RISØ

Risø-R-625(EN)

Nuclear Safety Research Department Annual Progress Report 1991

Edited by B. Majborn, K. Brodersen, C.F. Højerup
and F. Heikel Vinther

Risø National Laboratory, DK-4000 Roskilde, Denmark
March 1992

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Abstract The report describes the work of the Nuclear Safety Research Department during 1991. The activities cover health physics, reactor physics, operation of the Danish educational reactor DR 1, and waste management.

Lists of staff and publications are included together with a summary of participation in international working groups etc.

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1 Introduction

The Nuclear Safety Research Department was created at the major reorganization of the research departments at Risø in March 1990. The department has three sections: The Health Physics Section, the Reactor Physics Section (with the reactor DR1) and the Waste Management Section.

The objective of this constellation was to concentrate in one department most of Risø's commitments in the nuclear field and the research needed to fulfil them. The commitments include the maintenance and further development of scientific and technical knowledge within the fields of radiation protection, reactor safety and radioactive waste management as a basis for Risø's consultative services to Danish authorities and others. The waste management plant is responsible for the safe handling and storage of radioactive waste from Risø as well as from other Danish users of radioactive materials.

This report describes the work of the Nuclear Safety Research Department in 1991. Lists of staff and publications are included together with a summary of the staff's participation in international working groups etc.

2 Health Physics

The work in the Health Physics Section includes modelling of atmospheric dispersion of radioactive substances, operation of the Danish system for monitoring potential radioactive contamination, development of software for the handling and presentation of radiation monitoring data, research and development in dosimetry and instrumentation, as well as radon research. The section also takes care of personnel dosimetry and service on health physics instruments at Risø and contributes to the emergency planning and preparedness.

2.1 Modelling of Atmospheric Dispersion

The main project in 1991 concerned development of on-line models in close co-operation with the Meteorology and Wind Energy Department and other national and international groups. The main co-operation partners are: Danish Meteorological Institute (DMI), Kernforschungscentrum Karlsruhe (KfK), Naval Postgraduate School, Monterey, CA (NPS), Laboratoire de Mècanique des Transferts Turbulents et Diphasiques, Nantes (LMTTD) and Central Research Institute for Physics, Budapest (CRIP). The work mainly aims at improving the models in respect to their application in emergency preparedness both for conventional and nuclear releases.

The on-line dispersion model RIMPUFF (RIsø Mesoscale PUFF-model), was enhanced with a sophisticated new model for plume rise based on the model developed by the air pollution laboratory of the Danish National Environmental Research Institute. Development of a fast model for calculating gamma doses from puffs started as a co-operation project between Risø and CRIP. Computer programs were developed for graphical presentation of the output from the RIMPUFF. This work was done under a contract with the CEC concerning the implementation of RIMPUFF into a coming European system for real-time calculation of the consequences of nuclear accidents (RESYS). RIMPUFF will constitute a mesoscale atmospheric dispersion module in RESYS.

Using data from LIDAR measurements, it has been proven that RIMPUFF realistically can simulate short-time concentration fluctuations.

Aujeszky's disease is a serious problem for Danish farmers and considerable effort is made to prevent the spread of this disease. Thus, a combination was established between a meteorological station and the on-line model in order to permit an on-line risk evaluation of this mainly wind-dispersed disease.

As a part of a contract with the Spanish company AMBIO, the consequences were evaluated of different choices of stack heights for power plants at the Canary Islands. In this project a combination of RIMPUFF and a new version of

the flow model LINCOM was used.

Capacity to model chemically reacting species (first-order processes) was incorporated in RIMPUFF.

2.2 Assistance to the Danish Civil Defence Agency

Risø operates the Danish system for monitoring potential radioactive contamination. Data are collected from 11 measuring stations distributed across the country and transmitted to a computer at Risø as well as to a computer at a Civil Defence location. Software for handling and presenting the data was developed at Risø during 1990 and 1991.

The monitoring system has shown good general stability, but a few points still require some attention.

In March Risø participated in a major Swedish-Danish Barsebäck emergency exercise »KSI« assuming filtered venting through the FILTRA plant. As a result of this exercise, some modifications were made in the ARGOS system, which is a computerized system for communicating, presenting and storing monitoring data. In November Risø participated in a minor Swedish-Danish Barsebäck emergency exercise dealing with a fire in a building with radioactive waste.

2.3 Participation in Nordic Co-operation

Under the Nordic Nuclear Safety Programme 1990-1993, the health physics section is entrusted with the management of the BER-3 project titled: Evaluation and Harmonization of the Planning of Countermeasures and the Use of Intervention Levels.

A working group has analysed the use of interventions under the scenario for the emergency drill »Exercise Sievert/Gotland«. The scenario assumes a Chernobyl-like accident giving a large release, resulting in doses from plume passage over and deposition on the Swedish island of Gotland.

Two methods were applied in the analysis of the radiation protection consequences: Cost-benefit analysis and multi-attribute analysis. As a parameter in the analysis, three α-values were applied in the calculations: 100, 20 000, and 100 000 $/manSv. The results will be published in a BER-3.2 report.

The BER-3 project was presented at the »International Seminar on Intervention Levels and Countermeasures for Nuclear Accidents«, 7-11 October 1991 at Cadarache, France, organized by the CEC.

Within the framework of another project BER-1.1: Real-time Dispersion Modelling, Riso and the Swedish Meteorological and Hydrological Institute (SMHI) are coupling the Risø mesoscale puff model (RIMPUFF) to the SMHI long range dispersion model RAM. Methods for connecting the HIRLAM flow model to RIMPUFF are being investigated by the Danish Meteorological Institute (DMI) and Risø. The aim of this work is to establish an integrated system for calculating the dispersion of toxic materials over long (1000 km) and medium ranges. HIRLAM and RAM are used for calculating the long-range dispersion, while RIMPUFF, using the windfield data from HIRLAM, shall calculate the dispersion on local/medium scales (100 km).

The co-operation with the Swedish National Institute of Radiation Protection concerning emergency preparedness planning was continued. Four KASSANDRA-programs were produced for the Swedish reactor sites Ringhals, Forsmark, Oskarshamn, and Barsebäck comprising all twelve nuclear power units in Sweden. For a given release and under given weather conditions, doses and dose rates can be shown on a map of the surroundings of the plants.

For the Swedish nuclear power plant Ringhals 1, the importance of the iodine filter was evaluated. A reduction in efficiency of the filter from 99% to 96% caused a less than 15% increase in doses in the surroundings.

2.4 Dosimetry

2.4.1 Personnel Dosimetry

Risø's personnel dosimetry service covers the individual monitoring of the personnel at Risø and at the Niels Bohr Institute Tandem Accelerator. Only persons actually involved in radiation work are equipped with a personal dosemeter. For controlling the radiation levels in areas where the use of personal dosemeters is not required, an extensive area-monitoring programme using TL dosemeters has been established.

In 1991 approximately 800 persons were monitored. Of these, 176 persons received doses above the registration level for external doses of

0.2 mSv. The total dose (collective dose equivalent) registered to the monitored personnel was 0.29 man sievert which is nearly the same total dose as that registered in 1990. 59 persons received internal doses caused by intake of tritiated water. The contribution to the total dose from internal doses was 0.016 man sievert. For 1990 the total internal dose was 0.008 man sievert. Figure 2.1. shows the distribution of the registered doses for 1991.

Results from an »Inter-comparison Programme for Individual Monitoring« were evaluated. For the Riso personnel dosemeter, the results were in good agreement with the expected values. The programme is co-ordinated by the IAEA and carried out under a research agreement.

