Nuclear Safety Research Department annual report 2000

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Nuclear Safety Research Department Annual Report 2000

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Risø National Laboratory, Roskilde, Denmark
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Abstract This report presents a summary of the work of the Nuclear Safety Research Department in 2000. The department's research and development activities were organized in two research programmes: ”Radiation Protection and Reactor Safety” and ”Radioecology and Tracer Studies”. In addition the department was responsible for the tasks ”Applied Health Physics and Emergency Preparedness”, ”Dosimetry”, ”Environmental Monitoring”, and ”Irradiation and Isotope Services”. Lists of publications**,** committee memberships and staff members are included.

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1 Introduction

For Risø the main event during 2000 was the decision to close the research reactor DR3 after 40 years of operation. Obviously, this had a major influence on the Nuclear Facilities Department and on all users of DR3. For the Nuclear Safety Research Department, the main direct effect of the closure was that our irradiation and isotope services now have to be based on irradiations at foreign reactors.

In 2000 a new strategy for Risø was developed as a basis for negotiating a new performance contract with the Ministry of Information Technology and Research for the period 2002-2005. According to the new strategy, the research areas for Risø are:

- Energy
- Industrial Technology
- Bioproduction
- Radiation Safety

The department's research and development activities are organized in two research programmes: "Radiation Protection and Reactor Safety" and "Radioecology and Tracer Studies". The research subjects include dosimetry, optically stimulated luminescence, natural radioactivity, emergency preparedness, contamination physics, reactor safety, radioecology, aquatic tracers, radioecological models and radioanalytical chemistry.

In addition to the research and development work, the department is responsible for a number of other activities, which in 2000 were organized in the following tasks: "Applied Health Physics and Emergency Preparedness", "Dosimetry" (including personnel dosimetry and industrial dosimetry), "Environmental Monitoring", and "Irradiation and Isotope Services".

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 European Commission research programmes and the Nordic Nuclear Safety Research Programme.

This report presents a summary of the work of the department in 2000 with an emphasis on the results of the research and development activities. Lists of publications, committee memberships and staff members are included.

2 Radiation protection and reactor safety

The Radiation Protection and Reactor Safety programme carries out research and development in the fields of radiation protection, dosimetry, and reactor safety. The aim is to contribute to the protection against the harmful effects of ionising radiation through co-operation with the Danish nuclear and radiation protection authorities and to develop new methods and new applications of nuclear methods in research and industry.

2.1 Luminescence Dosimetry

Optically Stimulated Luminescence (OSL)

Over the last few years new powerful optical stimulation systems based on lasers and light emitting diodes (LEDs) have been developed for the automatic Risø TL/OSL reader. Furthermore, a software controlled heater plate may now be fitted underneath the beta source to enable irradiation of samples at elevated temperature. This allows investigations of the competition effects from thermally shallow traps and centres. Significant additional software developments include the facility to linearly vary the stimulation power during stimulation for performing linearly modulated OSL measurements. This is important for analysis of the OSL trap distribution in various materials.

Radioluminescence (RL)

The elevated temperature irradiation facility has been further expanded to allow the measurement of radioluminescence (RL) during beta irradiation. RL is the promptly emitted luminescence observed directly during irradiation of a sample and can be used for real time determination of the dose rate. The sample can be heated during irradiation and the RL signal is collected through a lens system and fed via a light fibre to an open port of the OSL unit, where it is detected by the same PM tube that is used to measure TL and OSL. This additional facility allows the measurement of TL, OSL and RL in the same software controlled automatic sequence.

Single grain OSL dosimetry

The recently developed solid state laser based single grain unit for measurement of the OSL signals from single sand sized quartz grains has been thoroughly tested using a variety of poorly zeroed materials. The system uses a focused green (532 nm) laser beam which can be automatically steered to selectively stimulate single grains located on a 10 x 10 hole grid pattern on the surface of a 10 mm diameter aluminium disc, giving a total of 100 grain positions on each sample disc. The system is capable of measuring the dose distribution from the grains which for the first time makes it possible to determine the equivalent dose in poorly zeroed materials (e.g. concrete and mortar). This is a major step forward in both dating and retrospective accident dosimetry. Materials investigated so far include quartz extracted from building materials used in the work environment such as dry premix concrete and mortar.

Clinical dosimetry

An important consideration in the use of ionising radiation in nuclear medicine (diagnostic and therapeutic studies) is the absorbed dose. The determination of the radiation dose received by different organs in the body is essential for evaluating the risks and benefits of any procedure. For this purpose, we have suggested the use of a remote fibre-optically coupled OSL dosimeter that has several advantages over other dosimeter types. These are 1) minimal disturbance of the radiation field (a small detector volume results in a near tissue equivalent response), 2) isotropic response to the incident radiation, 3) no electrical connections to the probe, 4) high spatial resolution due to a small detector volume and 5) real time reading of the absorbed dose and dose rate combined with a large dynamic measurement range.

We have developed a prototype of a real-time remote fibre-optical dosimeter probe, which uses optically stimulated luminescence (OSL) to measure the accumulated dose and radioluminescence (RL) to measure the dose rate. The dosimeter probe uses a small solid state dosimeter mounted onto the end of an optical fibre light guide. The dosimeter is stimulated through the light guide by a green laser beam (532 nm), and the emitted luminescence is filtered from the stimulation light and detected by a small compact photomultiplier tube. So far the system has been tested using BeO and Al_2O_3:C phosphors with promising results. A schematic diagram of the real time fibre OSL/RL dosimeter is shown in Figure 2.1.

