bang
Heino Bentzen (umtil 30 August)
Jørgen Christensen
Finn A. Christiansen (from 1 June)
Knud E. Christiansen
Kari Fernstrøm
Henning Frederiksen (until 31 July)
Bende Christian Hansen
Benny Kurt Hansen
Wagn Søndergaard Hansen
Thomas Hauschildt
Kim Peter Hejlund
Poul Aage Jacobsen
Børge Jensen (until 30 June)
Henning Jørgensen
Jens Verner Jørgensen (from 1 Sepetmber)
Benny Carl Kjølhede
René Kristiansen (from 1 August)
John Larsen
Niels Larsen (until 30 June)
Tim Granskov Madsen
Lars Mikkelsen (from 1 October)
Børge Nielsen
Charlotte A. Nielsen
Freddy Nielsen
Ove Lilholm Nielsen
Peter Nielsen
Carsten Nikolajsen
Jesper Nørgaard
Jan Henrik Olsen (from 1 October)
Erling Aarup Pedersen
Per Pedersen
Thomas D. Petersen
Bo Ransfort (until 31 July)
Henning Rask
Søren Roed
Finn Rudolfsen
Leif Rødskov
Michael Thomsen
Claus Thorsen
Arne West (until 30 June)
Arne Flemming Würtz
Ole H. Andersen
Bent Christensen (until 31 July)
Flemming Frederiksen (until 31 March)
John Gade
Finn Grandahl Jacobsen
Sten Brian Jensen
Jacob M. Mortensen
Morten Lillevang Nielsen
Palle Bøgelund Nielsen

Søren Ole Nielsen
Preben H. Petersen (from 1 September)

Waste Management Plant
Ruth Aagesen
Birthe Andersen
Winnie Andersen
Mogens Christiansen
Birthe Hansen
Jørgen Walther Hansen (until 14 July)
Signe Hansen
Ole Sølling Hansen
Kurt Jensen
Peter Nielsen
Palle Olsson
Jesper Bohn Rasmussen
Nina Thomsen

9.3 Office staff

Lene Birch (until 28 February)
Inge Blyitgen
Anni Lambæk Hansen
Margit Kloster
Berit Kornerup
Merete Larsen
Margit Nielsen
Lis Rasmussen

9.4 Ph.D. students

Mats Eriksson (from 1 March)
Jakob Helt Hansen

9.5 Guest scientists

Olga A. Barkovskaja, St. Petersburg Institute of Radiation Hygiene, Russia
Anatoli N. Barkovsky, St. Petersburg Institute of Radiation Hygiene, Russia
Alexander Bougai, Institute of Semiconductor Physics, Kiev, Ukraine
Less Colyott, Oklahoma State Ùniversity, Stillwater, USA
Geoff A.T. Duller, University College of Wales, UK
Kendra M. Foltz, University of Illinois, USA
Arunas Gudelis, Institute of Physics, Vilnius, Lithuania
Christer Högstrand, University of Kentucky, USA
Högne Jungner, University of Helsinki, Finland
Helena Karakaeva, Inst. of Animal and Plant Ecology, Russia
Steve W. M. McKeever, Oklahoma State University, USA
Rima Ladygiene, Radiation Protection Centre, Vilnius, Lithuania
Galina Lazorenko, Inst. of Animal and Plant Ecology, Russia
Evalda Maceika, Institute of Physics, Radiation Protection Department, Vilnius, Lithuania

Arkadi S. Mishin, St. Petersburg Institute of Radiation Hygiene, Russia
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Inna Molchanova, Inst. of Animal and Plant Ecology, Russia
Alexander V. Ponomarev, St. Petersburg Institute of Radiation Hygiene, Russia
Elena Ponomareva, St. Petersburg Institute of Radiation Hygiene, Russia
Valeri P. Ramzaev, St. Petersburg Institute of Radiation Hygiene, Russia
Bernd Rehs, Isotoplab. für Biol. u. Med. Forschung, Göttingen, Germany
Eddie J. Rhodes, Univ. of London, Royal Holloway and Bedford College, UK
Vitali V. Rymkevich, Minsk, IPEP
Irina Shtangeeva, University of St. Petersburg, Russia
Aleander Trapeznikov, Inst. of Animal and Plant Ecology, Russia
Vera Trapeznikov, Inst. of Animal and Plant Ecology, Russia
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Abstract (Max. 2000 characters)

The report presents a summary of the work of the Nuclear Safety Research and Facilities Department in 1998. The department´s research and development activities were organized in two research programmes: ”Radiation Protection and Reactor Safety” and ”Radioecology and Tracer Studies”. The nuclear facilities operated by the department include the research reactor DR3, the Isotope Laboratory, the Waste Treatment Plant, and the educational reactor DR1. Lists of staff and publications are included together with a summary of the staff´s participation in national and international committees.

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