2.4.2 CEC Technical Recommendations on Individual Monitoring

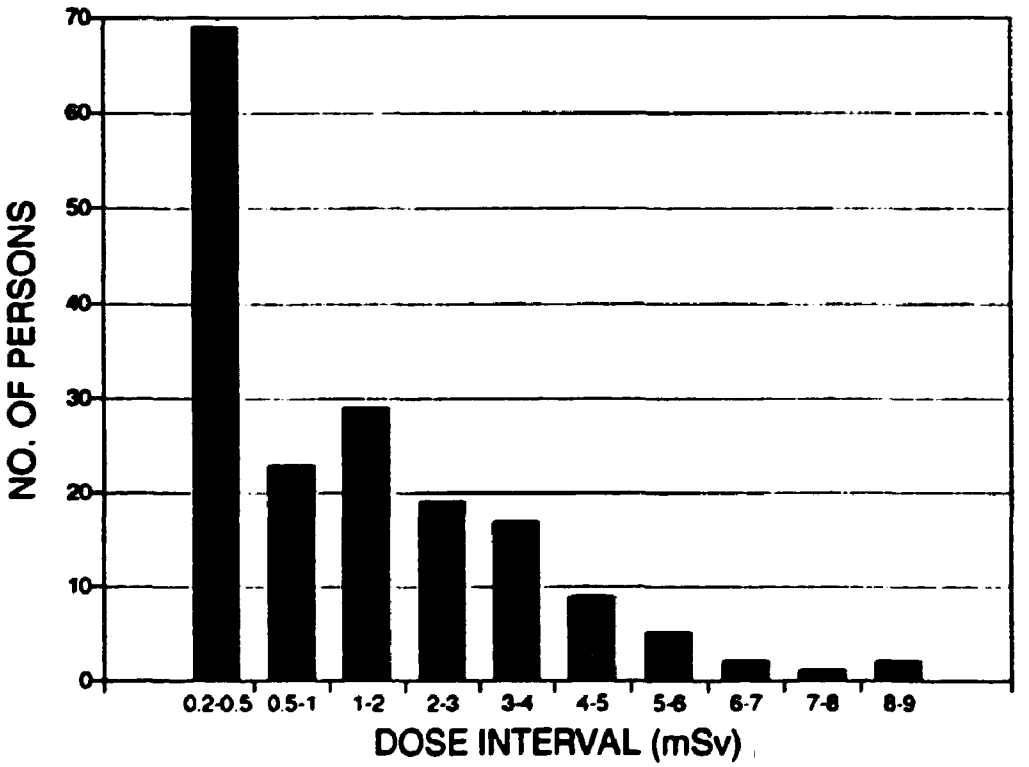
Together with other laboratories, the dosimetry group assisted the CEC in preparing a document on technical recommendations for monitoring the exposure of individuals to external radiation. The final document has been prepared and will be published in 1992.

Furthermore, a programme has been carried out for testing the performance of three different dosimetry systems in order to prove the adequacy of the recommendations prescribed in the document. The results of the study were reported at the Third International Conference on Radiation Protection Dosimetry, Orlando, 21-24 Oct. 1991. The results of the programme have proven the adequacy of the recommendations given in the document. Further evaluation of the results will take place and be published in 1992.

2.4.3 Dosimetry of Beta and Low-Energy Photon Radiations

In collaboration with six European laboratories, the group participates in a joint CEC research project aiming at improving the dosimetry of weakly penetrating radiations. The dosimetry group at Risø concentrated on characterizing the beta radiation field from a $^{106}Ru/^{106}Rh$ source using an extrapolation chamber. Furthermore the dosimetric characteristics of the highly sensi-

Figure 2.1. Distribution of wholebody doses (effective doses) in 1991 for the Riso personnel.



tive LiF:Mg,Cu,P TL phosphor were studied with a view to using this material for preparing thin detectors for weakly penetrating radiations.

Within the framework of EURADOS-CEN-DOS, studies continued on the determination of dose rates from low-energy beta sources. Measurements were made at four different laboratories of the dose rates from equal ^{147}Pm sources. The results were compared and various uncertainty sources identified. Results from this study were reported at the Workshop on Skin Dosimetry, Dublin, 13-15 May 1991.

2.4.4 Control of Irradiated Spices

In collaboration with the National Food Agency of Denmark, the group participated in an intercomparison programme for identification of irradiated spices using the TL measurement method. The results showed that the TL method is adequate for this purpose.

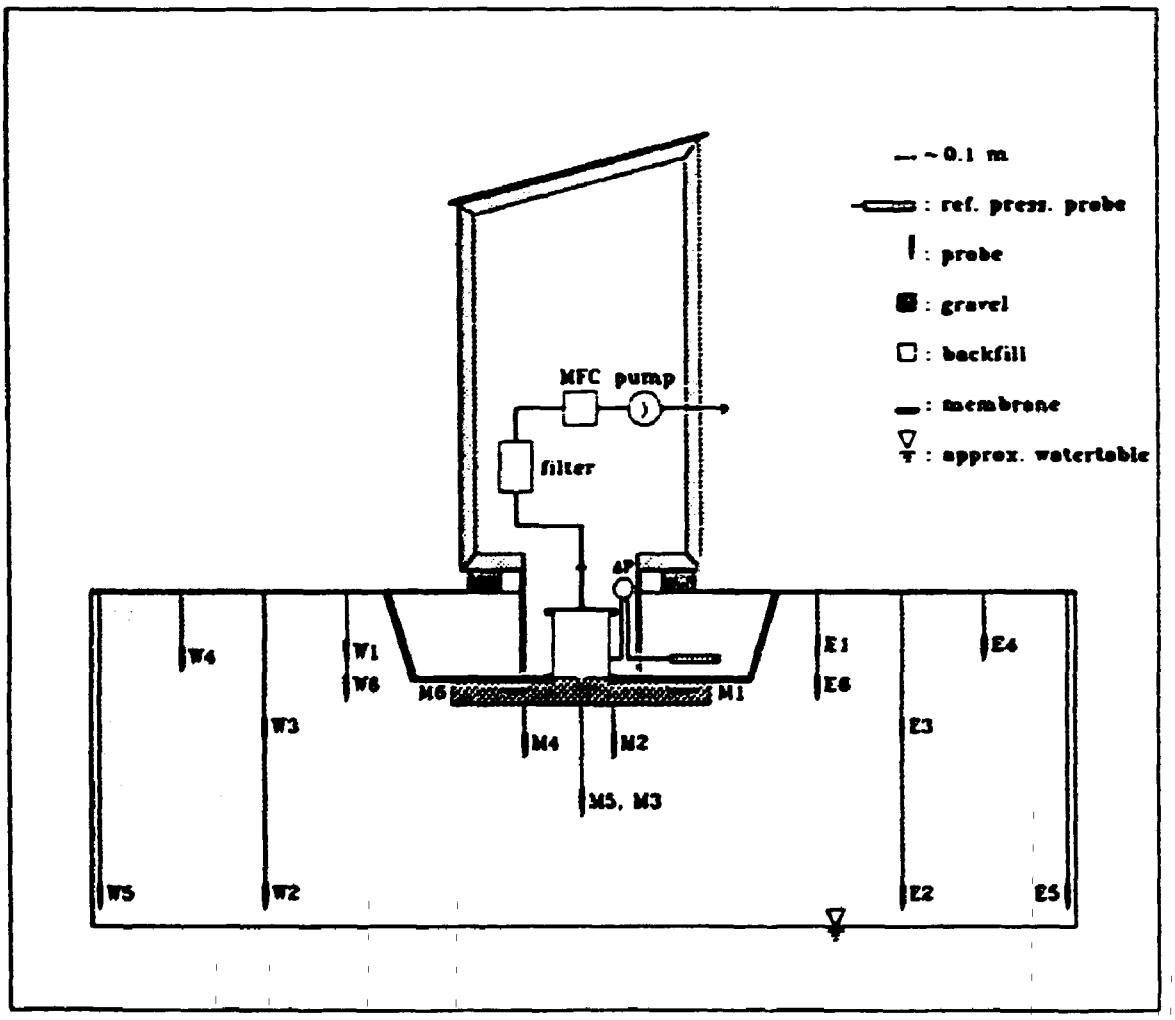
2.5 Radon Research

2.5.1 Radon Transport and Entry

A previously developed two-dimensional, finite-difference model for studying soil-gas transport has been extended to include radon transport. The model solves the equations for steady-state soil-gas and radon transport, including radon emanation, decay, diffusion, advection, and partitioning of radon between gas and liquid phases. The model is flexible, and problems related to houses, to our test structure, or to soil probes can be modelled in detail.