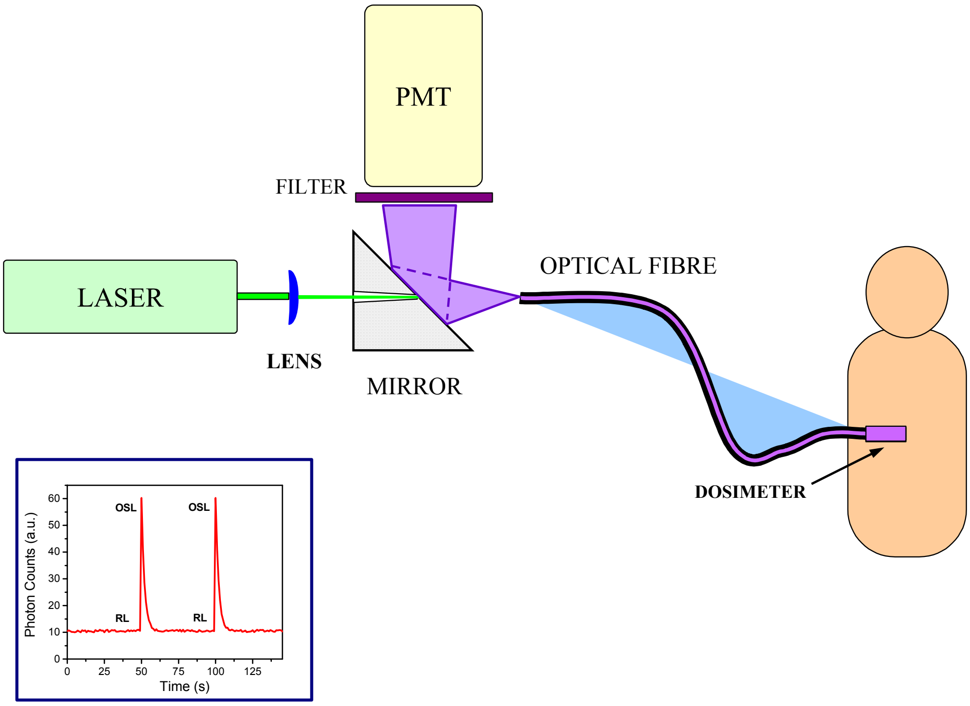

Figure 2.1. A schematic diagram of the real time fibre OSL/RL dosimeter

2.2 Natural radioactivity

National survey of radon in houses

Radon is a naturally occurring radioactive gas that is generated in the soil. The level of radon in soil air is typically 1.000 to 10.000 times higher than the level of radon in outdoor air, and even a minute pressure-driven entry of soil air into a house can cause an increased level of indoor radon. In Denmark, houses with annual mean levels above 1000 Bq/m^3 have been found. This is of concern because radon is believed to increase the risk of lung cancer. The authorities recommend that simple actions are taken to reduce radon levels in houses with levels above 200 Bq/m^3 and that more efficient countermeasures are used in houres with levels above 400 Bq/m^3.

In 2000, a new national survey was completed by the National Institute of Radiation Hygiene (SIS), Geological Survey of Denmark and Greenland (GEUS) and Risø. Measurements have been conducted in more than 3000 houses, and the main result is a map of Denmark showing the fraction of houses with radon levels above 200 Bq/m^3 in each of the 275 municipalities (see Figure 2.2). The map shows that there is a considerable regional variability of the Danish radon levels. For Denmark as a whole, 4.6% of the single-family houses or 65.000 houses are above 200 Bq/m^3. The survey includes an analysis of the association between radon and various building and geological factors. The three most important ones are: type of basement, province, and soil type.

Radon as a tracer of sub-marine groundwater
Natural radioisotopes can be excellent tracers of transport processes in the environment. In the EU project Sub-Gate, Risø uses radon-222 and radium-226 as tracers for sub-marine groundwater inflow to Eckernförde Bay in the western Baltic Sea. The hypothesis is that submarine groundwater is enriched in radon and radium. Hence a discharge to the seawater will increase the level of these isotopes in the vicinity of the points of entry on the seafloor. To this end, a relatively detailed mapping has been carried out on the basis of samples of sediments, groundwater, and seawater. In 2000 two cruises were carried out. In one of them, we obtained water samples from temporary wells in sub-seafloor aquifers and conducted radon analysis on board the research vessel. The measurements showed that the groundwater has a radon-222 concentration about three orders of magnitude higher than that of the seawater. The project will be completed in 2001.

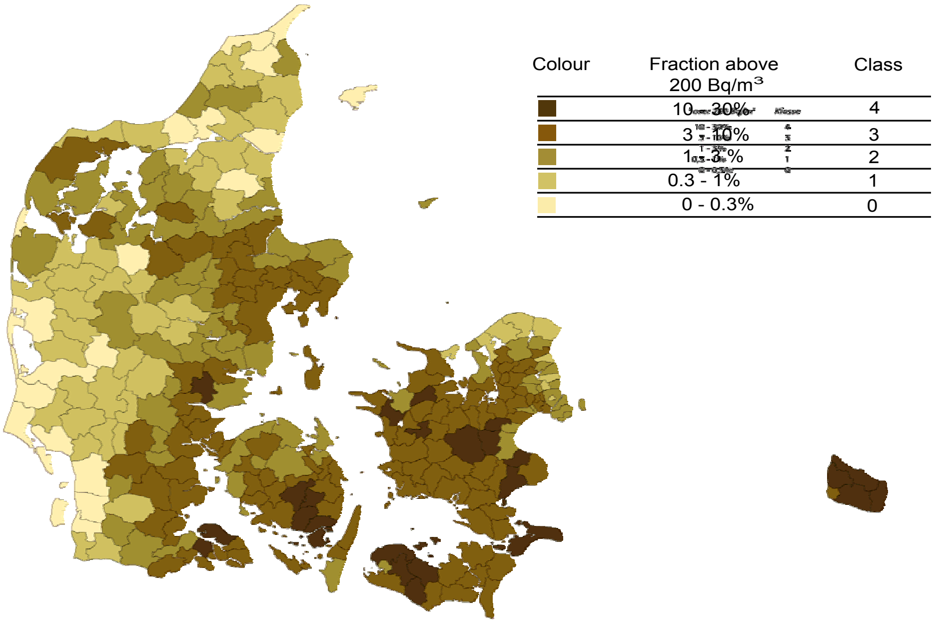

Figure 2.2. Map of Denmark showing the fraction of houses with indoor radon levels above 200 Bq/m^3 in each of the 275 municipalities.

2.3 Emergency preparedness

Nordic project: Agricultural countermeasures following a nuclear fallout
Risø is leading a Nordic Nuclear Safety Research project, NKS/BOK-1, on nuclear emergency preparedness. As one of the six sub-projects, an exercise Huginn was designed and carried out with the objective to test the ability to calculate the radiological and economical consequences of agricultural countermeasures following a nuclear fallout**.** Nuclear accidents affecting food-producing areas require both immediate resolutions concerning contaminated foodstuffs, and call for decisions on the future agricultural production. The Huginn exercise

aimed at the late-phase and was designed to test and compare the decision making process concerning the possible agricultural countermeasures.

The exercise demonstrated that it is possible based on available information to carry out cost-benefit analyses for many agricultural countermeasures, e.g., administration of Prussian Blue to cattle and sheep. For other countermeasures, more detailed and scenario-specific information will be needed to assess the radiological and economical consequences of the countermeasures. In particular, the necessary information on transfer factors to plants was not readily accessible. The exercise also showed that large differences exist between the Nordic countries, both with respect to the choice of countermeasures deemed applicable, and in the cost-effectiveness estimates of selected countermeasures. Such differences may be an obstacle to Nordic harmonisation following a nuclear accident.

Nordic project: Radiological monitoring systems

A second sub-project under the NKS project on nuclear emergency preparedness is a survey of radiological emergency monitoring systems in the Nordic and Baltic Sea countries. Radiological emergency monitoring systems are intended for early warning of unexpected increases in the background radiation levels, and systems for mapping radioactivity in the environment, resulting from radiological accidents. The Nordic and Baltic Sea countries all possess automatic early warning systems and most countries have established strategies, equipment and routines to map the national territory in case of fallout of radioactive material. National programs also exist for determining contamination levels of food, environmental samples, vehicles, goods etc., as well as any external or internal contamination of people.

2.4 Contamination physics

Risø's activities within the area of Contamination Physics is focused on improving the understanding of mechanisms governing the doses received in terrestrial environments after a major accident leading to a release of radiopollutants to the atmosphere. The work thus includes aspects of health physics, aerosol physics, and soil physics, as well as forced decontamination of urban, rural, and forest ecosystems.

Dose reduction in the village of Savichi, Belarus

With the financial support of IAEA, Risø headed a series of dose reduction experiments in the village of Savichi within the contaminated 30 km zone around the Chernobyl nuclear power plant. The main objective was to transfer expert knowledge to local officials in the areas affected by the Chernobyl accident on effective remediation methods. In a collaborative project of this nature, local preparedness representatives and reclamation stakeholders gain hands-on experience, which can prove very valuable in connection with further dissemination of the know-how in the affected areas. At the same time, the test provided a unique opportunity to support the current trend in Belarus towards resettlement in the deserted living areas, by demonstrating that significant reduction of external doses can be achieved with relatively simple methods. The high contamination levels in Savichi (in some areas as high as ca. 40 MBq m^{-2}) provided excellent testing conditions, with minimal statistical uncertainties. Further, the housing areas of Savichi are typical of those of the generally rather heavily contaminated Gomel region.

A range of methods were tested, including removal of top soil layers, various soil digging procedures, and a variety of methods to reduce the contamination level on building surfaces. As expected, removal of a thin topsoil layer gave a substantial dose rate reduction, by a factor of 4-7. Particular care should be taken to clean the soil areas nearest to the houses carefully. The triple digging procedure, where the vertical order of three layers of soil is changed manually, so that the optimal dose-reductive effect is achieved with the minimal impact on soil fertility, was found to be practically equally effective in reducing the external dose rate.

Also treatments of house surfaces particularly roofs were found to contribute significantly to the reduction of external dose in the test area. Especially a mobile trailer for cleaning of roofs proved to be a valuable tool for remediation.

Similar exercises are scheduled to take place in Belarus and Ukraine within the following year. The experience gained has great importance not only for the currently affected areas, but also for improving the Nordic preparedness, where Risø plays a leading role in the field of environmental decontamination techniques.

Figure 2.3. A representative of a Belarussian decontamination company gaining hands-on experience with the triple digging procedure in Savichi

2.5 Reactor safety

Decommissioning of Research Reactors

The DR-2 project aims at the determination of the residual activity in the reactor and the planning of the final decommissioning of the reactor. The reactor tank was opened by the removal of the concrete and lead shielding layers at the top of the tank. The surface contamination of the reactor tank and its components were measured both with respect to activity and beryllium, and a very limited contamination was detected. Movable components in the reactor tank were removed and their activity measured. The radioactive components were, where necessary, cut into pieces and deposited in concrete-lined waste drums, while non-active components were stored in plastic bags in the reactor basement. The components removed included the safety rods, the regulating rod, their guide tubes, grid plugs, magnet rods, and the V-tube facility for core irradiation. The most active component was by far the absorber part of the regulating rod, which had an activity of 23 GBq. All other removed components had activities less than 1 GBq. The dominating γ-activity was for all components cobalt-60. A computerised log-book for the project was prepared. All work was carried out as planned with no unexpected events.

Co-operation with Latvia on Research Reactor Decommissioning
An agreement on co-operation between Risø and the closed-down research reactor at Salaspils outside Riga has been concluded. It will involve exchange of information, mutual visits and activity calculations.

Decommissioning of the Nuclear Facilities at Risø National Laboratory
Contributions have been made to the comprehensive decommissioning study for the nuclear facilities at Risø.

Nordic project on Nuclear Risks from Areas close to the Nordic Countries
This project is part of the Nordic Nuclear Safety Research (NKS) programme and involves an assessment of the risks by nuclear facilities in the Western part of Russia and the Baltic states, i.e. the Kola, Leningrad and Ignalina nuclear power plants and the Russian nuclear naval vessels and icebreakers. The Danish contribution to this project concentrated on the Russian nuclear ships and included more than 100 contributions to a literature data base and the preparation of a status report reviewing available information on the Russian nuclear vessels.

The Nuclear Knowledge Preparedness Group
The Nuclear Knowledge Preparedness Group, whose members come from Risø National Laboratory, the Nuclear Office of the Emergency Management Agency and the Technical University of Denmark, has issued its annual report on the international status of nuclear power. The group has held two seminars on topics of current interest.

Core Melt-Down
A computer programme, which for the Three Mile Island accident models the behaviour of the melted core at the bottom of the reactor tank, has been finished. Calculations have been made and compared with evidence available from the accident, and reasonable agreement has been obtained.

Design Modifications for the Silicon Irradiation Facility
Detailed neutron distribution calculations have been performed on the DR-3 rig 7V4 to permit modifications of neutron distribution in the rig. The final design was prepared, but due to the shut-down of the DR-3 the modifications of the rig were never carried through.

Analysis of STORM data
Data from the resuspension experiment at the STORM facility at EU's Joint Research Centre at Ispra, Italy, have been analysed.

2.6 Dosimetry

Beta Spectroscopy

A Ph.D. project with the title "Development of a Portable Triple Silicon Detector Telescope for Beta Spectroscopy and Skin Dosimetry" was concluded. A portable and low-weight beta-spectrometer consisting of three silicon surface barrier detectors was constructed. The instrument can distinguish between counts originating from electrons and photons and is capable of measuring electron energies from 50 keV to 3.5 MeV. The skin dose at 0.07 mm tissue depth due to electron exposure is evaluated by comparing the measured electron energy spectrum with Monte Carlo calculations.

3 Radioecology and tracer studies

3.1 Radioactive Tracers in Nordic Waters

The Danish straits – the transit area between the North Atlantic and the Baltic Sea – has been monitored for ^{99}Tc and ^{137}Cs twice per year. The Sellafield discharge rate of ^{99}Tc showed a distinct peak in 1995. The concentration of ^{99}Tc peaked in the in-flowing bottom water in the Danish straits in June 1999, i.e. 4 years after the discharge. Since then, concentrations have decreased somewhat in accordance with the rate of discharge. This confirms an earlier estimate of the transit time based on the large ^{137}Cs discharges from Sellafield around 1975. The ^{137}Cs concentrations in the Danish straits are dominated by the outflow of low-salinity water from the Baltic contaminated with Chernobyl fallout, and thus inversely related to the salinity, whereas ^{99}Tc concentrations are positively correlated with salinity as the concentrations are dominated by the Sellafield discharges, cf. Figure 3.1. Data on environmental concentrations of ^{99}Tc and ^{137}Cs as well as of ^{129}I and other man-made radionuclides in combination are used to evaluate seawater transport of the radionuclides from the two European reprocessing plants to Nordic waters.