A test structure for experimental studies of radon transport under field conditions has been established at Risø. A cross-sectional view of the structure is shown in Figure 2.2. It consists of a 40 litre, stainless-steel cylinder placed in a 0.52 m deep quadratic excavation with a side length of 2.4 m. The excavation is lined with an airtight

Figure 2.2. Cross-sectional view of the radon test structure.



membrane, and soil gas enters the cylinder through a changeable interface in the bottom. The (de)pressurization of the cylinder is controlled by a mass-flow controller, and various parameters are logged onto a personal computer every 10 minutes.

Steady-state experiments have been conducted at the test structure. Four aspects were investigated: total flow resistance, pressure couplings, and radon concentrations under diffusive and advective conditions. Pressure couplings and radon concentrations were measured in 19 probes located in the soil surrounding the structure.

The experimental results have been compared with results of model calculations based on measured soil parameters. Measurements of gas permeability, soil moisture and radon emanation were made by the Department of Electrophysics, the Technical University of Denmark, whereas measurements of soil density and porosity were made by Risø.

For most of the probe locations, reasonable agreement was found between the measured and calculated values of the pressure couplings, the normalized radon concentration fields under diffusive and advective conditions, and the degree of radon depletion. However, discrepancies were found between measured and calculated absolute values of soil-gas entry rates and radon concentrations. The discrepancies indicate a need for further investigations concerning how detailed the soil characterization and modelling need to be in order to account for soil inhomogeneities.

2.5.2 Seasonal Variations

Seasonal variations of indoor radon concentrations have been studied in 70 single-family houses selected according to the type of substructure and the type of soil underneath the house. Five categories of substructure were included: Slab on grade, crawlspace, basement, and combinations of basement with slab on grade or crawl space. Half of the houses are located on clayey till and the other half on glaciofluvial gravel. In each house, radon was measured in a living-room and a bedroom, in the basement if present, and in the crawl space if present and accessible. The measurements were made with track detectors on a quarterly basis throughout a year.

For living-rooms and bedrooms, the seasonal variations ranged from being highly significant for the slab-on-grade houses to being insignificant for the crawl-space houses. For basements and crawl spaces, the geometric mean radon concentrations did not show significant seasonal variations.

For the distributions of the ratios of the seasonal to annual average radon concentrations, the standard deviations were found to be lower for the spring and autumn than for the summer and winter periods. This indicates that (for Danish climatic conditions) spring and autumn are the best seasons for carrying out screening measurements (say, of a few months duration) of radon in dwellings.

2.6 Development of Instruments and Methods

2.6.1 Optically Stimulated Luminescence (OSL)

In Optically Stimulated Luminescence (OSL), the research work continued with the development of a new OSL unit based on a simple halogen lamp light source for stimulation of quartz samples. The light from the halogen lamp is strongly filtered resulting in a green stimulation wavelength band which is necessary for OSL measurements of quartz samples. The green light scattered during the illumination of samples is discriminated by an ultraviolet detection filter pack placed in front of the photo detector cathode. In addition to the halogen lamp light source, the OSL unit incorporates an infrared diode array for measuring infrared stimulated luminescence (IRSL) from feldspar samples and for screening the purity of quartz. The new OSL unit can be fitted directly onto the automated Risø TL dating apparatus and thus permit combined infrared/green OSL and TL measurements to be performed by the same PM tube. The stimulation spectrum from the halogen lamp delivers about 16 mW/cm^2 at the sample. The new unit has successfully been used to date both archaeological and geological quartz samples with a significantly higher accuracy than previously obtained using the TL method. Another big advantage of OSL over TL is that much less sample material is needed for an age determination. A schematic diagram of the new OSL unit is shown in Figure 2.3.

In 1991 Risø delivered combined TL/OSL systems to the following research laboratories: University of Helsinki, Finland; University of Aberystwyth, Wales; University of Oxford, UK; University of Catania, Italy; University of Adelaide,

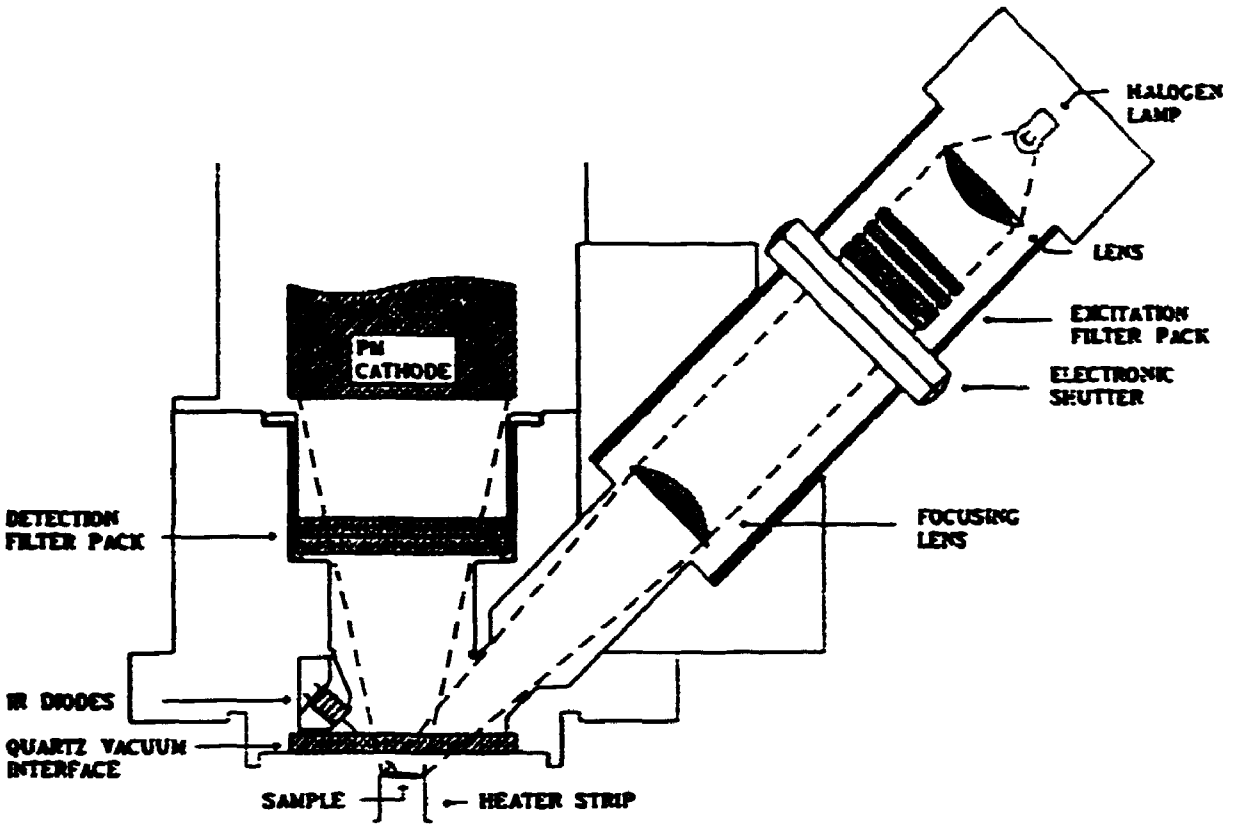


Figure 2.3. Schematic diagram of the combined green and infrared OSL unit attachable to the Risø TL system.

Australia; University of Melbourne, Australia; The Australian National University, Canberra (two pieces); University of Wollongong, Australia; Office of Nuclear Research for Peace, Bangkok; Rathgen Research Laboratory, Berlin; and Institute for Social Medicine, Berlin.