Under the Arctic Monitoring and Assessment project (AMAP-2), the ^{99}Tc pulse from Sellafield is now being followed in the Arctic. Several large seawater samples have been taken in East Greenland waters, including the East Greenland Current and the Denmark Strait, where the pulse was expected to appear around 2000-2001. The ^{99}Tc concentrations in the samples analysed till now are apparently still reflecting the old Sellafield discharges from the 1970's.

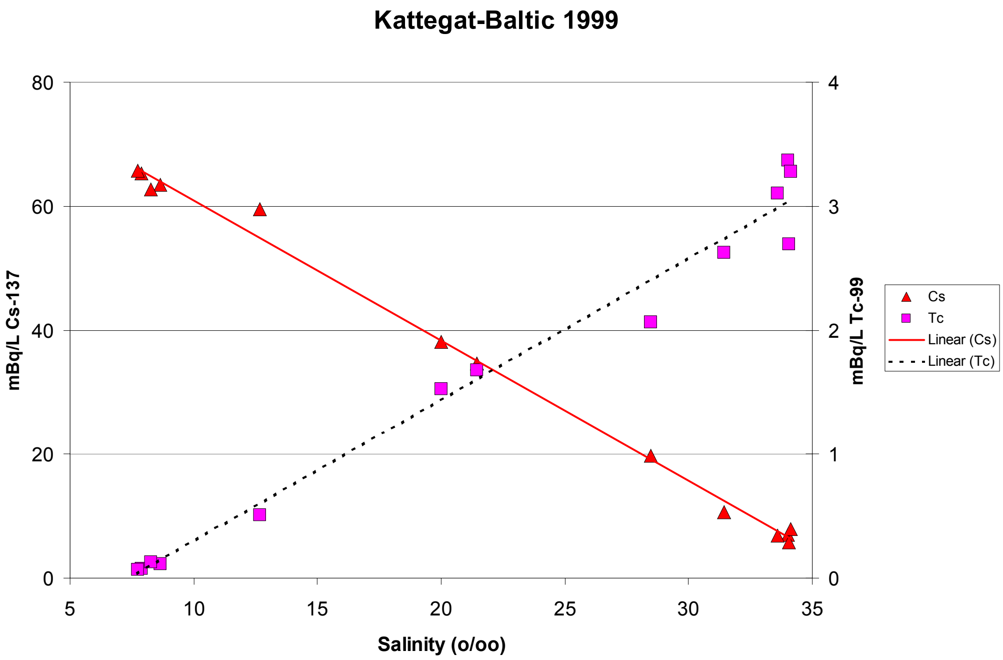

Figure 3.1. Concentrations of ^{137}Cs and ^{99}Tc in the Danish straits in 1999 shown versus salinity.

3.2 Transport and Transformation of Radioactive Substances in Marine Systems

The Framvaren Fjord in Southern Norway is unique in the sense that nowhere else is remobilization of sediment bound actinides so evident as in this fjord. This makes the fjord an ideal field laboratory for the study of sediment processes acting on actinides. The fjord has a well-known reputation for its excellent stability around the redox front, this greatly improves the possibilities for doing research on the behaviour of redox sensitive radioisotopes (eg. U, Tc, Pu, Np). During a field expedition we collected sediments, water and suspended matter. The aim of this investigation was to:

- Understand the mechanisms governing the remobilization of Pu, Am and Th isotopes from the sediments.
- Determine the role of the bacterial layer at the redox front in removing redox sensitive elements from the water column.
- Determine the cycling rate of the (organic) colloidal component and its role for the cycling of actinides in the anoxic water.

Work was done in the Baltic Sea on problems associated with determining vertical fluxes in marine waters. Results from sediment traps were compared with the ^{238}U - ^{234}Th method. Methods were tested of analysing and measuring the short-lived radionuclide ^{234}Th and of the reliability of the MnO_2 sorption method in low-salinity water with elevated organic matter concentrations. Studies in the Øresund were made to determine residence time of particle reactive matter using sediment traps, natural as well as artificial radioisotopes and stable element ratios. In northeast Skagerrak transport times were investigated for particle reactive pollutants to the high sediment accumulation area using sediment accumulation tracers (^{210}Pb, Th-isotopes) and combined transport/accumulation tracers (^{137}Cs, ^{238}Pu/^{239,240}Pu). Furthermore, work was done on the magnitude and mechanisms of actinide (Pu, Am) run-off from mire areas.

This is of special interest since the concentrations of plutonium are up to 100 times higher in mire water than in normal stream water.

3.3 Iodine-129 in the Danish Environment

Environmental samples, such as precipitation, lake water, animal thyroid, grass from Denmark and seawater from the North Sea, Kattegat, the Belt and Baltic sea were collected and analysed for ^{129}I by radiochemical neutron activation analysis. The ^{129}I/^{127}I ratio in sheep thyroids and grass from Jutland ranges from 5×10^{-8} to 4×10^{-7}, which is higher than the level before the 1990's in Europe, and those in Asia and America. The ^{129}I concentration in precipitation samples collected at Risø in Zealand ranges from 2.4×10^{-13} g/L to 18×10^{-13} g/L, and ratios of ^{129}I/^{127}I from 1.4×10^{-7} to 11×10^{-7}. These levels are slightly lower than those in Germany, but higher than in Uppsala, Zurich and Seville. Furthermore, the levels are more than one order of magnitude higher than in the USA. The concentrations of ^{129}I in lake water from different locations in Denmark and in seawater around Denmark are shown in Figure 3.2. Gradually decreasing ^{129}I concentrations were found moving from the North Sea and Kattegat to the Belt and then to the Baltic Sea. In the latter in 2000 the concentrations of ^{129}I in seawater from Bornholm and Møen have reached 6.0×10^{-13} g/L and 16×10^{-13} g/L, respectively, and in the Kattegat a level as high as 270×10^{-13} g/L was found. This is more than two orders of magnitude higher than the global fallout level. This higher level of ^{129}I in Denmark and other European countries is attributed to releases from the reprocessing plants at La Hague and Sellafield. Contributions from other sources, such as nuclear weapon tests and Chernobyl are insignificant.