2.6.2 The Measurement of Environmental Gamma Radiation

The instrument group continued the co-ordination of a CEC research project aimed at testing different detector types for environmental photon radiation and establishment of practical calibration procedures. Monte Carlo calculations were carried out to determine the scattered air kerma rates in free-field and shadow-shield calibration geometries using different certificated gamma sources. Four European laboratories participated in the intercomparison project.

2.6.3 Low-level Beta Multicounters

Development work continued on gas-flow anticoincidence multicounter systems for low-level beta counting applications by changing the mechanical counter geometry. The total height of the counter unit was halved resulting in an improved shielding effect. In 100 mm lead shielding and in a normal ambient radiation level, the background was reduced from 0.20 cpm to approximately 0.14 cpm implying a significant improvement. The new counter construction was further tested in the ultra-low radiation environment in the Asse salt mine. The ambient background in 1000 m depth is less than 1 nGy/h and thus a hundred times less than that on the surface. The counter background was reduced to about 0.03 cpm, i.e. by a factor of about five. The remaining signal reflects the inherent counter background and is due to impurities of the construction materials.

Two beta multicounter systems were delivered to the National Institute of Radiation Protection, Reykjavik, Iceland, and to the Alfred Wegener Institute, Bremerhaven, Germany.

List of Publications and Presentations

Aarkrog, A., Nielsen, S.P., Holm, E., Ohlenschlæger, M., Botter-Jensen. L., Quingjiang, Chen., (1991). Behaviour of long-lived radionuclides in terrestrial and marine (North Atlantic Region) environments. 1. Terrestrial environment: Dynamic models of the human food chain and determination of less well known long-lived radionuclides. Final report. In: Radiation protection programme. Progress report 1985-1989. Volume 1. EUR-13268 (v.1) p. 577-588.

Aarkrog, A., Hansen, H., Botter-Jensen, L., Nielsen, S.P., Clausen, J. (1991). Radioaktiviteten i Risøområdet juli-december 1990. (Radioactivity in the Risø district July-December 1990). Risø-I-538 21 p.

Aarkrog, A., Hansen, H., Botter-Jensen, L., Nielsen, S.P., Clausen, J. (1991). Radioaktiviteten i Risø-området januar-juni 1991. (Radioactivity in the Risø district January-June 1991). Risø-I-571(EN) 22 p.

Andersen, C.E., Søgaard-Hansen, J., and Majborn, B., Radon entry into a simple test structure. Paper presented at Fifth International Symposium on the Natural Radiation Environment, Salzburg, 22-28 September 1991.

Brøns, P., Hansen, H., Andersen, E. (1991). Vor radioaktive klode 3. Naturlig radioaktivitet i hverdagen. *Nat. Verden* (no.5) p. 193-208.

Brøns, P., Hansen, H., Andersen, E. (1991). Vor radioaktive klode 5. Nedfald fra kernevåbenforsøg. *Nat. Verden* (no.8) p. 313-320.

Botter-Jensen, L., Ditlefsen, C., Mejdahl, V. (1991). Combined OSL (infrared) and TL studies of feldspars. *Nucl. Tracks Radiat. Meas.* v.18, p. 257-263.

Botter-Jensen, L. and Duller, G.A.T., A New System for Measuring OSL from Quartz Samples. Paper presented at International Luminescence and ESR Dating Seminar, Aberystwyth, Wales, 24-25 Sept. 1991.

Botter-Jensen, L. (1991). Ny teknik til måling af strålingsdoser. *Risønyt* (no.3) p. 14-15.

Christensen, P. (1991). Calibration and evaluation procedure for the Risø badge. In: *IAEA Intercomparison for Individual Monitoring*, Vienna, 1989, PTB Bericht: PTB-Dos-20, p. 171-173.

Christensen, P. (1991). Individual monitoring in mixed photon-beta fields. In: *IAEA Intercomparison for Individual Monitoring*, Vienna, 1989, PTB Bericht: PTB-Dos-20, p. 272-286.

Christensen, P., Study of LiF:Mg,Cu,P TL detectors for individual monitoring for weakly penetrating radiations. Paper presented at 23rd International Symposium, *Radiation Protection Physics*, 8-12 april 1991, Gaussig, Germany.

Christensen, P., Julius, H.W., Marshall, T.O. (1991). Implication of new CEC recommendations for individual monitoring for external radiation dose to the skin and the extremities. In: Proceedings of a workshop held in Dublin May 13-15 1991. *Radiat. Prot. Dosim.* 39, p. 91-94.

Francis, T.M., Böhm, J.L., Chartier, J.-L., Christensen, P. (1991). Experience gained on extrapolation chamber measurement techniques from an intercomparison exercise conducted with a ^{147}Pm source. In: Proceedings of a workshop held in Dublin May 13-15 1991. *Radiat. Prot. Dosim.* 39, p. 109-114.

Hedemann Jensen, P., Thykier-Nielsen, S. (1991). Shielding factor calculation for plume radiation. Final report. In: Radiation protection programme. Progress report 1985-1989. Volume 3. EUR-13268(v.3), p. 2619-2631.

Heikel Vinther, F. (ed) (1991). List of selected publications from Risø's Health Physics Department 1957-1989. Risø-M-2914, 95 p.

Heikel Vinther, F. (ed) (1991). Nuclear Safety Research Department annual progress report 1990. Risø-M-2944(EN), 36 p.

Herrnberger, V.R.D., Thykier-Nielsen, S. Comparison of wind models for real time dispersion simulation of tracer experiments conducted over complex terrain during weak flow conditions. In: 19th. NATO/CCMS International Meeting on Air Pollution Modelling and its Applications, Ierapetra, Crete, September 29 - October 4 1991. Vol. 2. (University of Athens, 1991) p. 567-568.

Julius, H.W., Marshall, T.O., Christensen, P., Type testing of personnel dosimeters for photon energy and angular response. Paper presented at Third Conference on Radiation Protection and Dosimetry, 21-24 October 1991, Orlando, USA.

Le Grand, J., Roux, Y., Meckbach, T., Jacob, P., Hedemann Jensen, P., Thykier-Nielsen, S. (1990). External exposure from airborne radionuclides. In: Proceedings of the seminar on methods and codes for assessing the off-site consequences of nuclear accidents, Athens, 7-11 May 1990. Preprint, Volume 1. Commission of the European Communities. EUR-13013(v.1), p. 385-406.

Majborn, B. (1991). CENDOS-EURADOS 1988-89 neutron dosemeter irradiations. Results from Riso National Laboratory. In: Schraube, H. (ed), Response of proton-sensitive etched track detectors to fast neutrons: Results of a joint multilaboratory experiment. GSF-Bericht-22-90, p. 43-48.

Majborn, B., Seasonal variations of radon concentrations in single-family houses with different substructures. Paper presented at Fifth International Symposium on the Natural Radiation Environment, Salzburg, 22-28 September 1991.

Menzel, H.G., Christensen, P., Dennis, J.A. (eds) (1991). Skin dosimetry. Proceedings of a workshop held in Dublin, May 13-15 1991. *Radiat. Prot. Dosim.* 39, 208 p.

Mikkelsen, T., Jørgensen, H.E., Thykier-Nielsen, S. (1990). Model validation experiments over short distances. In: Proceedings of the seminar on methods and codes for assessing the off-site consequences of nuclear accidents, Athens, 7-11 May 1990. Volume 1. Commission of the European Communities. EUR-13013(v.1), p. 97-117.

Mikkelsen, T., Kristensen L., Thykier-Nielsen, S., Pécseli, H.L., Jørgensen, H.E. (1991). Validation experiments for near-site region atmospheric dispersion models. Final report. In: Radiation protection programme. Progress report 1985-1989. Volume 3. EUR-13268(v.3), p. 2969-2982.

Olsson, O., Holm, E., Bøtter-Jensen, L., Development of a low level - low background beta-particle spectrometer. Paper presented at ICRM low-level radioactivity measurements symposium, Monaco, June 4-7 1991.

Pelliccioni, M., Prokic, M., Esposito, A., Nuccetelli, C., Christensen, P. (1991) Energy response of graphite-mixed magnesium borate TLDs to low-energy x-rays. *Appl. Radiat. Isot. v.42*, p. 1037-1038.

Roed, J., Gjørup, H.L., Hedemann Jensen, P., Heikel Vinther F. (1991). Experimental and modelling approach to assess indoor doses in urban agglomerations and evaluation of the decontamination through run-off of deposited materials. Final report. In: Radiation protection programme. Progress report 1985-1989. Volume 3. EUR-13268(v.3), p. 3061-3072.

Sinnaeve, J., Olast, M. (eds) (1991). Improvement of practical countermeasures: The urban environment. Post-Chernobyl action. Final report. EUR-12555, 311 p.

Thykier-Nielsen, S., Mikkelsen, T., AMBIO report. Dispersion studies on Gran Canaria and Tenerife (Riso National Laboratory, Roskilde, 1991) 32 p.

Thykier-Nielsen, S., Mikkelsen, T., RIMPUFF users guide. Version 30 (PC version). (Riso National Laboratory, Roskilde, 1991) 58 p.

Thykier-Nielsen, S., Mikkelsen, T., Gassmann, F., Herrnberger, V., Comparison of windfield-dispersion models with tracer experiment in weak natural flow conditions of complex terrains. In: Jahrestagung Kerntechnik '90. Nürnberg 15-17 May 1990. Fachsitzung. Atmosphärische Ausbreitung von Radioaktivität in komplexen Gelände. (INFORUM, Bonn, 1990) p. 42-64.

Thykier-Nielsen, S., Mikkelsen, T., Herrnoerger, V., Real-time wind and dispersion simulation of tracer experiments conducted over complex terrain during weak and natural flow conditions. In: Proceedings of the specialists' meeting on advanced modelling computer codes for calculating local scale and mesoscale atmospheric dispersion of radionuclides and their applications, Saclay, 6-8 March 1991, (NEA/OECD, Paris, 1991) p. 86-112.

Walmod-Larsen, O., Lippert, J. (1991). Målestationer for radioaktivitet viser store udsving. I luft fra Centraleuropa kan radonmængderne være store. *Ingeniøren, v.17* (no.20) p.24.

Walmod-Larsen, O., Harmonization of countermeasures in Scandinavia. Paper presented at international seminar on intervention levels and countermeasures for nuclear accidents, Cadarache, France, 7-11 October 1991.

3 Reactor Physics

n the Reactor Physics Section, work is done in he following areas:

) Reactor physics research
) Nuclear safety investigations
) Activities at the DR 1 reactor

3.1 Reactor Physics

n the field of reactor physics, some further deve- opment work has been carried out on the system f LWR codes, which is the result of many years f work.

- A model for reconstruction of detailed fuel pin powers from coarse mesh core simulator calculations has been developed and tested (3.1.1).
- A new method for calculation of flux distributions in LWR fuel assemblies, based on collision probabilities and interface currents, is under development and an excerpt of the theory presented in (3.1.2).
- The Nodal Expansion Method, which is used for large node reactor calculations in 3 dimensions, has been written in a 2-dimensional version and used in an international benchmark calculation (3.1.3).
- Four of the most used reactor physics codes are written in ALGOL, which by the end of 1992 becomes an obsolete language at Risø. Therefore the work of transferring them into FORTRAN has been undertaken and is well underway (3.1.4).
- Our neutron cross section library is of a rather old date. Work is going on to replace it with the new JEF-2 file from the NEA Data Bank (3.1.5).
- Calculations of the reactivity worths of stainless-steel absorbers have been made for the DR 3 reactor. Also the construction of a new facility for storage of spent fuel elements has required extensive safety documentation calculations (3.1.6).

3.1.1 Pin Power Reconstruction

Core simulators are codes used for calculations of power distributions in reactor cores during operation. They are typically coarse mesh codes utilizing neutron cross sections calculated by separate support codes.

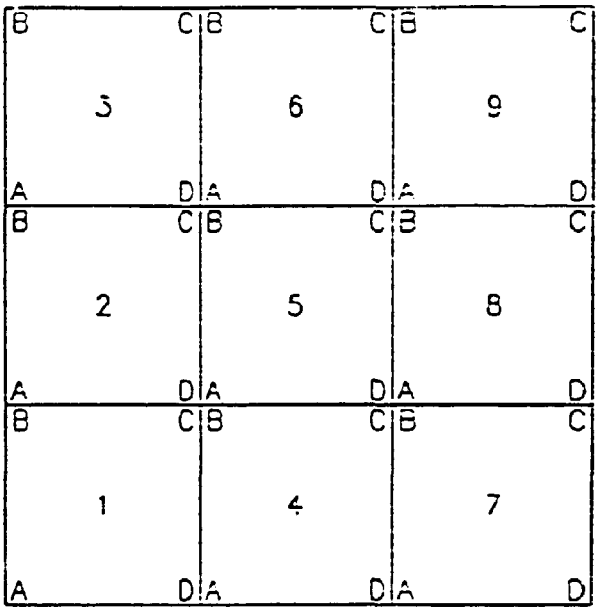


Figure 3.1. A node (5) with its eight neighbours.

They are well suited for calculating the average powers in the coarse meshes, which may often be sections of whole fuel assemblies. Thus, there is a need to develop some methodology to estimate the detailed fuel pin powers from the assembly averages.

Such a method has been developed and implemented in the COSIMA core simulator code.

The method utilizes the fact that in addition to the average node fluxes, also the average node surface fluxes are known.

This makes it possible to find an expression of the flux inside a node (in the x-y plane) with 5 terms:

$$\varphi(x,y) = \sum_{i,j=0,1,2} a_{ij}x^iy^j$$

with the additional restriction that either i or j be 0.

This is now done for a node (5) and its eight neighbouring nodes (Figure 3.1).

The flux in corner point A of node 5 can then be expressed as the mean of C_1, D_2, A_5, B_4 and similarly for the other three corners of 5. Forcing the flux in node 5 to attain these new values in the corners provide 4 new equations, such that the full 9 terms expansion

$$\varphi(x,y) = \sum_{i,j=0,1,2} a_{ij}x^iy^j$$

can be made.

The final flux and power distribution in the individual pins are then constructed as a superposition of the $\varphi(x,y)$ as found above and the detailed pin-flux distribution from the cross section generating support program, in our case the LEWARD code.

3.1.2 Nodal Collision Probability Theory

Detailed neutron energy spectra may be calculated locally in a reactor in the form of multigroup flux solutions of the integral transport equation. The classical solution method using collision probabilities to describe the interaction between regions is suitable for small systems such as a unit cell consisting of a cladded fuel pin or control rod with surrounding water, but is inadequate due to excessive computing times for larger systems such as a whole fuel assembly. The advent of nodal solution techniques has brought such problems within reach for practical applications.

In the nodal method, the coupling between cells (or nodes) is established by the so-called interface current technique, thus eliminating all non-neighbour connections, while the collision probability method is maintained for the flux distribution within each cell.

The nodal method is implemented in a new BWR fuel assembly code under development. Collision, escape, and transmission probabilities are calculated by three subroutines modelling pin cells, control-blade rods, and fuel box boundary cells (water gaps). Fluxes and interface currents are calculated by traditional iterative methods. A few preliminary tests have been run to see that things »look reasonable«.

Work is now in progress to improve the above-mentioned subroutines with respect to geometric resolution and efficiency of the numerical integration techniques. Furthermore, a new method to improve the solution efficiency of the equation system has been proposed as described in an internal report. Basically, the method employs Gaussian elimination of the fluxes, leaving only a reduced set of interface current equations in terms of multiple flight transmission probabilities to be solved iteratively, and the convergence has been proven to be good.

3.1.3 2-Dimensional NEM Code

In the Nodal Expansion Method the flux inside a homogeneous node is expanded in polynomials. This is an improvement compared to ordinary diffusion codes, where the flux in a node is assumed constant. Therefore, one should expect better results from a NEM code. At the same time, it lends itself to a more flexible boundary condition specification than do the diffusion codes.