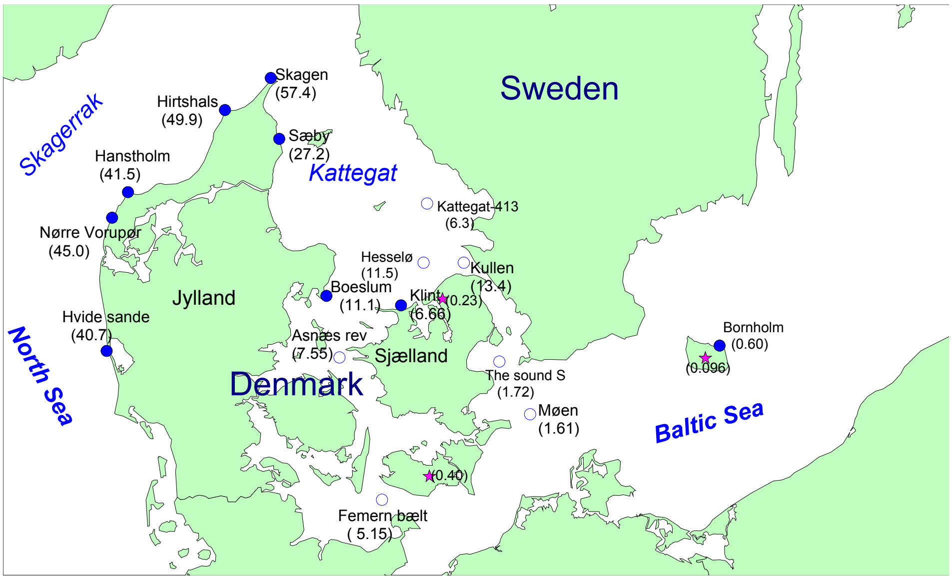

Figure 3.2. ^{129}I concentrations (10^{-12} g/L) in surface seawater and lake water. Sampling locations for coastal seawater ❍, for inner seawater ●, and for lake water ★.

3.4 Technetium in a Stratified Fjord

The fission product technetium-99 (^{99}Tc) has been used as a marine tracer to map ocean flow from its main release point in the Irish sea up into Arctic waters, and the pattern of releases has been followed in Danish waters. This oceanographic work is possible because of the conservative nature of ^{99}Tc in the pertechnetate (TcO_4^-) form, *i.e.* it behaves like water in its oxidised state. However, reduction of TcO_4^- to Tc(IV) results in a significant change in its chemistry and the reduced form is known to be particle reactive. We have therefore recently started investigating the behaviour of Tc as it is carried by ocean flow into estuaries or fjords, which may have conditions that lead to the reduction of Tc.

Our results from a stratified fjord show that Tc associations change in response to the changing chemistry of the water. In the oxic surface water it is entirely in the solution phase (<0.45 µm). As the oxygen levels become depleted and the sulfide concentrations increase to the extent that sulfide exceeds oxygen in concentration, Tc begins to be removed from the solution phase and becomes bound to colloidal and particulate matter. A fraction, however, remains in the solution phase, even when the water becomes highly anoxic at depth. The particle-bound Tc is removed to the sediments and thus the sediments of such reducing systems represent a sink for at least some of the Tc reaching this fjord. We are currently investigating the sediments of this and other fjords to understand the processes leading to Tc reduction and uptake in more detail.

3.5 Radioanalytical Chemistry

Due to the permanent shutdown in 2000 of Risø's nuclear research reactor DR 3, only a few projects using neutron activation analysis for the determination of trace elements were carried out in 2000.

Co-operation with the John F. Kennedy Institute continued with determination of Cu in placenta tissue for the diagnosis and verification of Menke's disease and determination of Cu in liver tissue for the diagnosis of Wilson's disease.

Work was concluded on an EU-project concerning certification of road dust as a reference material for platinum, palladium and rhodium, which are used in automotive catalytic converters. All irradiations necessary for this project were performed at the NRG high flux reactor in Petten, The Netherlands. Only platinum was determined because no suitable radiochemical methods are available for palladium and rhodium. The European Commission accepted the results on platinum.

Determination of heavy metals in incineration ash was carried out in connection with an EU-project concerning certification of a reference material (BCR CRM 176). Irradiations were performed at the NRG high flux reactor in Petten for the determination of As, Sb, Cr and Hg.

The co-operation between the University of Helsinki, the St. Petersburg University and Risø continued concerning clean up of soil, polluted with heavy metals.

3.6 Transfer of ^{137}Cs from soil to lamb

Studies on the transfer of Chernobyl radiocaesium through the soil-grass-lamb foodchain have been carried out in Nordic projects since 1990. The purposes of these studies have been to make comparisons between locations and years of the uptake and transfer of radiocaesium and investigate reasons for variability (e.g.

soil type, lamb's intake of soil and fungi), to establish time-series of data in order to document long-term trends, to use the data for radioecological modelling, and to estimate radiation doses to humans from consumption of lamb.

The present work covers follow-up during 1998-2000 on the collection of data from Ribe. The study area is a coastal site of about 9 ha permanent grassland with sandy soil. Sampling has been carried out annually of soil, grass and lamb. Soil cores were collected to 10-cm depth and sectioned into two 5-cm depth zones. Grass was cut a few cm above ground from an area of 4 m^2. Samples of lamb's neck were obtained from three individual animals.

The ^{137}Cs concentrations found in soil, grass and lamb during 1998-2000 follow the declining trend seen from previous years. The values have been compared with the corresponding levels predicted from model calculations. The results are shown in Figure 3.3 showing a comparison between observed and predicted concentrations of ^{137}Cs for the entire time period 1990-2000. Soil concentrations (kBq m^{-2}) are marked with diamonds, grass concentrations (Bq kg^{-1} dw) with triangles, and lamb concentrations (Bq kg^{-1} fw) with circles. The observed values from the present project period are shown with open marks and those from previous years with closed marks. This comparison shows that the observed results from 1998-2000 are well described by the values predicted by the model.

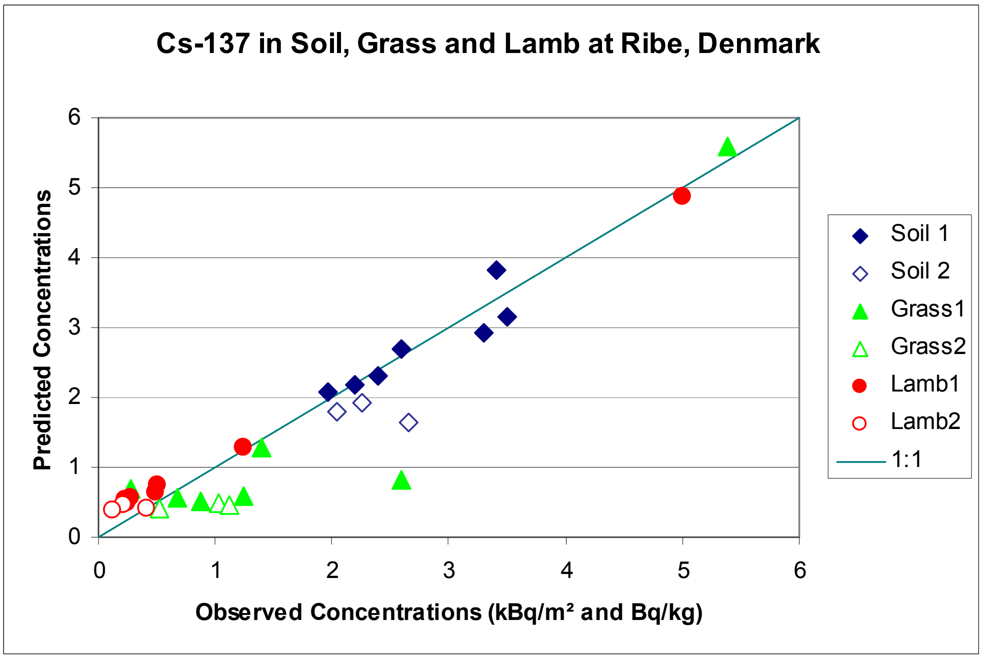

Figure 3.3. Comparison of observed and predicted concentrations of ^{137}Cs in soil, grass and lamb at Ribe.