When a NEACRP benchmark exercise on PWR fuel assemblies required checker-board boundary conditions, it was decided to modify our 3-dimensional NEM code into a 2-dimensional code, which was subsequently used for the benchmark. The results from the other participants in the benchmark are not yet available.

The speed of the code is somewhat slower than the diffusion codes, but has been found to be very sensitive to the choice of convergence parameters.

3.1.4 Computer Code Conversion

At the end of 1992 the ALGOL based computer at Risø will be closed. Most of the reactor physics programmes developed at Risø during the last twenty years have been implemented on the machine in the programme language ALGOL. This language cannot be applied on modern computers, therefore a programme conversion from ALGOL to FORTRAN has been initiated.

During 1991 two programmes have been converted to FORTRAN, that is the simulator of DR 3, DR3SIM, and another important code for reactor physics calculations for DR 3 called DIFF2D. The work will continue in 1992 with two other important reactor physics codes.

3.1.5 Neutron Cross-Sections

Work is in progress on replacing the old UKNDL cross-section library (from 1970) with the Joint Evaluated File (JEF) data from the Nuclear Energy Agency (NEA). The NJOY program system with updates for processing nuclear data in the ENDF/B-VI format has been implemented and tested on the VAX-8700. The international co-operation on benchmark testing of the JEF data continued to the end of the year, and so we are awaiting the release of the first version 2.2 of the JEF-file.

3.1.6 DR 3 - Reactor Physics

The research reactor DR 3 at Risø is going to have a new intermediate storage facility for spent fuel elements. For that purpose criticality calculations have been performed on different fuel storage configurations and accident scenarios.

The results show that even if the storage facility is flooded with water the configuration is still well subcritical.

In future the DR 3 reactor will utilize stainless steel absorbers to compensate for part of the uranium burnup. The benefit from this is a more constant axial flux distribution due to less use of the coarse control arms.

A model of the stainless steel absorbers has been implemented in the simulator DR3SIM and the results tested against measurements.

3.2 Safety-Related Work

The safety-related work consists of

- Studies of aerosol behaviour and of hydrogen phenomena in containments (3.2.1)

works in the framework of the SIK projects initiated by the Nordic Committee on Safety Research (NKS)

- SIK-2, on »Severe accidents« (3.2.2)
- SIK-3, on »Safety-related data for neighbour reactors« (3.2.3)

the EEC project

- ENTOREL, which examines the reliability of robots, (3.2.4) and the Risø Study Group for Nuclear Preparedness, which has been dealing mainly with initial studies of
- Advanced reactors (3.2.5)

3.2.1 Aerosol Behaviour and Hydrogen Phenomena in Containments

A thermal-hydraulic code, CORAN, for COntainment Response ANalysis, was obtained from the NEA Data Bank. It has now been installed on a PC. In parallel with this, the code was also installed on Risø's Vax 8700. During installation, a number of problems were encountered. The most important one is an instability in the chosen (explicit) integration procedures. Introduction of an implicit scheme was not successful, but subdivision of the original fixed-length timestep proved efficient.

Hydrogen Deflagration

A Ph.D.-project was initiated on the subject of hydrogen deflagration in relation to reactor accidents. The experimental part of the project has benefitted from the hospitality of the Battelle Institute in Frankfurt am Main, Germany, and of the Whiteshell Laboratories in Pinawa, Canada. Presently, the experimental work is concentrated around multiple ignition. These experiments are being performed at Whiteshell.

3.2.2 SIK-2, Severe Accidents

SIK-2.6, Assessment of Aerosol Modelling, is one of the tasks in the Nordic SIK-2 project on Nuclear Reactor Accident Analysis.

In the middle of 1991, permission from the USNRC was obtained, so that work on some of the proprietary codes could commence. Through the hospitality of VTT, Finland, access to some of the source texts and to a number of otherwise inaccessible manuals was obtained. The codes considered are primary system codes. Reporting is underway.

3.2.3 SIK-3, Safety Related Data for Neighbour Reactors

The objective of the SIK-3 project is to collect, systematize and evaluate safety related data of nuclear installations within and close to the Nordic borders. The data include design features and operational practices significant for the plant safety. The data collected and the expertise gained in the project have two main applications:

- On basis of the data, the safety authorities can respond to general safety related questions concerning a particular design. Such questions can come from politicians, the public, or the media.
- In case of an emergency situation in a plant located in a neigbouring country, the data can help the Nordic safety authorities to determine the severity and course of the accident, potential external consequences and necessary emergency response actions.

The data are presented in reports consisting of about 100 pages for each nuclear power plant or installation.

Riso has the project management of SIK-3, which was started in 1990 and will continue until the end of 1993.

Reports on the following nuclear installations have been finished:

- Greifswald I-VIII
- Leningrad I-IV
- Ignalina I-II
- Ship reactors

3.2.4 ENTOREL

ENTOREL (ENvironmental TOlerance and RE-Liability) is part of an EEC cost shared action programme named TELEMAN. The objective of this programme is to develop remote operated robots to be used in nuclear power plants, reprocessing facilities etc.

ENTOREL is headed by the Risk Analysis Group and is conducted in collaboration with CEN, Belgium, Harwell, UK, and Interatom, Germany.

Data on radiation damage in components are collected and organized in a database. All the other partners in the Teleman-project will have access to this database. Furthermore a general reliability model of a gantry crane robot was set up based on identified top events, fault trees and FMEA (Failure Modes and Effects Analysis).

3.2.5 Studies of Advanced Reactor Concepts

In the Study Group established in 1987 with the purpose of gathering the people in Denmark possessing knowledge in the nuclear-technological field, the work up to the middle of 1991 has been concentrated on collecting data and information concerning reactors in the neighbour countries to Denmark, i.e. Sweden and Germany. This work has resulted in several reports on the specific power plants and is now finished apart from a continuous minor updating effort.

As a new study object we have chosen the new concepts for advanced reactors. Three types have been selected for further examinations, the PWR-types, the BWR-types, and the fast reactor types.

Among the PWRs, the types PIUS, SIR, and AP600 have been looked at. In the BWR category the SBWR and the ABWR are candidates, and as the fast reactor the IFR/PRISM concept has been chosen.

When these 6 types have been evaluated, a final choice for further detailed studies of one or more concepts will be made.

3.3 Danish Reactor DR 1

The reactor has been used almost exclusively for educational purposes. 54 high school classes have carried out one-day or half-a-day experiments at the reactor. The total number of students has been more than 900.

Some of the experiments were:

- Determination of the reactor's temperature-, power-, and bubble coefficients
- Neutron activation analysis
- Measurements of neutron cross sections

A number of students from the Technical University of Denmark have carried out experiments at the reactor over a period of three weeks.

Bit Errors in Computer Memories

A Danish software house has experienced problems with bit errors in small computers. The computers are used on long distance passenger flights and the errors in the SRAM's (Static Random Access Memory) were observed after 150 - 300 hours of flying. A series of tests was conducted to rule out »conventional« causes like vibrations, extreme temperatures etc.

An initial exposure to a neutron source available at DR 1 resulted in the same bit errors. Another test with gamma radiation showed no effects after a dose of 0.5 Gy.

Fast neutrons are encountered at flight altitudes. The neutrons are produced when cosmic rays interact with oxygen and nitrogen. Subsequently, the fast neutrons react with silicon in the memory chips producing α-particles and protons. These particles ionize part of the chip resulting in a shift in the memory (a bit error or a single event upset).