3.7 Environmental monitoring

Risø Environment

The department is responsible for monitoring of radioactivity in the environment at Risø. The programme comprises monitoring of radioactivity in air, precipitation, sediments, seawater, grass, sea plants, milk and wastewater from the Waste Management Plant. The samples are measured for γ-activity, tritium, and gross β-activity. External γ-radiation is monitored at 25 locations around Risø.

The results are reported in the Risø-I-Report series "Radioactivity in the Risø District". The results from the latest report January-June 2000 show that the mean concentrations in air were 0.43 μBq m^{-3} of ^{137}Cs, 2.9 mBq m^{-3} of ^{7}Be, and 0.16 mBq m^{-3} of ^{210}Pb. The average external background dose rate on the Risø site measured with thermoluminescence dosimeters was 121 nSv h^{-1}, which is somewhat higher than the background dose rate of 83 nSv h^{-1} from the area around Risø. The additional dose rate on the Risø site is due mainly to the Waste Management Plant. The concentrations of tritium in water from Roskilde fjord have continued to decrease in 2000 following the discharges from the Waste Management Plant arising from a leakage in 1999 from the research reactor DR3. None of the measured levels are of any concern from a radiological protection point of view.

Danish Environment

Risø has investigated environmental radioactivity in Denmark since 1957. The monitoring programme covers fallout nuclides in abiotic samples, food and vegetation and has focused on ^{90}Sr and ^{137}Cs. The results are reported annually to the European Commission in agreement with the requirements on EU Member States of the Euratom Treaty in Articles 35 and 36.

Levels of ^{137}Cs and ^{90}Sr in Danish food are determined from the main food components and also analysed from a composite sample of the total diet for an average individual adult. During the period 1962-2000 the daily individual intake of ^{137}Cs has varied from 0.1 to 12 Bq (Figure 3.4).

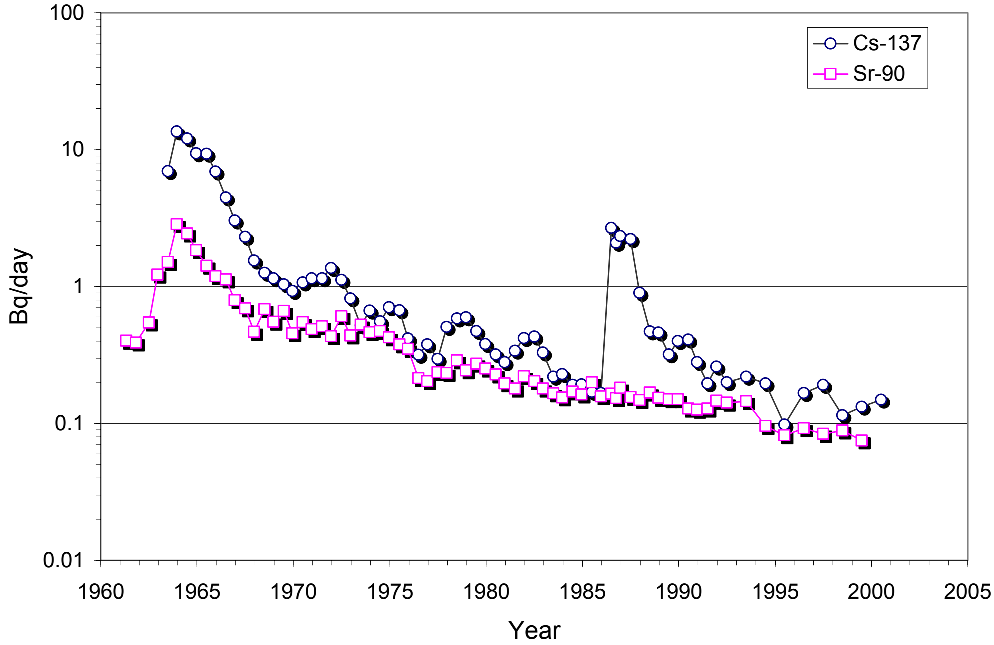

Figure 3.4. Daily intake of ^{137}Cs and ^{90}Sr from Danish diet during 1962-2000 (Bq/d).

4 Applied health physics and emergency preparedness

The major task for the Applied Health Physics and Emergency Response Preparedness (AHF) is primarily radiation protection for Risø employees including radiation hygiene surveillance, professional advice, and teaching radiation protection for staff members at the nuclear facilities. AHF also has the responsibility for the operation and maintenance of eleven measuring stations around the country for measurement of radioactive fallout in order to give an early warning of nuclear accidents. This work is performed as a service for the Danish Emergency Management Agency (DEMA).

Surveillance programme
The surveillance programme includes radiation and contamination surveillance of working operations at the nuclear facilities where personnel is or can be exposed to radiation and contamination. The γ-radiation levels at different locations are measured daily and surface and air contaminations are analysed from smear and air samples. Air contamination is also measured continuously at central working places. System samples from the nuclear facilities are analysed by γ-spectroscopy. X-ray and laser equipment is inspected once a year. The overall surveillance programme in 2000 included about 82,000 measurements and analyses.

Shielding design for gamma-irradiation facility
A new gamma-irradiation facility is to be built for irradiation and instrument calibration purposes. The facility will contain one ^{137}Cs-source with a source-strength of 9250 GBq, one ^{137}Cs-source with a source-strength of 370 GBq, one

^{137}Cs-source with a source-strength of 3.7 GBq, and one ^{60}Co-source with a source-strength of 370 GBq. The Monte Carlo code MCNP 4B has been used to calculate the photon transport to design the necessary shielding of sources and rooms. These calculations have shown that the ^{60}Co-source is determining the necessary shielding thickness of walls and ceiling. Radiation levels in adjacent rooms are all due to scattered photons from surfaces in the radiation room as the direct beam is absorbed in the soil outside the room. Scattered radiation from walls and ceiling at distances of 1 - 4 metres from the sources contributes with 2.7 - 5.2% of the total air kerma rate from the ^{137}Cs-sources and 2.9 - 6.1% of the total air kerma rate from the ^{60}Co-source.

Decommissioning of reactor DR 2
The research reactor DR 2 was closed in 1975. Before the reactor will be decommissioned the content of activity in all essential construction parts, *e.g.* reactor tank, concrete shield, primary and secondary cooling system, beam plugs will be determined. The first step was taken on 25 May 2000 when the concrete shield was removed from the top of the reactor block as shown in Figure 4.1.

Figure 4.1. The 13-ton concrete shield is removed from the top of the reactor block on 25 May 2000. Below the concrete shield is a 10-cm lead shield.

After removal of the concrete and lead shield the gamma-dose rate above the open reactor tank was about 400 μSv/h originating mainly from ^{60}Co in neutron activated steel components. The activity content in all objects from the reactor is determined from γ-spectrometric measurements in free air. The horizontal activity distribution in the objects is determined behind a shield with a lead collimator.

The permanent measuring system
Central computers at DEMA and Risø collect data on an hourly basis from gamma monitoring stations placed at eleven different locations in Denmark. Each station contains a high-pressure ionisation chamber, a gamma spectrometer with NaI-detector, equipment for measurement of precipitation and temperature and a microcomputer for data collection and communication with the central computers. All eleven stations have continued to operate smoothly in 2000 with only a limited number of technical malfunctions, primarily transmission errors.

Revision of the Danish emergency plan for nuclear accidents

The Danish emergency plan for nuclear accidents has been updated by the Danish Emergency Management Agency. AHF has contributed to this update with regard to Risø tasks, organisational aspects and the difference in response from Risø to nuclear accidents at Risø and accidents at nuclear facilities in neighbouring countries. In addition, the dose limit criterion for triggering the emergency response plan after an accident at the nuclear facilities at Risø has been changed to an operational dose rate criterion at the fence line of 10 μSv/h.

Radiation Protection research

The work on internal dosimetry has been concentrated on measurements with an anthropomorphic phantom in the whole-body counter to investigate how inhomogeneous distributed activity in the body will affect the assessment of radionuclide content in the body. A detailed calibration was made with an anthropomorphic phantom ("IRINA") developed by the "Research Institute for Industrial and Sea Hygiene" in St. Petersburg, Russia. The phantom is made from 71 bricks with mass 0.5 kg and 1 kg. The bricks are made of tissue-equivalent polyethylene. Two rods with radionuclides can be placed in each brick. Figure 4.2 shows the relative counting efficiency for different positions of ^{60}Co activity in the phantom relative to the efficiency for position B22.

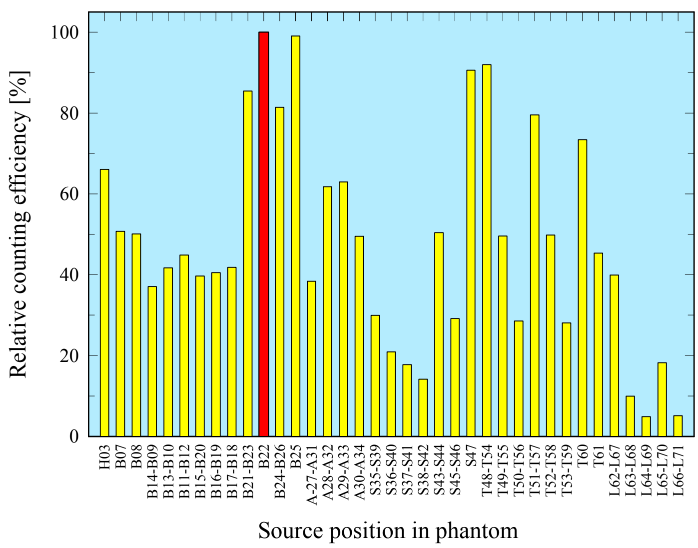

Figure 4.2. Relative counting efficiency for ^{60}Co (1173 keV) for different positions of activity in the phantom relative to the efficiency for phantom position B22.

The counting efficiency for an arbitrary activity distribution can be calculated by proper weighting of the measured efficiencies of the single bricks. The average relative counting efficiency for 1173 keV photons from ^{60}Co has been calculated to be approximately 45% with equal weighting of the 71 bricks. If it is assumed that about 80% of a ^{60}Co intake is concentrated in the liver (bricks B16, B17 and B24) and the remaining 20% in the rest of the body (ICRP 30), the body content will be overestimated by approximately 15% if the activity is determined from a calibration of the whole body counter with homogeneously distributed activity in the body.

5 Dosimetry

Risø High Dose Reference Laboratory

The activities of the accredited Risø High Dose Reference Laboratory HDRL were again increased in 2000 with the issue of 107 reports and 70 dosimeter certificates. Measurements of dose distribution in irradiated products were to a large extent carried out in collaboration with LR Plast, Glostrup, Denmark. This company operates two 10-MeV electron accelerators and irradiates products for sterilization for several medical device manufacturers. The measurement reports of Risø HDRL provide confidence that the products are irradiated in accordance with international standards.

Two courses on “Validation and Process Control for Electron Beam Sterilization” were arranged with 14 participants from 9 countries.

The laboratory moved to temporary localities during 2000, but normal operation was maintained during this period.

Accreditation for high-dose measurement.

This EU-supported project (IC15-CT96-0824), which was carried out in collaboration with National Physical Laboratory, UK, and with dosimetry laboratories in Hungary, Poland and Albania, was concluded in 2000 with the issue of guidelines for high-dose laboratories seeking accreditation. These guidelines were made available on the internet.

Blood-irradiation facilities

A revised procedure for dosimetry at blood-irradiation facilities is being implemented. These facilities are used at hospitals for irradiation of blood for infusion in order to suppress the graft-versus-host reaction in patients. According to the international rules, the dose to the blood shall be within 25 and 40 Gy. We use TL-dosimeters for these measurements.

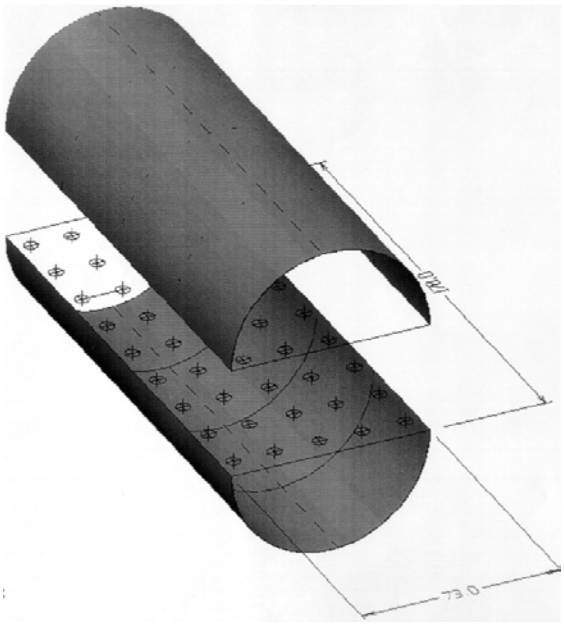

Figure 5.1. Phantom for dosimetry at blood irradiation facilities. Dosimeters are placed in 45 locations.