A number of tests were conducted with a special check program loaded into the computer. The program records the time and location of the error (and resets the error). The mean time between failures ranged between 6 and 8 hours, and the time between failures followed an exponential distribution. The neutron flux in the test was a factor of 200 higher than the one actually en-

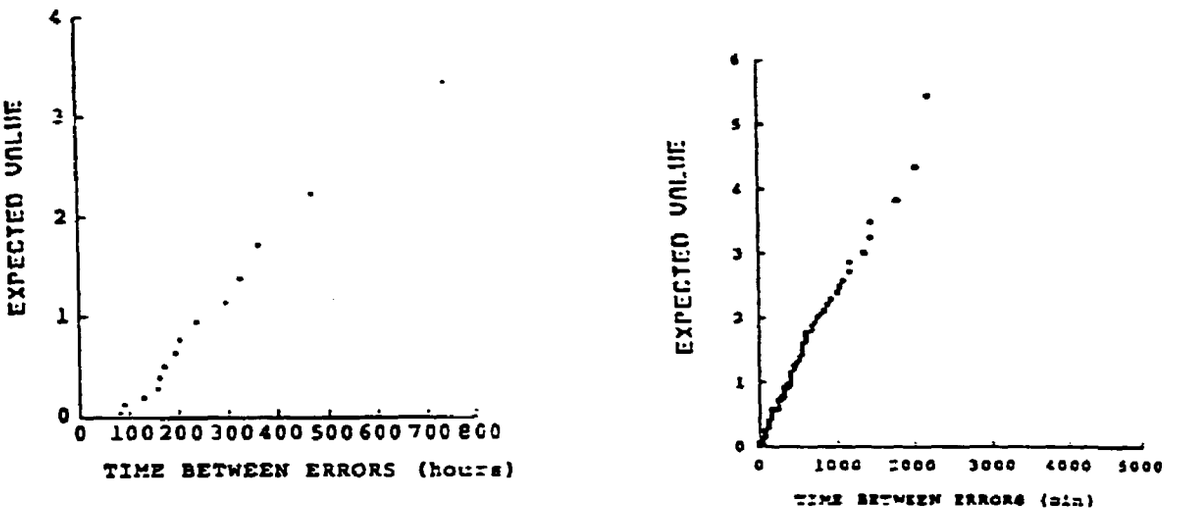


Figure 3.2. Verification of the exponential distribution of the time between failures.

countered during flights.

In Figure 3.2 the exponential distribution of the time between errors is demonstrated. The expected values have been plotted against the observed values. The points should then fall on a straight line.

List of Publications and Presentations

Becher, P.E., Sikkerhedsaspekter ved avancerede reaktorer. Presented at the meeting of the Nuclear Preparedness Group at Risø, Jan. 22 1991.

Bujor, A. (1991). Discussion of the Concept of Safety Indicators from the Point of View of TfuX2 Accident Sequence for Forsmark-3. Risø-M-2926.

Bujor, A. (1991). Review on Hydrogen Generation, Transport, Combustion, and Mitigation Techniques in the Reactor Containment. Risø-I-532.

Fynbo, P.B. (1991). Implementering af CORAN. Risø-I-553.

Fynbo, P.B. (1991). Tjernobyl - 5 år efter. *Ingeniøren*, vol. 17, no. 17.

Højerup, C.F., Avancerede reaktorer. RP-01-91. Paper presented at the meeting of the Nuclear Preparedness Group at Risø, Jan. 22 1991.

Højerup, C.F., Opstart og drift af svensk BWR. Risø-I-535. Paper presented at the meeting of the Nuclear Preparedness Group at Risø, June 13 1991.

Højerup, C.F. (1991). Advanced Reactors - SIR (Safe Integral Reactor). A Technical Description. Risø-I-563.

Højerup, C.F., A nodal collision probability method for use in the LWR assembly flux calculations. Presented at the Meeting on Reactor Physics Calculations in the Nordic Countries, Stockholm, April 16-17 1991.

Højerup, C.F., Nonbøl, E., Core-follow Studies of Quad Cities Cycle 1 and 2 with Special Emphasis on Pin Comparisons at the End of Cycle 2. Proceedings of the international topical meeting on advances in mathematics, computations, and reactor physics. Vol. 3. Pittsburgh, PA, 29 April - 2 May 1991.

Nonbøl, E., Ølgaard, P.L. (1991). Greifswald Nuclear Power Plant I-VIII. Risø-I-542.

Nonbøl, E. (1991). Hjemtagning af koder fra NEA Databank. Risø-I-557.

Nonbøl, E. (1991). Kritikalitetsberegninger på nyt mellemlager for brændselselementer på DR 3. Risø-I-578.

Nonbøl, E., Beskrivelse af uheldssekvens fra tidligere Barsebäckøvelse. Presented at the meeting of the Nuclear Preparedness Group at Risø, June 13 1991.

Nonbøl, E., Pin Power Implementation in the Nodal Code COSIMA. Presented at the Meeting on Reactor Physics Calculations in the Nordic Countries, Stockholm, April 16-17 1991.

Olsen, J. (1991). Reaktorkursus DR 1. Januar 1991. Risø-Dok-149.

Thomsen, K.L. (1991). Nodal Collision Probability Methods with Separation of Flux and Current Solution. Risø-I-565.

4 Waste Management

The Waste Management Section takes care of collection, purification, conditioning and storage of radioactive and/or chemically toxic waste materials arising in connection with the nuclear installations or other laboratory work at Riso. The facilities are also used as a centre for management of radioactive waste recieved from other Danish users of radioactive substances (laboratories, hospitals and industry). It is not planned to dispose of the radioactive waste packages stored at Risø within the nearer future, but the Waste Management Section contributes to the international research efforts concerned with documentation of safe storage and disposal of radioactive waste. Experimental work is carried out on long-term properties of bituminized or cementitious materials. Some work on soil chemistry is also carried out.

4.1 Waste Management

The radioactive waste water purification plant, the bituminization plant and the compaction system for low-level solid waste were operated as in previous years. The total release with purified water (excluding tritium) was −182 MBq, partly in form of ^{131}J. This is more than three times the amount released last year but still only about 2% of the permitted releases. Further details are given in [1].

Some new measurement methods employed on the off-gas from the bituminization plant indicated a considerable release of ^{14}C in form of carbon dioxide when used ion exchange resins from DR3 are treated in the plant. A change in procedure is under consideration.

A total of 119 drums with conditioned low-level waste was produced and put in ad hoc storage awaiting transfer to a new storage facility under construction. The building will be ready for use medio 1992. External radiation levels from the existing storage facility (Betonrørslageret) for older drums with low-level waste were remeasured and evaluated due to some concern expressed by employees at the new National Environmental Research Institute laboratory situated near the storage area. The results were in good agreement with previous estimates of the external radiation and well below any reasonable level of concern. During the next 2 to 3 years the waste units will be moved from the old storage area to the new building under construction. This is done to upgrade the storage conditions for the waste units and to obtain greater planning flexibility for use of the area north of the facility where the old drums are placed now.

Decommisioning work at the Risø Hot Cells continued during 1991 and resulted in further transfer of samples of irradiated fuel and packaged α-contaminated equipment to the storage facility for these types of waste (Centralvejslageret).

The inactive waste-water purification plant and the collection system for inactive chemically toxic wastes were operated as usual.

Some further documentation have been prepared as background for the application for a permit to dispose of sludges from the waste water purification plant outside Risø. The sludge is an example of materials where it have to be defined whether the slight content of radioisotopes is below regulatory concern. Presently and as a general question this is of considerable interest to radiation-protection authorities also internationally.

This and many other aspects of radioactive waste management are discussed within the EC system by the ACPM for the Plan of Action concerned with management of radioactive waste within the European Communities. Risø participates together with representatives of the Danish nuclear regulatory authorities in the committee and in working groups under the committee. In 1991 considerable efforts have been spent on assisting in formulation of the 3rd CEC report on »Radioactive Waste Management in the European Community, Present Situation and Outlook.«

4.2 Waste Material Properties Research

The research efforts of the Waste Management Section are concentrated within three main areas:

- Properties of cementitious materials.
- Our previous CEC contract work on cemented waste and concrete used as a barrier material was published [2,3,4] and used as background for a paper (to be published in 'Waste Management') describing experiments with

and modelling of hygroscopic water uptake in cemented waste containing easily soluble salts. The matter is of some concern in case of near-surface disposal.