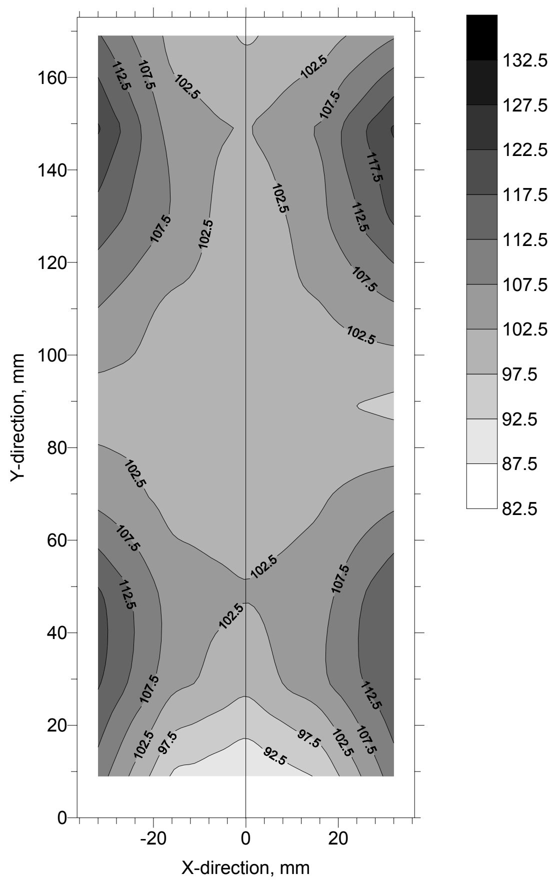

Figure 5.2. Dose distribution in blood irradiation facility. The measurement is based on dose measurement in the phantom shown in Figure 5.1

Personnel Dosimetry

A quality manual was prepared for Risø Personnel Dosimetry Laboratory, and approval of the laboratory was applied for according to the Danish rules for Personnel Dose Monitoring. The procedures of the laboratory were simplified in the process of writing the manual, and fewer types of TL-dosimeters are now used.

New software for personnel registration was implemented during 2000. The old software could not operate past the end of year 1999, and some "year-2000" problems were discovered. They were corrected, and all data were correctly reported to the National Institute of Radiation Hygiene.

6 Isotope and irradiation services

After the closure of the DR 3 reactor was decided in September 2000, the Isotope Laboratory has applied for revocation of its status as a nuclear installation and this was granted from 16 January 2001. The laboratory intends to continue its operations on a reduced scale, but still supplying radioactive materials within all the fields that have been covered so far, by using irradiation services in foreign reactors.

The laboratory has not been able to cover all the needs for neutron irradiated materials in Denmark as the reactor DR 3 was only running 2 out of 12 scheduled reactor periods in year 2000. When it was economically feasible, bulk irradiations were obtained from the Norwegian or Swedish research reactors and distributed to the Danish customers. In other cases the laboratory provided consulting services advising the customers and helping them with contacts to the foreign reactors. The production of short-lived isotopes has also suffered from the lacking access to irradiation facilities but the most urgent needs have been covered by irradiations in the Swedish research reactor, and for production of sodium-24 with low specific activity the reactor DR 1 has been used on four occasions. Some long-lived isotopes were partly in stock, others were produced from high-flux irradiations in the Swedish reactor. In that way the Isotope Laboratory has continued to produce radioactive isotopes and other radioactive materials for industry, hospitals and research institutions and deliver the radioactive materials needed for Risø's own research as ready-to-use preparations.

A total of 502 irradiations were carried out for use by Risø and 29 different external customers in Denmark, Germany, Italy, U.K., Slovakia, Spain and Australia, 211 of these irradiations were performed in foreign reactors. Altogether 78 shipments of other radioactive products were sent to a variety of institutes, industry and hospitals.

For research applications at Risø 24 irradiations were performed and 104 deliveries of specially prepared radioisotopes were made. For educational purposes 523 solid radioactive sources were supplied to the Nordic countries.

Overall, the number of irradiations decreased to 40 % and other radioactive products to 82 % of last year's figures and the number of sources for educational purposes was 84 % of last year's. These figures indicate the impact of the reactor closure.

7 Education

7.1 External teaching

In each autumn semester during the period 1998-2000 a senior scientist from the department has given a reactor physics lecture course for engineering students at the Technical University of Denmark. The course has comprised 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. Owing to the retirement of the senior scientist from Risø in 2001, the course will not be continued.

The DR 1 reactor has been used for educational purposes for a number of years. In 2000 a number of students from the Technical University of Denmark have participated in a reactor laboratory course at DR 1 as in previous years. During this course they have carried out experiments at the reactor over a period of three weeks. In addition, a number of high school classes have carried out one-day or half-a-day experiments at the reactor during the first half-year of 2000. In connection with the decision to permanently close the DR 3 reactor in 2000 and start to prepare for its decommissioning, it was also decided to terminate the educational activities at DR 1 and start to prepare for the decommissioning of DR 1 as well.

Two lectures on off-site emergency planning and response have been given at a one-week course at the research centre SCK•CEN in Mol, Belgium. The course entitled *Training course on off-site emergency planning and response to nuclear accidents* is part of the European Radiation Protection Education and Training (ERPET) programme.

7.2 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.

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

7.3 Internal teaching

The section of Applied Health Physics and Emergency Response Preparedness has given lectures and courses in radiation protection for Risø staff members. The following lectures have been given in 2000:

Periodic internal courses

- two introduction courses for new Risø employees
- course on health physics for 15 Risø staff members, 1 person from a private company seeking authorisation to work with radioactive substances and 3 laboratory technician trainees
- introduction course on working conditions in radiation and criticality areas for 2 external employees working at Risø

Education of new staff members

- training of a new health physics technician
- one specialised course for 3 new engineers at reactor DR 3

Re-training of staff members

- one specialised course for staff members at reactor DR 3

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
B. Majborn and P. Hedemann Jensen

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

Danish National Council for Oceanology
H. Dahlgaard

8.2 International

European Union

Consultative Committee Euratom - Fission
B. Majborn

External Advisory Group Euratom – Fission
S.P. Nielsen

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

Group for Nuclear Safety Research Index, NSRI
E. Nonbøl

OECD/NEA

Committee 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

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Radiation Measurements
L. Bøtter-Jensen

Radiation Physics and Chemistry
A. Miller (Editor-in-Chief)

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Other Committees

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

The Board of the Nordic Society for Radiation Protection
J. Søgaard-Hansen

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

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

International Solid State Dosimetry Organization
L. Bøtter-Jensen

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

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

9 Publications

9.1 Publications in international journals, books and reports

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The report presents a summary of the work of the Nuclear Safety Research Department in 2000. The department's research and development activities were organized in two research programmes: "Radiation Protection and Reactor Safety" and "Radioecology and Tracer Studies". In addtion the department was responsible for the tasks "Applied Health Physics and Emergency Preparedness", "Dosimetry", "Environmental Monitoring", and "Irradiation and Isotope Services". Lists of publications, committee memberships and staff members are included.

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