- The work was also used in connection with an invited rewiev article on pore structure in cementitious materials presented [5] at the 15th Int. Symp. on the Scientific Basis for Nuclear Waste Management, arranged by E-MRS in Strasbourg in November 1991 (to be published in Cement and Concrete Research). The paper describes the pore structure within the frame of percolation theory and with reference to the many methods used for characterization. The pore structure is very complex involving at least two types of porosity. The study is valuable as background for SANS measurements on cement paste (see below).

Considerable modelling work has also been done in connection with these two papers and on general cement chemistry in preparation for future work.

Experimental work under a new CEC contract on cement was initiated, and the first annual report May-Dec 1991 is available. The studies are carried out in co-operation with AEA Technology, Harwell.

The main topic is crack closure in concrete due to deposition of calcium carbonate from a flow of bicarbonate-containing groundwater. Actual closure of cracks as well as deposition of more or less impervious layers on the crack surfaces are of importance for safety assessments. The first is a positive feature because flow is prevented, but the second is negative, preventing access to the buffering alkalinity present in a cementitious backfill material. Studies on material relocation in (granulated) cementitious products due to a flow of CO_2-free water are also carried out.

Work on characterization of the micro-structure of degrading cement using SANS (Small Angle Neutron Scattering) was continued also under this contract. The improved experimental facility and the more advanced data-handling and curve-fitting procedures appear to give interesting results (co-operations with the Chemistry Section and the Solid State Physics Department).

- Properties of bituminized waste materials.
  Our previous CEC contract work on bituminized waste is presented in [3,4]. A conceptual model for water uptake in bituminized waste containing easily soluble salts is presented in [3] and has been utilized in formulating a dynamic computer model of the phenomenon. It runs on a PC but is not yet finished. A description is in preparation.
- A new CEC contract within the area (in co-operation with CEN Cadarache, France, and CEN/SCK Mol, Belgium) has been accepted, but the formal signatures were delayed. There are therefore no new experimental results available. The proposed studies are of direct relevance for the type of bituminized waste produced at Risø.
- Radioactive contaminated soil may arise in connection with accidents or may be found during decommissioning of nuclear installations. Some research projects may also produce relatively large quantities of contaminated soil.

Cement solidification of radioactive contaminated soil is difficult, but may be possible using a special additive available from the Danish firm Geodur A/S. The process has been studied since 1989 and some results are presented in [6]. However, they should be seen in connection with further work made under the KAN2 project, which is one of the Nordic co-operative efforts. The work on the Geodur part of the KAN2 project has been finalized, and a preliminary version [7] of the final report is available. The conclusion is that cement solidification is of rather doubtful value for the retention of cesium and strontium within contaminated soil. However, there may well be very good effects on heavy metals and α-emitters.

The participation in the KAN2 project continues, partly in support of the scenario formulations concerned with waste from large accidents, and partly as an experimental study of some interesting interaction effects between contaminated soil and concrete used as barrier material in a disposal facility.

4.3 Soil Chemistry

Soil chemistry or geochemistry is of very great importance for the safety of waste disposal and for the general understanding of the behaviour of pollutants in the underground as well as in surface soil. For historical reasons the migration of radionuclides etc. in the underground has mainly been the concern of the Chemistry Section, while

the Waste Management Section has taken an interest in soil chemistry and hydrology of the unsaturated surface layers.

In previous years this was done in the form of a project combining field studies in forests (performed by the Danish Forest Research Institute and the National Environmental Research Institute) with laboratory studies and modelling using the ECCES model (the Waste Management Section in co-operation with the Systems Analysis Department). It has now been thought worthwhile to turn the soil chemistry part of this model into a more simple and flexible unit. This smaller model SAMUS (Single Area Model for Unsaturated Soil) is written in Pascal in a PC version. It is operational, but some obvious improvements remain to be made, including calculation checks and the writing of a description of the model. Use of the SAMUS model is proposed for some future co-operation projects with the Danish Forest Research Institute.

List of Publications and Presentations

Brodersen, K., Carugati, S., Driftsrapport for Behandlingsstationen med tilhørende lagre. Perioden 1/1 til 31/12-1991 (in Danish).

Atabek, R., Billon, A., Vitorge, P., Brodersen K., Ewart, F.T., Haworth, A., Ramsay, J.D.F., »Characteristics of buffer materials and radionuclide behaviour in cementitious and clay barriers.« In: Radioactive Waste Management and Disposal. Proceedings of 3rd European Community conference on radioactive waste management and disposal, Luxembourg 1990, L. Cecille, ed. (Elsevier Appl. Sci. London 1991), EUR 13389, pp. 363-377.

Brodersen, K., Berghman, K., Glasser, F., Longomazino, N., Nomine, J.C., Wang, J., »Chemical and thermal stability of waste products.« Ibid, pp 242-256.

Brodersen, K. and Nilsson, K. (1991). »Mechanisms and interaction phenomena influencing releases in low- and medium-level disposal systems.« Task 3: Characterization of radioactive waste forms. A series of final reports (1985-89), No. 31. EUR 13662. 92 p. (Also available as Risø-M-2908).

Brodersen, K. and Nilsson, K., »Pores and cracks in cemented waste and concrete«. Paper presented at the XV Int. Symp. on the Scientific Basis for Nucl. Waste Management, E-MRS 1991 fall meeting, Strasbourg, Nov. 1991. Symposium D: Chemistry of cements for nuclear applications.

Brodersen, K., Hjelmar, O. and Mortensen, K., »Cement conditioning of waste materials and polluted soil using the Geodur process.« In: »Hazardous, Radioactive and Mixed Wastes. Vol. 2« Proceedings of the ASTM symposium , Williamsburg, US 1990. Gilliam/Wiles eds. ASTM stp 1123 (January 1992).

Brodersen, K., »Cement solidification and interaction between cement and radioactive contaminated soil«. Preliminary report to the KAN2 project. KAN2(91)1. (August 1991).

Appendix 1

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Frits Heikel Vinther (acting head until 1991.11.30)

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Appendix 2

Participation in International Working Groups, etc.

IAEA, The International Atomic Energy Agency

Co-ordinated Research Programme on Intercomparison for Individual Monitoring (Christensen).

ICRP, International Commission on Radiological Protection

Committee 4, Application of the Recommendations (Gjørup).

OECD, Nuclear Energy Agency

CSNI, Steering Committee (Højerup).
CSNI, PWG4, Confinement of Accidental Radioactive Releases (Fynbo).
CSNI-PWG4, Subgroup of Experts on Accident Consequences (Thykier-Nielsen).
NEA-Databank, Steering Committee (Højerup).
NEA-CRP, Committee on Reactor Physics (Nonbøl).

CEC, Commission of the European Communities

Article 37 Group of Experts (Walmod-Larsen).
CGC 6 Nuclear Fuel Cycle (Brodersen).
ACPM for Plan of Action (Brodersen).
Task 3 of the Waste Research Programme (Brodersen).
Working Party on Criteria for Recycling Materials from the Dismantling of Nuclear Installations (Heikel Vinther).
Working Group on Reactor Dosimetry (Olsen).
Group of National Experts on Assistance in the Event of a Nuclear Accident or Radiological Emergency (Heikel Vinther).
Expert Group on Environmental Gamma Monitors (Bøtter-Jensen).
Expert Group on Transfrontier Emergency Planning (Walmod-Larsen).
Group of Technical Experts on Radiation Protection Dosimetry (Christensen).
EURADOS-CENDOS, Skin Dosimetry (Christensen, chairman).
EURADOS-CENDOS, Criticality Accident Dosimetry (Majborn).

EAES, European Atomic Energy Society

Public Relations Correspondents Group (Walmod-Larsen).

Nordic Cooperation

Steering Committee for NKS Projects (Heikel Vinther).
Reference Group on KAN Projects (Brodersen).

Editorial Boards

Radiation Protection Dosimetry (Bøtter-Jensen).

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Abstract (Max. 2000 characters)

The report describes the work of the Nuclear Safety Research Department during 1991. The activities cover health physics, reactor physics, operation of the educational reactor DR 1, and waste management.

Lists of staff and publications are included together with a summary of participation in international working groups etc.

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